LESSONS
in SCIENCE

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BY

FREDERIC DELOS BARBER, A.M.,
Professor of Physics, Illinois State Normal University

MERTON LEONARD FULLER, M.Di., M.A.,
Meteorologist, U. S. Weather Bureau; Lecturer on Meteorology,
Bradley Polytechnic Institute

JOHN LOSSEN PRICER, A.M.,
Late Professor of Biology, Illinois State Normal University

AND

HOWARD WILLIAM ADAMS, B.S.,
Professor of Chemistry, Illinois State Normal University

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PREFACE

This book is in effect a simplification, for younger pupils, of the authors' "First Course in General Science." There are fewer quantitative conceptions, many mathematical problems have been eliminated, and, where it has been possible without sacrificing clearness, much detail has been omitted. The chapters on *Weather* and *Microörganisms* have been made far less technical. The logical and seasonal order of topics has been improved by following the discussion of *Foods* with the chapter on *Refrigeration* and preceding it with the treatment of *Microörganisms.* In fact, the whole treatment has been so largely rewritten that it may fairly be regarded as a new book. It discusses, in terms that the youthful mind can understand, phenomena of science constantly met in the home, the school, and the community. It arouses the pupil's curiosity about them and sets him to finding the explanation of them. Each topic is pursued far enough to avoid superficiality and to give continuity to the course. The course is progressive; the earlier chapters are relatively easy; as the ability of the pupil grows, the course becomes correspondingly difficult. Numerous cross references are given to stimulate frequent reviews. Topics not essentially important in the environment of any class, or in the environment of the community, may easily be omitted without seriously breaking the continuity of the course.

Like its predecessor this book assumes that the first year of science instruction should *not* aim primarily to survey the entire field of nature and present scattered bits and choice morsels from every special science in order that the pupil may decide in which of the sciences he would like to specialize further. Nor is first-year science regarded as only an introduction to the special sciences. It has been shown to have a vastly more important function to perform, namely to give a rational, orderly, scientific understanding of the pupil's environment to the end that he may correctly interpret it. General science has justified itself by its own intrinsic value as a training for life's work.

We wish to express our appreciation of the aid rendered by those who have assisted in the preparation of the illustrations or who have granted us permission to use illustrations from their publications. The hearty coöperation of manufacturers and business men and the interest they have manifested in our efforts to present faithfully the application of science to the actual affairs of life have been most helpful. The authors wish to make particular acknowledgment of assistance from the following sources: The Century Company, Figs. 1, 59, 78, 303, 306, 311. Detroit Heating & Lighting Company, Figs. 15, 16. Westinghouse, Church, Kerr & Co., Figs. 35, 36. American Home Magazine Co., Figs. 37, 38, 39. General Electric Co., Figs. 40, 41. Central Electric Co., Figs. 31, 32, 44, 46, 47, 48. Welsbach Company, Figs. 50, 51, 52, 53. Curtis Publishing Co., Fig. 60. Kalamazoo Stove Co., Figs. 67, 99. Patric Furnace Co., Figs. 68, 69. Williamson Heating and Ventilating Co., Figs. 70, 71, 72, 83, 84, 85. American Radiator Co., Figs. 184, 185. Durham Manufacturing Co., Fig. 100. Mechanical Refrigerator Co., Fig. 224. Monthly Weather Review, Figs. 113, 115, 117, 132, 141, 153, 156, 157. Dr. S. Adolphus Knopf and Moffat, Yard & Co., Fig. 181. Hoover Suction Sweeper Co., Fig. 187. Municipal Journal, Fig. 188. Standard Sanitary Manufacturing Co., Figs. 239, 246, 260, 261. R. D. Wood & Co., Figs. 245, 249. Bishop & Babcock Company, Fig. 249. Rensselaer Manufacturing Co., Fig. 251. National Meter Co., Figs. 254, 255. International Harvester Co., Figs. 275, 314, 316, 318, 320. Singer Sewing Machine Co., Figs. 276, 277, 278, 279, 280, 281, 282. Mississippi Power Co., Figs. 296, 297, 302. DeLaval Manufacturing Co., Figs. 283, 284, 285. American Book Co., Fig. 304. James Leffel & Co., Figs. 309, 310. Westinghouse Manufacturing Co., Fig. 54. Swift & Co., Figs. 212, 213, 214. Creamery Package Co., Fig. 211. United States Weather Bureau, Figs. 118, 119, 123, 124, 125, 134, 140, 142, 143, 144, 145, 154. Hersey Manufacturing Co., Fig. 253. Pearse, Greeley, and Hansen, Figs. 271, 272, 274. Erie Railroad Company, Fig. 291. John Wiley & Sons, Fig. 273. Some of the illustrations appear unmodified; some have been adapted to their present use; others have been prepared especially for the book.

THE AUTHORS

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LESSONS IN SCIENCE

CHAPTER I

THE PRODUCTION AND USE OF LIGHT

I. PRIMITIVE LIGHTING

1. The Discovery of Fire.—There probably was a time when primitive man was without fire. In those days he had no artificial heat or light, and he ate his food uncooked. Perhaps man first obtained fire from dead trees ignited by lightning, perhaps from oil wells which are known to have been burning for centuries. With fire came warmth, light, and cooked food. The light from the camp fire also furnished protection from wild animals. Gradually the fire came to be the center of the home. It is probable that we owe more than we realize to fire for what it has done toward building up and strengthening home ties.

FIG. 1.—A Roman lamp. From *Stories of Useful Inventions.* (By courtesy of The Century Company.)

2. The Primitive Lamp.—Perhaps a pine knot snatched from the fire constituted the first portable light. How recently pine knots have been in common use is shown by the fact that Abraham Lincoln learned to read by the light of them. Perhaps by collecting the grease obtained from cooking and placing it in a rude vessel with a bit of bark or a thread of twisted moss for a wick, man made the first lamp. We would consider the light produced by such a lamp a poor one indeed, but the Eskimos still use such primitive lamps. The bowl is hollowed out from soapstone; the fat comes from the animals they slay. The Eskimo lamp serves also as a stove. By its heat all their cooking is done and their snow huts are warmed.

3. **Greek and Roman Lamps.**—The lamps of Greece and Rome were no better than the Eskimo lamps of today, but the lamp bowls were often very costly and elaborately ornamented (Fig. 1). The rich used lamps of bronze or silver; the middle classes, lamps made of terra-cotta; the poor, cheap iron lamps.

4. **The Early Candle.**—The earliest lamps could not conveniently be moved about. The oil or fat, especially when warm, spilled out of the bowl. It was noticed, probably, that when some fats were cold they became quite stiff and solid. Tallow is much more solid than lard. Someone concluded, therefore, that it would not be necessary to use a lamp bowl at all if tallow were used and a small wick imbedded in it. The tallow prepares its own bowl during the process of burning. Like lamps, candles have been used from prehistoric times.

5. **Modern Candles.**—While the candles our grandfathers and grandmothers made were of tallow, the modern candle is made of paraffin which is obtained from petroleum. Over 300,000,000 paraffin candles are sold in the United States each year, about two dozen candles for each family.

Exercise 1.—How the Candle Burns

Place a piece of candle upright on a square of pasteboard after melting a little of the paraffin at the bottom of the candle to make it stick. Light the candle. After it has burned three or four minutes notice what is happening to the paraffin near the wick. This cup corresponds to the bowl of the primitive lamp. To have a perfect cup three things are necessary: (1) There must be no draft in the room; (2) the wick must not be too large for the candle; (3) the wick must be in the center of the candle. Is it desirable to have the cup perfect? Why?

Hold one of the strands of candle wicking in a vertical position and light its upper end. Does it burn readily? Does it continue to burn? Is its flame like that of the candle flame? Is it the burning of the candle wick that is the chief cause of the candle flame? If not, what is it?

Blow out the candle flame and examine the wick. Is it wet? With what is it wet? Does it remain wet all the time that the candle is burning? Re-light the candle and, using two iron nails, squeeze the wick; then examine the nails to see whether or not there is any paraffin on them. The wick is constantly soaked in melted paraffin while the candle burns. But is it the liquid paraffin which burns?

Re-light the candle and blow out the flame again. Notice the smoke which rises from the wick. How long does it continue to rise? Re-light the candle. Hold the lighted match in one hand. Blow out the candle and quickly thrust the lighted match into the column of rising smoke about 1 in. above the candle. What happens? (Fig. 2.) Try the same again. Make several trials to see how far above the tip of the wick you can hold the match and still have the candle re-light. Does it make any difference how long you wait after blowing out the flame before applying the match? Do drafts through the room make a difference? What do you now think it is that burns?

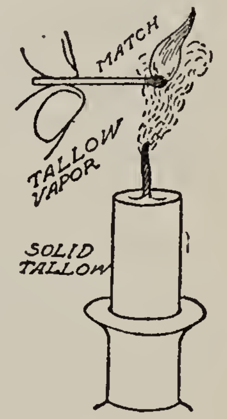

FIG. 2.—Lighting the candle vapor.

Have you ever seen a frying pan in which bacon or eggs were frying become so hot that the smoke rising from the fat caught on fire? This sometimes happens. The fat, however, begins to smoke some time before it gets hot enough to catch on fire.

THE EXPLANATION.—*All kinds of greases, fats, and oils when heated sufficiently hot give off* VAPORS *in large quantities. This simply means that these fats and oils are changed by heat from liquids into vapors, or gases, exactly as water is* *changed by heat from its form as liquid water into steam, or water vapor.* It is paraffin vapor which burns in the candle flame.

Exercise 2.—The Flashing Point and the Burning Point

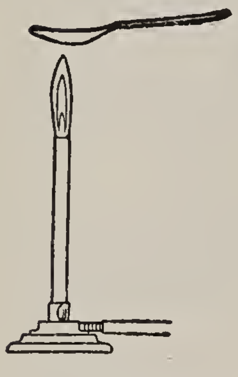

FIG. 3.—Flashing point of paraffin.

Put a little paraffin in a large spoon and slowly heat it until it begins to smoke, VAPORIZE (Fig. 3). Then test the smoke, vapor, frequently with a burning match to see when it will ignite. At a certain temperature of the liquid paraffin in the spoon the vapor becomes dense enough to produce a momentary flash over the surface. The paraffin is then at the FLASHING POINT. Continue to heat the paraffin in the spoon slowly, testing the vapor as before. When the vapor becomes dense enough to burn continuously, the paraffin has reached the BURNING POINT.

DEFINITIONS.—*The flashing point of paraffin, lard, tallow, or oil is that temperature at which the vapor arising and mixing with air produces a momentary flash when ignited.*

The burning point is that temperature of the substance at which the vapor arising and mixing with air produces a continuous flame when once ignited.

It is now evident that in lighting a candle the burning match must be held against the wick long enough to melt and then to vaporize the paraffin in it in such quantities that the vapor is ignited by the match and burns with a continuous flame. The heat from the candle flame continues to melt and to vaporize the paraffin fast enough to produce a steady flame.

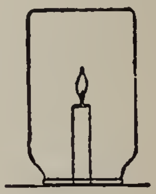

FIG. 4.—Excluding fresh air from the candle.

6. Fresh Air is Necessary.—We have seen that the vapor from the heated tallow or paraffin rises and mixes with the air. Is the air really necessary that the vapor may burn? We can answer the question best by trying an experiment.

Exercise 3.—Shutting the Fresh Air Away from the Candle

Light a piece of candle 1 or 2 in. in length and stand it on the table before you. Watch it for a minute to see that it burns properly. Now invert a tumbler and place it over the candle. Does the candle continue to burn? Remove the tumbler. Re-light the candle. Try the experiment again, using a 2-qt. fruit jar instead of the tumbler. Does the candle continue to burn longer this time? Why? Re-light the candle. Again place the fruit jar over the burning candle. Watch carefully to see what happens just as the flame goes out. Is there much smoke given off for a moment after the flame dies out? What is this smoke? If it is paraffin vapor, why does it not burn? (Fig. 4.)

Now carefully raise the jar and set it aside while you re-light the candle, letting just as little fresh air into it as possible. Again place the jar over the candle and notice carefully how long the flame continues this time. Raise the jar, blow all the smoke out of it; re-light the candle and again place the jar over the candle. Does the flame burn longer than it did before? Explain.

Explanation.—As long as the wick is hot there will be plenty of paraffin vapor. But this vapor cannot burn alone. The flame is the result of the uniting of the vapor with one of the gases, oxygen, in the fresh air. The air is not *fresh* when the vapor has burned out the oxygen. *No matter how much of the burned air and vapor you may have in the tumbler, or how well mixed they may be, you can not get a flame till you have some of the fresh, unburnt air mixed with the vapor.*

II. THE KEROSENE LAMP

7. The First Kerosene Lamp.—The kerosene lamp has been in use only about 60 years. The lamps which had previously been used usually burned heavy oils and fats, which gave only low, flickering, smoky flames. During the first half of the last century whale oil was in common use along the seacoast. Whale oil lamps were less smoky and disagreeable than most lamps of the period. A few lamps had been made which burned so-called BURNING FLUIDS. But these fluids were very inflammable and dangerous. Up to about 1860 candles were by far the safest and best sources of artificial light which the world had ever used.

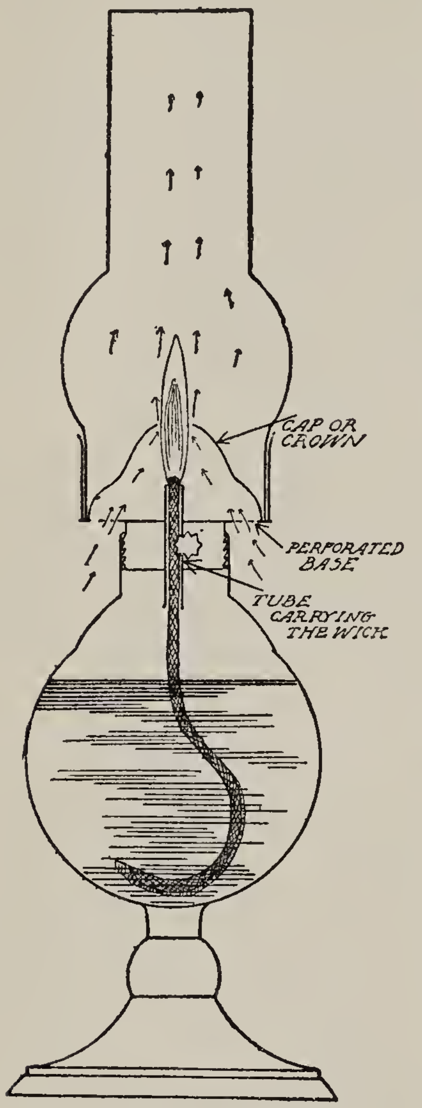

FIG. 5.—Parts of the burner.

It was in August, 1858, that the first successful oil well was sunk in Pennsylvania. Petroleum had been known for a long time, but it had never before been found in commercial quantities and little use had been made of it except as medicine. Soon after it was obtained in large quantities, the discovery was made that an oil could be obtained from crude petroleum which would burn freely and still be safe to handle. This new oil was called *kerosene,* though some people, supposing that it came from coal, called it COAL OIL. We still sometimes hear it called by that name. Inventors soon made lamps well suited for the burning of this oil. The common kerosene lamp of today is, in principle, exactly like those earliest lamps.

8. Parts of the Kerosene Lamp.—The ordinary kerosene lamp really consists of three parts: (1) The BOWL for containing the oils; (2) the WICK; (3) the BURNER AND CHIMNEY. The wick is usually made of soft, loosely woven cotton cloth. What is its purpose? What does it do?

Burners vary much in construction, but all have certain necessary parts, namely: (1) The CAP, OR CROWN; (2) the PERFORATED BASE; (3) the TUBE FOR THE WICK.

Exercise 4.—The Use of the Burner and Chimney

Examine a burner carefully and discover these parts. Make a sketch in your notebook of *your* burner showing clearly each of these parts. Label all parts of your sketch somewhat as the sketch, Fig. 5, is labeled. *Do not copy the sketch from the book but sketch your lamp.*

Study carefully the device for regulating the height of the wick.

Light the lamp, place the chimney in position, and observe the steadiness of the flame. If there is not much draft through the room there should be very little flickering of the flame. It should burn with a steady flame.

Wave your book past the bowl of the lamp so as to produce a strong gust of air against the under side of the burner. What is the effect upon the flame? Can you tell why it becomes smoky? Did you increase or decrease the amount of air which was passing through the chimney and past the flame? Hold the lamp up before you and blow strongly into the bottom of the burner. What is the effect upon the flame? Is it a case of too much air or not enough?

Wrap a towel about the base of the burner to prevent air from entering through the perforated base. What is the effect upon the flame? If you could see only the upper portions of the chimney could you be certain from the behavior of the flame whether too much or too little air was entering the burner?

Place a piece of cardboard or window glass for an instant on the top of the chimney so as to close it. What is the result? What is the effect upon the flame of having too little air? What is the effect of having too much air? What do you think is the chief purpose of the burner and chimney?

FIG. 6. Burning kerosene without a burner.

Kerosene burns just as freely without the use of a burner or chimney. This can be easily shown by placing some kerosene in a tumbler and covering the tumbler with a sheet of tin in which a slit has been cut by means of a cold chisel. An ordinary lamp wick is drawn into the slit as shown in Fig. 6. In this case, however, the flame will be smoky and unsteady no matter how still the air in the room may be.

Evidently, the chief purpose of the burner and chimney is *to regulate the air supply. If the air supply be either too abundant or too scarce the flame will be unsteady and smoky.* We shall see later why this is so. We shall also study later the principle by which the burner and chimney regulate the air supply.

9. How Kerosene Burns.—Just as we proved that it was not the liquid paraffin which burned in the case of the candle, so we can show that it is not the liquid kerosene which burns in the case of the kerosene lamp.

Exercise 5.—It is Kerosene Vapor that Burns

Remove the chimney from the lamp. Light it. Hold the lighted match ready to apply. Blow out the flame. Quickly apply the lighted match to the rising column of smoke. Does it ignite? If not, be quicker in applying the match next time. Repeat the experiment to see how far above the wick you are able to ignite the vapor.

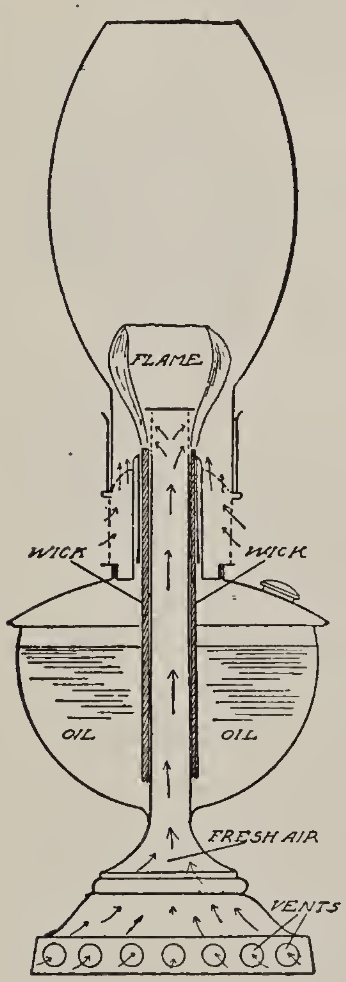

Fig. 7.—Center-draft lamp.

Have you ever noticed a strong odor of kerosene in the room after "blowing out" a lamp? (Art. 86.) Explain. Can this be prevented by first turning the wick down so as to produce a low flame before blowing it out? Explain.

10. Center Draft Burners.—Many large kerosene lamps use circular wicks. They have an open tube extending from the top of the burner down through the center of the bowl to the open central portion of the base. The rim of the base is perforated so that a current of fresh air can readily pass upward through the tube to supply the *inside* of the flame. There are, of course, perforations through the sides and bottom of the burner to supply fresh air to the outside of the flame. Such lamps are known as CENTER DRAFT lamps. (Fig. 7.)

III. EVAPORATION, BOILING TEMPERATURE, AND DISTILLATION

EVAPORATION

11. **Need of New Terms.**—We have thus far been studying the burning of paraffin in the candle and of kerosene in the ordinary lamp. Gasoline has often been used for producing artificial light where gas or electricity is unobtainable. Gasoline lamps of many different kinds have been made and in many homes gasoline is used both for lighting and cooking. With this increase in its use people have discovered that gasoline is also one of man's most dangerous servants if not carefully and properly handled. Many accidents have resulted from its use. Most people who use gasoline know that it is more dangerous than is kerosene. But many people are using gasoline every day who do not know just why it is dangerous, what to do with it, or how to handle it to make it a safe and obedient servant.

We should like to study gasoline; we hope to learn its nature and how to handle it. Before we can do so, however, we must know the meaning of certain terms and how to use them correctly. We must know where gasoline comes from and its relation to kerosene. These topics will be studied next.

12. **Evaporation.**—We are all aware that damp clothes hung upon the line at any time except when it is raining soon lose the water they contain and become dry. We wash our porches and floors and soon they are dry. We place a basin of water in an exposed place and the water soon disappears.

The explanation is that *the water changes from a liquid to a gas or vapor, and escapes into the air.* This process by which water changes from its liquid form into a gas, or vapor, we call EVAPORATION.

The washerwoman also knows that on some days the clothes will dry much more rapidly than on others. We know that the freshly washed floors will dry more quickly if we open the doors and windows or build a fire in the furnace or stove. The farmer has learned to tell very accurately, by watching the weather, whether or not the fields and roads are drying rapidly. The question arises: What are the conditions under which evaporation takes place most rapidly? This question can best be answered by experiment.

Exercise 6.—Effect of Extent of Surface on Rate of Evaporation

Fill a small drinking cup about half full of water, measuring exactly the amount used. Again measure the same amount of water, and place it in a large, shallow pan or basin. Set the cup beside the pan in a safe place where it will not be disturbed. The two vessels should have the same temperature and be exposed to the same air currents. Examine them daily and note the rate of evaporation in each, till one is dry. Measure the amount of water remaining in the other.

Which is dry first? What conclusion do you draw regarding the effect of extent of surface on evaporation?

Exercise 7.—Effect of Temperature on Rate of Evaporation

Place one drinking cup containing a measured quantity of water on or near the stove or radiator. The water should not boil, but be kept warm. Place another cup of the same size and shape containing the same amount of water in a cooler place. Watch these two cups till one is dry. Draw a conclusion regarding the effect of temperature on the rate of evaporation.

Exercise 8.—Effect of Air Currents on Rate of Evaporation

Place two drinking cups of the same size and shape, each about one-half full of water (measuring amounts accurately), side by side in an open window or in some other position where the wind can sweep past them. Turn a large, 2-qt. cup or a small pail over one of the cups of water. Examine the cups of water daily and note which suffers the greater evaporation. What is your conclusion?

Exercise 9.—Rate of Evaporation Varies with Different Liquids

Place two drinking cups of the same size and shape side by side in some safe place. Fill one about half full of water, and place in the other the same amount of alcohol or gasoline. (*Caution.—It is dangerous to leave gasoline in a closed room. It should be in the open air and no flames should be brought near it.*) Note which evaporates more rapidly. Draw your conclusion.

Exercise 10.—Effect of Evaporation on Temperature

Let a few drops of alcohol or gasoline fall upon the back of your hand. Does it produce the sensation of heat or cold? Wrap a small piece of cotton cloth around the bulb of the thermometer and tie with a cord or thread. Take the reading of the temperature. Drop a few drops of alcohol or gasoline upon the cloth. Watch for a change in temperature. Repeat the experiment. Does the thermometer record the lowest temperature when the liquid is first dropped upon it or a little later? How do you account for this fact? Wet your hand and hold it out of the window where the wind can strike it. What is the sensation?

Draw a conclusion regarding the effect of evaporation upon temperature.

Hunters usually wish to approach their game from the leeward side, that is, so that the wind will blow from the game toward the hunter. Why do they wish to do so? In order to tell the direction of the wind when it is too light to be observed readily by ordinary means the hunter often wets one finger at his mouth and then holds it high above his head where the wind can strike it. Try the experiment when you are out of doors and decide how it is that this tells the direction of the wind.

Why do we often feel chilly if we sit down with damp clothing on? Why does fanning one's self produce the cooling effect that it does? Is the cooling effect of fanning increased or decreased by the fact that one has been perspiring freely?

In regions having a dry, hot, windy climate like Arizona and New Mexico, it is found that butter can be kept hard and sweet for long periods simply by setting the dish containing the butter into a larger dish containing water and then spreading over the butter a piece of soft absorbent cloth, such as a clean towel, so that its corners and edges dip down into the water. The butter keeps sweet longer if placed where the wind strikes it. Explain.

In the same regions drinking water is generally kept during the summer months in a large, porous, earthen vessel called an OLLA (ŏl-yà), which is hung out of doors, usually under a porch or tree. The olla being porous, its outer surface is constantly covered with a film of water. Evaporation taking place over so large a surface cools the water within the vessel far below the temperature of the surrounding air.

13. **Laws of Evaporation.**—From these and similar experiences we draw the following conclusions:

I. *The rate of evaporation from any given amount of liquid increases when the exposed surface is increased.*

II. *Increasing the temperature of a liquid increases the rate of its evaporation.*

III. *The rate of evaporation is increased by the continual removal of vapor above the surface of the liquid.*

IV. *Some liquids evaporate much more rapidly than do others.*

V. *Evaporation of a liquid always produces a cooling effect upon surrounding bodies.*

TEMPERATURE AND THE THERMOMETER

14. **Temperature.**—We are all familiar with the common use of the term TEMPERATURE. By it we mean the *hotness* or the *coldness* of a body. On a cold day we say that the temperature is low; on a warm day we say it is high. We can *generally* tell when one body is warmer than another if we feel of the two bodies at the same time. We cannot, however, be certain of our judgment. Different substances *feel* to be of different temperature when they are in fact of the same temperature. The bare-footed boy knows this to be true. A piece of iron and a piece of wood lying side by side on a hot day will be of the same temperature. Will they feel so?

Which feels the warmer? What would be the case on a cold day? Which would then feel the colder?

If at the close of a long ride on a very cold, windy day we were to step into an unheated room we would at once say that the room was warm. If we were to remove our wraps and sit down we should soon find, however, that the room was really cold.

The truth is we cannot depend upon the appearance of objects, nor upon our sensations of heat and cold, to tell us the temperature of surrounding bodies. In all our work we shall be obliged to use an instrument especially constructed for this purpose, the THERMOMETER.

15. The Principle of the Thermometer.—

Exercise 11.—How Heat Affects the Thermometer

Fill a small flask with water. Fit a glass tube, 12 or 15 in. long, into a one-hole rubber stopper. Press the stopper down tightly into the flask. This should force the water well up into the tube.

Light an alcohol lamp or Bunsen burner. Hold the flask for about one second in the flame. Notice carefully the first movement of the surface of the water. Does it rise or fall at first? What does it do later? Repeat the experiment till you feel certain that you see that the second motion is opposite to the first motion.

The first motion is due to the fact that the heat first strikes the glass and expands it. This makes the flask larger—increases its volume. If the volume of the flask grows suddenly larger, what would you expect to see happening to the surface of the water? The second movement is due to the fact that, when heated, the water increases in volume much more rapidly than the glass vessel does.

The common thermometer consists of a very small glass tube ending in a glass bulb at its lower end. This bulb and the tube are partly filled with mercury or alcohol. The air is nearly all removed from the upper portion of the tube. The tube is then closed by heating the glass till it softens and closes together. The principle of the thermometer may be summed up thus: *When heated, the glass in the thermometer expands, increasing the capacity of the bulb and tube, but the heat soon penetrates to the liquid which then expands to a still greater extent.* Alcohol expands more than 40 times as much as does the glass vessel, and mercury expands about 7 times as much as does the glass vessel for a given change in temperature.

16. The Fixed Points of Temperature in Nature.—The thermometer just described is still without any scale. In placing a scale upon it, the position of the surface of mercury or alcohol is marked when the thermometer is cooled or heated to some certain FIXED TEMPERATURES IN NATURE. The distance between the lower and higher temperature marks is then divided into a certain number of equal parts called DEGREES.

1. It has been long known that water always freezes and ice always melts at a certain temperature. For pure water this temperature is called the FREEZING POINT OF WATER.

2. It has also been known that at the average atmospheric pressure at sea level water always boils at a certain temperature. The temperature of the steam arising from water boiling under the atmospheric pressure which exists at the sea level, is therefore, called the BOILING POINT OF WATER.

3. About two hundred years ago Fahrenheit found that a mixture consisting of 1 part common salt, or of sal ammoniac, a substance closely resembling salt, and of 2½ parts snow or crushed ice always melted at a certain temperature considerably below the temperature of freezing water. Fahrenheit called this third temperature the MELTING POINT OF A MIXTURE OF SALT AND ICE.

There are a great many other fixed points of temperature in nature. For example, pure iron always melts at exactly the same temperature; so does lead, and so does zinc. Both pure mercury and pure alcohol have certain temperatures at which they boil and others at which they freeze. When in good health the human blood always has the same temperature. But in marking the common thermometer the three temperatures first mentioned, namely, the freezing point of water, the boiling point of water, and the melting point of a mixture of ice and salt, are the only temperatures which we commonly use.

17. Fahrenheit's Thermometer.—In making the thermometer which bears his name Fahrenheit marked the position of the mercury "0°" when the thermometer was cooled down to the temperature of the mixture of ice and salt. It is believed that he was induced to call this temperature 0° partly because it was the unusually low temperature reached by the weather in Holland in the winter of 1709. He called the temperature of freezing water "32°" and the temperature of boiling water "212°."

18. Centigrade Thermometer.—Much later Celsius made his so-called CENTIGRADE THERMOMETER. On this thermometer the freezing point of water is marked as "0°" and the boiling point of water as "100°."

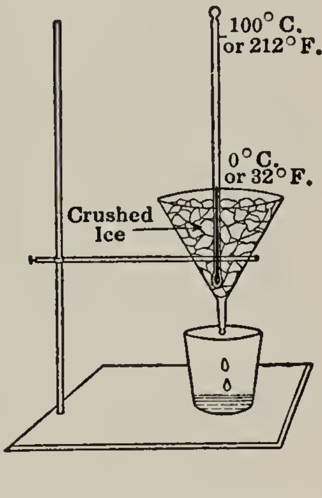

FIG. 8.—Freezing point of water.

Often both scales are placed upon the same thermometer stem. It is also true that the scale may extend far above the boiling point of water and far below the melting point of the mixture of ice and salt.

19. Determining the Freezing Point on a Thermometer.—

Exercise 12.—Testing a Thermometer for the Freezing Point

Suspend a funnel in the ring of an iron support. Clamp a thermometer by means of the burette clamp at such a height that the bulb hangs well down in the throat of the funnel. Pack the funnel full of finely broken ice or snow, heaping it well up around the stem of the thermometer. The stem should be surrounded with ice or snow up as nearly as possible to the point marked 0°C., or 32°F. Keep plenty of ice or snow in the funnel and see that it remains tightly packed around the thermometer for some minutes. Does your thermometer record correctly the freezing point of water? If not, what is the amount of the error? (Fig. 8.)

Even very good thermometers are often slightly incorrect.

BOILING POINT

20. The Temperature of Boiling Water.—

DEFINITIONS.—*A liquid is said to* EVAPORATE *when it changes from the liquid form to the vapor form at the surface only.*

A liquid is said to BOIL *when it changes to the vapor form beneath the surface and the bubbles of vapor rise to and escape from the surface.*

A liquid is said to be VAPORIZED *whenever it changes to vapor. A liquid is vaporized when it evaporates or boils.*

Exercise 13.—To Determine the Temperature of Boiling Water

Fill a 4-oz. distilling flask half full of water. Slip a chemical thermometer into the hole in a rubber stopper. Push the thermometer far enough through the stopper so that the bulb will dip into the water when the stopper is fitted into the mouth of the flask. Before inserting the stopper and thermometer it is well to place a few small nails or some common glass beads in the flask. The presence of something of this kind in the flask will cause water to boil more steadily and prevent "bumping." (Fig. 9.)

Clamp the iron ring to the stand at a point about 2 in. above the flame. Place a wire gauze upon the ring and set the flask on the gauze. Steady its top by clamping it loosely with the burette clamp. Adjust the flame so that it will not be too high. Slip it under the flask and watch for results.

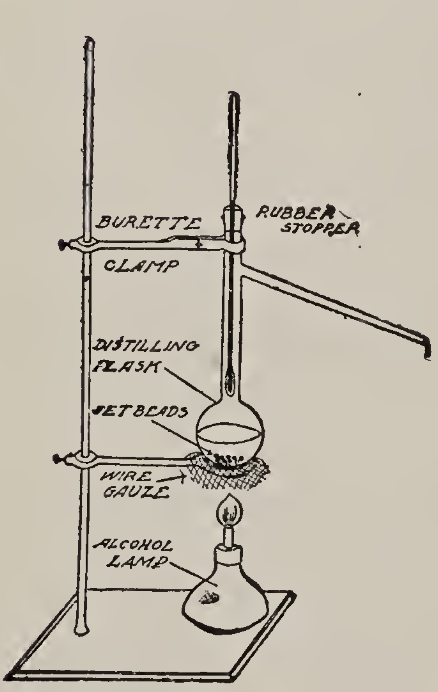

FIG. 9.—Boiling point of water.

The first small bubbles which you see rising through the water are bubbles of air, not of steam. Keep watch of the reading of the thermometer. Do you see any evidence of steam, or water vapor, before the water actually boils? Does the steam rise from a pan of hot water on the stove before the water really begins to boil? At what temperature by your thermometer does the water finally boil? Continue to heat the water to see if it is possible to raise the temperature higher. Can you see steam in the upper portion of the flask? Can you see it immediately after it escapes from the side tube? (*Caution.—Do not permit the flame to reach higher than the surface of the water in the flask, else the flask will probably crack.*)

If you are not careful you may be led to give incorrect answers to the last two questions. *Steam, or water vapor, is invisible.* But something escaped from the side tube. What do you now think that it was? What happens to steam when it is again cooled after escaping from the flask? We sometimes say that we see steam escaping from an engine or locomotive. This is not strictly true. We see only the small particles of water which have been formed again from the steam and which are floating in the air.

Unless you are living at or very near the sea level you have probably found that the temperature of the boiling water according to your thermometer is somewhat below 212°F., or 100°C.

21. The Temperature of the Steam Arising from Boiling Water.—In the last experiment the bulb of the thermometer was *in the water*, therefore the thermometer recorded the temperature of the water itself. Would it record a different temperature if it were raised above the surface of the water, high enough so that no water could touch it, but still be surrounded by steam?

Exercise 14.—Temperature of Steam Arising from Boiling Water

Raise the thermometer higher in the rubber stopper used in Ex. 13. The bulb of the thermometer should be up in the neck of the distilling flask but below the side tube. Replace the lamp and bring the water to a boil. What temperature does the thermometer record now? See if the temperature can be raised by causing the water to boil more rapidly. (*Caution.—Do not permit the flame to reach higher than the surface of water in the flask.*)

The temperature of the steam which escapes from boiling water is always a little lower than the temperature of the boiling water itself. This is exactly what we should expect, for the heat is being applied to the glass vessel and then transferred to the water. The water is constantly in contact with glass which is slightly above the temperature of boiling water. Moreover, if there are impurities in the water their presence will tend to change the boiling temperature; gener-

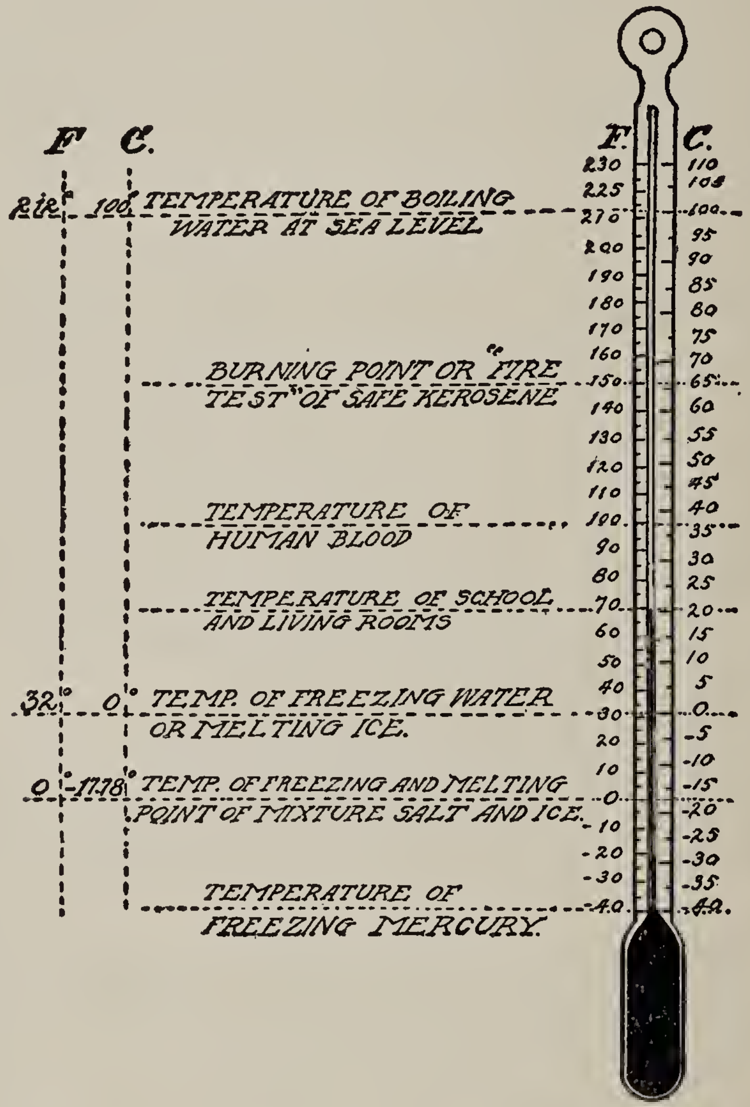

Fig. 10.—Thermometer scales and some fixed temperatures in nature.

ally they raise the temperature, although certain dissolved gases lower it.

DEFINITION.—*The temperature marked* 100° *C., or* 212° *F., and called "boiling point" is the temperature of steam arising from boiling water when the pressure is equal to that of the atmosphere at the sea level.*

In the experiment did your thermometer indicate a temperature of 100°F., or 212°F.? Can you explain why it did not?

22. Comparison of the Fahrenheit and Centigrade Scales.—The Fahrenheit scale is nearly always used on thermometers sold in the United States for common use; the centigrade scale is nearly always used on thermometers intended for use in laboratories. In encyclopedias, government reports and many other publications to which we frequently refer, we are very likely to find temperatures given in either of the two scales. We ought to learn to think temperatures in either scale (Fig. 10).

Exercise 15.—Comparing Temperature on the Fahrenheit and Centigrade Scales

By studying Fig. 10, tell as near as you can what the temperature of the blood is on the centigrade scale. What should be the temperature of the school room on the centigrade scale? Which are the greater, the Fahrenheit or the centigrade degrees? How many degrees are there on the Fahrenheit scale between the freezing point of water and the "boiling point" of water? How many degrees are there on the centigrade scale between the freezing point and the "boiling point"? How many Fahrenheit degrees equal 1 centigrade degree? Which is the colder, 0°C. or 0°F.? Are there any temperatures which are above 0°F. but below 0°C.? You should use a thermometer having both scales on it frequently and always record the readings on both scales. In this way you will soon be able to think temperature by both scales.

23. The Boiling Point of Alcohol.—In Ex. 14 we found that the temperature of the steam, or vapor, arising from boiling water remained the same whether the water boiled slowly or rapidly. We should like to find out whether the same thing is true of alcohol.

Exercise 16.—To Determine the Boiling Point of Wood or Grain Alcohol

Fill a distilling flask half full of alcohol. Put in some glass beads or nails. Insert the stopper and thermometer, adjusting the thermometer in height so that the bulb will extend somewhat below the side tube and still be above the base of the neck of the flask. Clamp the flask in the ring stand at the proper height above the alcohol lamp or burner. Set the stand in a metal tray such as a large dripping pan. *Since alcohol is inflammable it should be handled with care. Before lighting the lamp, place a piece of cardboard between the flask and the delivery tube to avoid any possibility of the escaping alcohol vapor being accidentally set on fire by the flame* (Fig. 11).

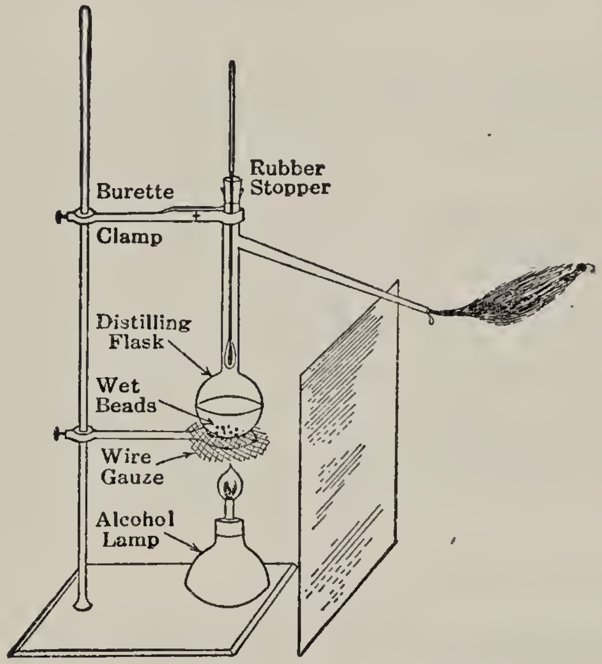

Fig. 11.—Distillation of alcohol.

Light the lamp or burner and notice all that takes place as the alcohol is brought slowly to a boil. Record the temperature of the alcohol vapor when the vapor first begins to escape from the side tube. Do you suppose that this vapor will burn?

Taking care that no one is in front of the delivery tube, light the escaping vapor with a match. Does the vapor continue to burn as long as the boiling continues?

After three or four minutes read the thermometer again. Has the "boiling point" changed? Does rapid boiling change the "boiling point" of alcohol?

Should the "boiling point" of your sample of alcohol not remain constant but rise with continued boiling your alcohol probably contains water. The simplest test for pure alcohol is the test of the boiling point. Wood alcohol, as pure as can be obtained by distillation, has a constant boiling point of 66°C., or 150⅘ °F. Ordinary grain alcohol has a constant boiling point of 78°C., or 172⅖ °F. These are the boiling points at the sea level. In our school rooms these temperatures will be slightly lower. Then, too, our thermometers may not be exactly correct. *But in any case the boiling point of pure alcohol will not change with continued boiling. All pure substances in the liquid state have certain constant boiling points.* Some are much higher than that of water, for example, the boiling point of mercury is 357°C.; some are much lower, as oxygen, — 182°C., or hydrogen, — 252°C.

Distillation

24. Boiling Point of a Mixture of Alcohol and Water.—

If pure wood alcohol boils at 66°C. and continues to boil at that temperature till all of the alcohol has been turned into vapor the question arises: What would take place if we had a mixture of alcohol and water? With our distilling flask, thermometer, and lamp or burner we can soon answer the question.

Exercise 17.—Distillation of Alcohol

Fill the distilling flask about one-fourth full of alcohol and add an equal amount of water. Place some beads or small nails in the flask, insert the stopper and thermometer, and place the cardboard between the flask and the side tube. Light the lamp or burner and notice carefully the temperature at which boiling first takes place. Watch the temperature carefully as the boiling continues.

Iight the escaping vapor as you did in Ex. 16. Allow the vapor to continue burning as long as it will do so. Does the flame finally go out? Can you relight it? Can you explain why the vapor does not continue to burn well? After a few minutes, you will probably find that the vapor will not burn at all. Why? About what part of the mixture of water and alcohol has boiled away when the vapor no longer burns?

Continue to watch the temperature at which the liquid in the flask boils. Does the temperature finally reach that of boiling water? How do you account for this fact? About what portion of the mixture of water and alcohol has boiled over when the temperature reaches this point?

Did drops of liquid form at the end of the side tube? What do you suppose they were, water or alcohol?

Explanation of Ex. 17.—We have seen that alcohol boils at a much lower temperature than does water. It is also true that alcohol vapor condenses, i. e. changes from vapor form to liquid form, at a much lower temperature than does water vapor. It is probable that in your experiment, the side tube was so heated that most of the alcohol escaped as vapor while some of the water vapor condensed and formed drops of water at the end of the tube. If we had kept the side tube cool enough, we could have caused both the water vapor and the alcohol vapor to have condensed.

DEFINITION.—*This process of changing a liquid into vapor by means of heat and then of changing the vapor back into a liquid by cooling it is called* DISTILLATION.

The liquid obtained from distillation is called a DISTILLATE.

Because different liquids have different boiling points we are often able to separate the liquids in a mixture as we have just separated the alcohol from the water. *It is not true, however, that the alcohol has been entirely separated from the water by this one distillation.* The first portion of alcohol which passed over as vapor and which we burned contained some water; the water which remained in the flask at the close of the experiment likewise contained some alcohol. To get the alcohol nearly free from water it is necessary to re-distil several times. The factories where alcohol is made in large quantities are called DISTILLERIES because the alcohol when first made is mixed with water and must be separated from it by means of distillation (see Art. 299, page 272). We shall soon see that all the kerosene and gasoline which we use have been separated from petroleum by this same process of distillation.

IV. PETROLEUM AND ITS PRODUCTS

25. **Petroleum.**—When petroleum first comes from the well it is usually of a dirty, dark, bluish-brown color; usually it gives off a strong odor which is disagreeable to most people. In the region of oil wells the whole atmosphere is charged with this odor for miles around. This simply means that as the petroleum comes from the well some of it immediately evaporates, or passes off into the air in the form of vapor, or gas, NATURAL GAS.

We are not greatly surprised to find that this is so, for we have seen that water left uncovered is constantly evaporating. We have also seen that alcohol left uncovered evaporates even more rapidly. It is the same with all other liquids, though some evaporate very rapidly and others very slowly.

We have also seen that heating water or alcohol, or a mixture of the two, increases the rate of evaporation. If we heat either liquid hot enough, it boils and vaporizes with great rapidity.

26. **The Distillation of Petroleum.**—Remove the stopper from the bottle of petroleum. Notice carefully the color and odor. If we were to place a little in a vessel and heat it, we should see that it boils quickly. Hence, petroleum would seem to behave very much as water or alcohol does so far as evaporation and boiling are concerned. To understand the real nature of petroleum, however, it will be necessary to keep constantly in mind all the facts we observed when we distilled the mixture of alcohol and water. What did we notice in regard to the boiling point of the mixture? Did it remain constant? At what temperature did it begin to boil? What was its boiling point when we stopped the experiment? What was our conclusion? We must keep these things in mind while we perform the following experiment:

Exercise 18.—To Distil Petroleum

Fill a 4-oz. distilling flask half full of petroleum,[1] using a funnel so that no petroleum enters the delivery tube. Put some small nails or beads into the flask. Clamp the flask to the stand as in Ex. 16 and insert the stopper and the thermometer, which, at the beginning of the experiment, may have a scale which reads to about 100°C. or 212°F. The lower end of the bulb of the thermometer should reach about ½ in. below the side tube.

As the experiment proceeds the thermometer may have to be raised or lowered in the stopper in order that its reading may be taken. Place the piece of cardboard between the distilling flask and the vessel into which the distillate will drip. *Guard against possible accident, such as the cracking of the flask.* While it is extremely improbable that the flask will crack, it is well to set the entire apparatus in an ordinary dripping pan or some flat-bottomed vessel and to keep a wet towel near with which to smother the flames in case of accident (See Fig. 11).

Place the lamp under the flask and gently heat the petroleum. Notice that it begins to boil very soon. As soon as you see the vapor pass over into the delivery tube and there condense, read the thermometer. Catch the distillate in a small, clean bottle. Notice the color and appearance of the distillate. Watch the thermometer carefully. Is the temperature rising steadily? When it reaches 70°C., or 158°F., remove the bottle in which you have been catching the distillate and place another in position. Label the first bottle "Distillate No. 1." Does the temperature still continue to rise? When it reaches 80°C., or 176°F., again remove the bottle in which you have been catching the distillate and label it "Distillate No. 2."

Caution. At this point remove the 100°C. thermometer and insert one reading to 360°C. or 680°F.

In the next bottle catch the distillate till the temperature has risen to 120°C., or 248°F. Label this "Distillate No. 3." Catch in a fourth bottle the distillate which passes over between 120°C. and 150°C. and label it "Distillate No. 4." Finally in a fifth bottle catch the distillate which passes over between 150°C. and 300°C. It will be found necessary to heat more strongly now and possibly

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[1] Crude petroleum, just as it comes from the well, should be used. Road oil will not answer as the lighter distillates are usually removed from oil sold for the purpose of oiling roads.

to enclose the flask partly in a shield of tin or asbestos paper in order to raise the temperature to 300°C. This last portion of the distillate will probably contain about one-half of the entire distillate. Remove the lamp and pour as much of the residue as possible out of the flask while it is still hot. When it cools it will be solid and cannot be removed readily from the flask. Wash the flask out clean with gasoline so that it will be ready for future use.

Caution.—Gasoline should be used for this purpose out of doors, or, if in the house, the doors and windows should be left open so that the wind may quickly remove the vapor from the room. Never use gasoline when there is a flame near.

27. The Products of Petroleum.—In this last experiment we have separated the crude petroleum into six different portions. The process is FRACTIONAL DISTILLATION, and the products are practically the products of petroleum as they are sold on the market. We shall be able to remember these products better if we put them in a table thus:

TABLE I.—PRODUCTS OF PETROLEUM[1]

	Boiling points
1. Distillate No. 1—"Petroleum Ether,"	40°– 70°C. or 104°–158°F.
2. Distillate No. 2—"Light Gasoline,"	70°– 80°C. or 158°–176°F.
3. Distillate No. 3—"Heavy Gasoline,"	80°–120°C. or 176°–248°F.
4. Distillate No. 4—"Naphtha"	120°–150°C. or 248°–302°F.
5. Distillate No. 5—"Illuminating Oil" or "Kerosene"..........	150°–300°C. or 302°–576°F.
6. The Residue—The thick, tarry substance remaining in the flask.	

28. Purifying the Petroleum Products.—These products of petroleum obtained by distillation will have a strong odor, and the kerosene will probably show considerable color. Formerly all illuminating oil was highly colored and had this same strong odor. Nowadays all of the products of petroleum are carefully cleansed and purified before they are put

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[1] Every refiner of petroleum has his own method of separating petroleum into its commercial products The method varies with the quality of petroleum used and the demands of the market. The method here given, however, is typical.

on the market. The purifying removes nearly all of the color and most of the offensive odor. The process of purifying kerosene is much too difficult for us to undertake.

29. The Uses of These Petroleum Products.—

Petroleum Ether is subdivided into several portions to each of which a special name is given. It is used chiefly in surgery and in dissolving substances like resin and heavy oils.

Light Gasoline is chiefly used in gasoline gas machines (see Art. 39).

Heavy Gasoline is the common gasoline sold at the grocery store and gasoline service station. It is used in gasoline stoves, in gasoline lamps, in automobiles and gasoline engines. It is also sometimes used in paints.

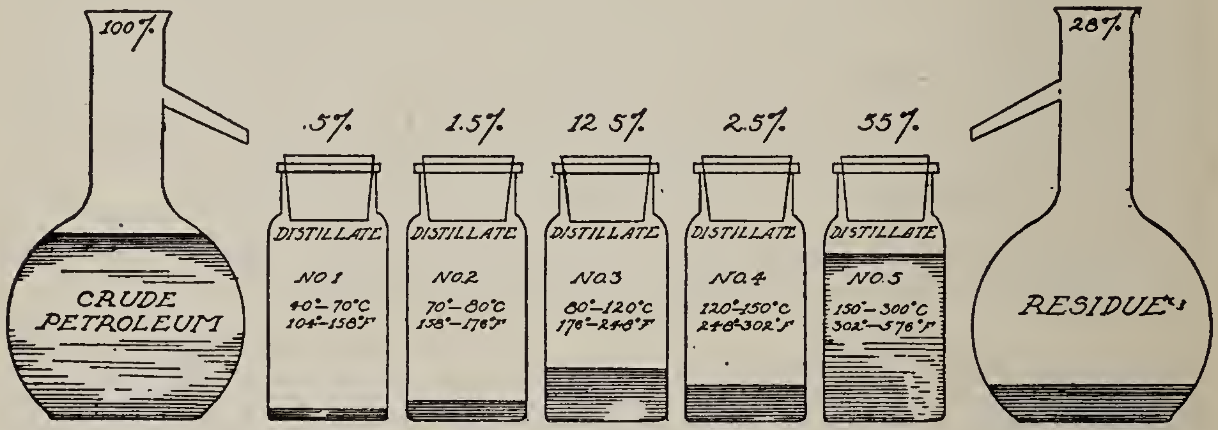

Fig. 12.—The products of petroleum.

Naphtha, often called "heavy naphtha," is used as a substitute for turpentine in making paints and varnishes, and also for cleaning heavy oils from machinery.

On account of their evaporating so rapidly when exposed to the air or, as we say, being so very *volatile*, these first four products of petroleum are called the light oils or spirits.

Kerosene or Illuminating Oil is chiefly used to furnish light when burned in the ordinary kerosene lamp. It is also frequently burned in stoves of special construction for heating purposes.

The Residue is manufactured into lubricating oil, PARAFFIN OIL, and SOLID PARAFFIN. A small amount of COKE still remains after these are removed.

SUGGESTION.—It would be well for you to catch the different distillates which you obtained in Ex. 18 in small bottles, cork them air tight, label each with its correct name and boiling points, then set them away for future reference. Your parents and friends will be glad to see samples of the crude petroleum and these products (Fig. 12).

V. PROPERTIES OF GASOLINE—SOURCES OF DANGER

DENSITY, FLASHING POINT AND BURNING POINT

30. The Grades of Gasoline as the Merchant Knows Them.—We have seen that gasoline is a name applied to some of the lighter, more volatile products of petroleum. We have also seen that it is separated both from the lighter petroleum ether and the heavier naphtha and kerosene by means of fractional distillation. We have further seen that there are two grades, at least, of gasoline—light gasoline and heavy gasoline. When we buy gasoline at the gasoline service stations we get heavy gasoline. This heavy gasoline may be either LOW TEST or HIGH TEST gasoline. The low test gasoline is a heavier liquid than the high test. The refiner and the merchant need to know quite accurately how heavy the gasoline is in order to know its value and how suitable it is for a certain use. The density of gasoline is determined by means of a BAUMÉ HYDROMETER.

FIG. 13. Baumé hydrometer.

31. Baumé's Hydrometer.—This instrument (Fig. 13) consists of a glass tube 8 to 10 in. in length. Near its lower end this tube has been blown into a large bulb, and still farther down, at its very end, it has been blown into a small bulb and sealed. Some mercury or small shot is dropped down the tube into the lower, small bulb. Some melted sealing wax is then dropped down inside the tube and made to close the opening between the two bulbs. Care is taken to have the instrument so weighted that it floats with the stem above the large bulb above the surface when placed in water. The instrument is then GRADUATED by floating it in lighter liquids and marking the scale on a strip of paper which is slipped down inside the stem. The stem is then sealed and the instrument is complete.

The instrument is called a *Baumé* hydrometer (*hydro*—water, and *metron*—measure), because Baumé invented the scale used upon it. Oils of all kinds including the products of petroleum, also syrups, vinegars, and many other liquids are regularly bought and sold on the market at prices which vary according to the density of the liquids as determined by this hydrometer. It must be remembered that the *light gasoline* has a lower boiling point and is a lighter liquid per gallon than the *heavy gasoline.* But it must also be remembered that the grading of the lighter gasoline by the Baumé hydrometer is about 85° to 88°, while the heavy gasoline grades from about 56°B. to 65°B. At the present time LOW TEST gasoline generally tests from 56° to 60°. That is, it is always true that the lighter the oil, the higher it will grade in Baumé degrees; the heavier the oil, the lower it will grade in Baumé degrees. Kerosene grades about 45° Baumé, and is written "45°B."

32. The Inspection of Oil.—If the different grades of gasoline, naphtha, and kerosene have been properly distilled and purified we are able to tell fairly closely the range of boiling points of the different oils, simply by testing their DENSITY, by means of this hydrometer. The different states have passed laws governing the manufacture and sale of the products of petroleum. These laws have been passed for the protection of the purchaser and user. There are oil inspectors in nearly all cities and in many of the smaller towns whose duty it is to inspect the products of petroleum offered for sale and to set that they are really what they are said to be. In most, if not all, of the states *the products of petroleum must be thus inspected before they are offered for sale.* This test for density by means of the Baumé hydrometer is *one of the tests.*

33. Flashing Point.—The *most important test,* however, which can be given the products of petroleum is to test their FLASHING POINT (Art. 5, Ex. 2). This consists in determining the temperature of the oil at which the vapor arising from it will flash when a flame is brought near it. It is this test which determines whether an oil is safe or unsafe to have about a building or to be put to certain uses. A good, legal quality of kerosene is not to be considered dangerous to have in a room. Any quality of gasoline, on the other hand, is *always* to be considered dangerous, *and must be cared for accordingly.* A very simple experiment will show us that this is so, and will help us to understand why it is so.

Exercise 19.—Flashing Point of Gasoline and Kerosene

Put four or five tablespoonfuls of kerosene in a tin cup. Place the bulb of the thermometer in the oil and take its temperature. Record this. Light a match and try to set the kerosene on fire. Are you successful? Try again. Make a sufficient number of trials to satisfy yourself whether or not you are able to set the kerosene on fire. It is not probable that you will succeed, but if you should finally get it to burn, smother the flames quickly by placing a piece of glass over the dish so as to exclude all air. Take the temperature of the oil again and record all that happened.

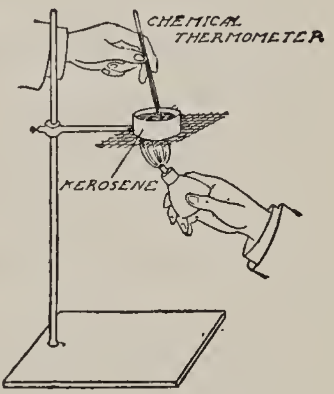

FIG. 14.—Flashing point of kerosene.

Now place two tablespoonfuls of gasoline in another cup. Take its temperature. Remove the thermometer. Try lighting the gasoline as you did the kerosene. *Be sure that the glass is close by so that you can cover the dish quickly in case the oil catches on fire. Also be sure that the can of gasoline has been removed from the room, or tightly corked.* When the flame has been extinguished, remove the glass from the dish, light another match and bring it slowly down above the dish to see at what height above the surface of the gasoline the flash does take place. Try again. Is it the liquid gasoline which burns?

Set the gasoline to one side, and make a further study of the kerosene. If you have a good quality of oil, you have probably not yet succeeded in making it burn. Fit the wire gauze on the ring of the stand. Set the cup of kerosene on the gauze and heat very gently (Fig. 14). Test the oil frequently with the lighted match to see if the vapor arising from it will catch on fire. When it is hot enough it will suddenly flash when the lighted match is applied. Smother the flame, using the glass as before. Take its temperature. This temperature is somewhat, perhaps slightly, above the FLASHING POINT. If the flame continues to burn above the surface of the oil, you have heated it several degrees above the flashing point. It is, indeed, above the BURNING POINT. Let the oil cool. But to do so you must put out the flame. Take the temperature each minute or two, as it cools, and after each reading of the thermometer test the oil with a lighted match to see if it still burns. When it no longer burns, you have passed the BURNING POINT. It may still flash, however, but the flame immediately goes out. It is still above the FLASHING POINT if this is the case. When the oil no longer flashes it has cooled below the flashing point.

DEFINITIONS.—*The flashing point of an oil is the lowest temperature of that oil at which it will give off enough vapor so that when mixed with the air above, it produces a momentary flash when a flame is brought near the surface of the oil.*

The burning point, or fire test, of an oil is the lowest temperature of that oil at which it will give off enough vapor to maintain a continuous flame when once ignited.

The burning point of kerosene may be from 20° to 60°F. higher than its flashing point. In ordinary kerosene it is usually from 40° to 50°F. higher. Most of the states have laws which forbid the sale of oil as illuminating oil, or kerosene, which has a flashing point lower than about 110°F. or a burning point lower than about 150°F. This is the most important of all of the tests which the inspector applies to kerosene.

The better qualities of kerosene have a flashing point of 120°F. to 140°F. If a lighted match be dropped into it, the flame is extinguished. It has no unpleasant odor and burns up completely without charring the wick of the lamp. Such an oil is obtained by rejecting the first of the distillate after the boiling point of the petroleum has reached 150°C. and also the last portion just before the boiling point reaches 300°C. This choice distillate is then carefully purified.

A fair quality of oil is obtained by using all of the distillate from 150°C. to 300°C. and carefully purifying it. The cheaper grades of oil contain larger amounts of the portions rejected from the higher grades. They therefore have low flashing and burning points, and char the wicks.

34. Use of Kerosene in Kindling a Fire.—If instead of catching on fire itself a good quality of kerosene will put out a burning match, how is it that kerosene may be used as a kindling in starting a fire? It is a common thing for people to dash a little kerosene upon the fuel in a stove when starting a fire. Can you readily start a coal fire by the use of kerosene alone as kindling? Why does kerosene ignite so much more readily when poured upon wood or paper than when poured upon coal? Is it ever safe to use kerosene as kindling when starting a fire? These and other questions which may arise are easily answered by remembering that *kerosene vapor burns only when the kerosene is heated to its burning point.*

When the oil is poured upon wood, especially if the wood is splintered or in the form of shavings, it becomes an easy matter to heat small portions of the oil which saturate the smaller splinters or shavings to the burning point. When the oil lies spread as a thin coat over the chunks of coal it is difficult to raise any portion of the oil to its burning point, unless the coal is very finely divided, because the heat applied to the oil passes on into the coal and it becomes necessary to raise the temperature of the whole chunk of coal to the burning point of kerosene. The match does not furnish a sufficient amount of heat to do this.

Danger of an explosion from the use of kerosene arises only when the oil is heated above its flashing or burning point. Evidently if the oil is poured upon unheated fuel and is then ignited, the flame will consume the vaporized oil as rapidly as it is vaporized. If, however, the oil is poured upon heated fuel or live coals, or even upon fuel in a heated stove, there is then danger that the oil will be vaporized in large quantities and mixing with the air will produce an explosive mixture. If the flame be then applied a violent explosion is certain to occur. Therefore, *kerosene should never be used as kindling if there are live coals in the stove or if the stove is itself still hot.*

DANGER IN USING CHEAP KEROSENE AND GASOLINE

35. Danger in Using Cheap Kerosene.—Many experiments with lamps of different shapes and materials show clearly the danger which comes with the use of inferior qualities of kerosene. With the temperature of the room 73° or 74°F. the temperature of the oil in the lamp bowl has been found to vary from 76° to 100°F. With the temperature of the room 82° to 84°F. the temperature of the oil is from 84° to 120°F. With the temperature of the room 90° to 92°F. the temperature of the oil in the lamps in some cases ran as high as 129°F., though these were exceptional.

From these facts it is evident that the oil within the lamp is likely to be heated to a temperature considerably above the temperature of the room. It is also evident that *no oil should be used which does not have a flashing point considerably above the highest temperature ever reached by the air of the room.* Explosions occur because the oil has been heated to a temperature above the flashing point.

36. Oil May be Dangerous when Standing in the Can.—The following facts must be kept constantly in mind by all users of petroleum products:

1. *Any oil is a dangerous oil and must be kept away from all fires or open flames if it has a flashing point which is at or*

below the highest temperature ever attained by the room or building in which it is stored.

2. *In fact, merely removing the can of oil from the room does not remove all of the danger. If the room has been closed for some time, the vapor which has escaped may have saturated the air in the closets, cupboards, or even trunks, and this saturated air will explode when ignited.*

3. *Gasoline has a flashing point far below the temperature of any living room. If the can is not air tight, the vapor of the gasoline is certain to escape into the room. Unless the room is very well ventilated, the air in it may become so saturated with the vapor of the gasoline that it will burn, with an explosion when ignited. In its low flashing point lies the danger of using gasoline.*

4. *The flashing point of legal kerosene is sufficiently above the ordinary room temperatures so that no corresponding danger exists in its use.*

37. May Gasoline be Used with Comparative Safety?— Yes, by observing the following precautions:

1. *Keep the main can of gasoline in some well-ventilated out-building.*

2. *If the can must be kept in the living rooms, see that it is corked as tight as possible, that it is in as cool a place as possible, and that the room is well ventilated.*

3. *Never take a flame of any kind near the can, nor near any large quantity of gasoline.*

4. *Never attempt to fill a gasoline stove or lamp by lamp light.*

5. *In case gasoline is spilled by accident, or has leaked from the receptacle, open wide the doors and windows of the room to change the air completely before bringing a flame into the room. Also thoroughly ventilate all cupboards and closets in which there is a possible chance of the air having become saturated with the gasoline vapor.*

If these precautions are observed there will be but little danger in handling gasoline.

VI. THE GASOLINE GAS MACHINE

38. Gasoline Easily Vaporizes.—We have seen that gasoline exposed to the air vaporizes rapidly. We have also seen that if any considerable quantity of gasoline remains exposed to the air of a room for a short time that the air becomes so charged with vapor of gasoline that it burns readily. In fact, the mixture frequently explodes violently when a flame is brought near. This is the cause of most accidents which occur from the careless use of gasoline.

Because gasoline does evaporate so readily when exposed to air it is possible, by using a properly constructed machine, to produce GASOLINE GAS. Several gasoline gas machines are now in use furnishing gasoline gas for use in country residences and in school buildings which are out of reach of a city supply of common illuminating gas.

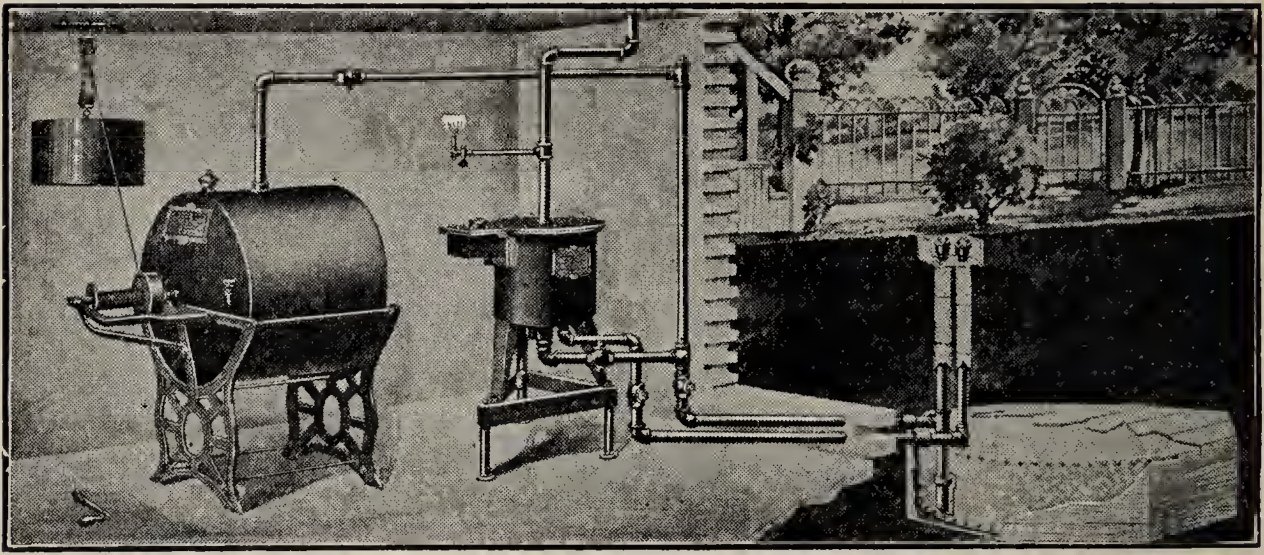

FIG. 15.—A gasoline gas machine.

39. Gasoline Gas Machines.—There are several different types of gasoline gas machines. Every machine must, however, consist of two distinct and different parts and usually possesses a third. The essential parts are a BLOWER or PUMP, and a CARBURETER. The third part is called a MIXER.

THE BLOWER is a simple device for forcing a current of air out through the carbureter and back into the pipes of the building. It maintains the pressure on the gas. Fig. 15 shows a common form of blower. It consists of a large fan operated by means of a heavy weight. The weight is wound up at intervals as required. It exerts a constant pressure upon the pump. As long as lights are burning, the pressure is being reduced and the pump works to maintain the pressure.

The Carbureter is a large tank capable of holding several barrels of gasoline. It is buried in the ground usually some distance from the wall of the basement of the building. There are different styles of carbureters. The cuts (Figs. 15 and 16) show one form made of heavy sheet steel. It is shaped much like a cheese tub, but is divided into *four cells* by the three false bottoms. Upon each of these shelves, or bottoms, stands a spiral coil of absorbent material like lamp wicking. This absorbent material is intended to form a coil-like partition extending from top to bottom of each cell so that the air must, in passing through one cell, pass through the long coil-like passage. The bottom of the passage is gasoline; each side is the absorbent material saturated with gasoline. The cells are so connected that air in passing through the carbureter must pass through all four of these long, coil-like passages. If straightened out the passage would be 2 in. high, 3 in. wide and 300 ft. long. *The purpose of the carbureter is to expose the gasoline to the air as much as possible so that the air will become fully saturated with the gasoline vapor producing gasoline gas.*

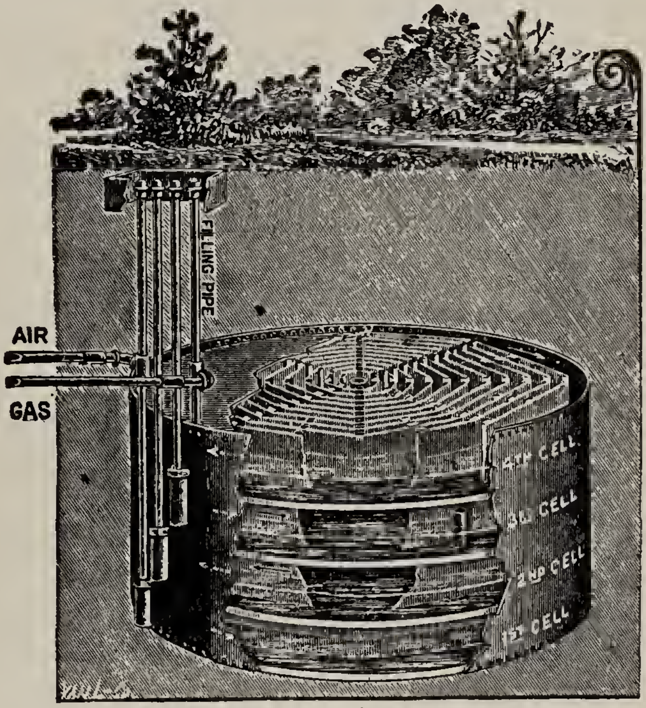

Fig. 16.—Sectional view of the carbureter.

The Mixer is a device for maintaining the proper mixture of gasoline vapor and air. Gasoline consists of many different compounds (See Art. 71). Each compound has a certain rate of evaporation, at a given temperature. The lighter portions of the gasoline evaporate more quickly than the heavier portions. This means that for some time after each refilling of the carbureter the air is more completely charged with vapor than is the case later when the lighter portions of the gasoline have evaporated and only the heavier portions remain in the carbureter. The purpose of the mixer is to keep the gasoline gas, *i. e.,* the mixture of air and gasoline vapor, the same at all times.

The gasoline gas machine is used successfully, not only to furnish gas for lighting purposes, but also for cooking in a gas range exactly as city illuminating gas is used. *Only* 86° *to* 88°*B. gasoline can be used successfully in these machines.*

VII. MANUFACTURED GASOLINE AND MOTOR SPIRIT

40. Importance of Gasoline.—Up to about the year 1900 kerosene, or illuminating oil, was by far the most important product of petroleum. Only a certain percentage of the crude oil—generally from 30 to 50 per cent.—could be refined as illuminating oil and about 20 per cent., as gasoline. There was a good market for the kerosene but only a light demand for the gasoline. As a consequence, kerosene sold for a higher price than did gasoline. With the general introduction of electric lighting in towns and cities the demand for kerosene fell off; while at the same time, with the perfecting of the automobile and the coming of the gasoline engine into general use, the demand for gasoline increased greatly. About 1910 the demand for gasoline became greater than the supply, and the price became higher than that of kerosene. This increased demand for gasoline has led oil refiners to adopt the plan of putting nearly all of the distillates of petroleum up to illuminating oil together and selling them as gasoline.

While the common grade of gasoline, heavy gasoline, used to have a density of about 72° to 74°B., it now commonly has a density considerably greater, from 56°B. to 64°B. (see Art. 31). This heavier gasoline does not work so well in automobiles during cold weather and manufacturers have been obliged to modify their engines so that they could burn the grade of gasoline obtainable.

41. Manufacture of Gasoline from Natural Gas.—In the vicinity of petroleum wells the atmosphere is charged with the odor of escaping gases. A considerable portion of the flow from an oil well evaporates immediately at the temperature of the atmosphere. This is natural gas. Recently it has been found possible to change this escaping gas into an oil closely resembling gasoline. This is done by placing the gas under very high pressure and at the same time cooling it to a very low temperature. In 1911 there were 176 plants in the United States for changing natural gas from petroleum wells into gasoline and over 7,400,000 gal. were produced; in 1917 there were 886 plants which produced 218,000,000 gal.

42. Manufacture of Motor Spirit, or Motor Oil.—During recent years oil refiners have been constantly searching for some method by which they could profitably produce more gasoline from a barrel of petroleum. In 1911 W. M. Burton, a chemist in the employ of the Standard Oil Company of Indiana, perfected a process of producing a good substitute for gasoline from the residue of petroleum after the illuminating oil has been removed. This new oil is called MOTOR SPIRIT or MOTOR OIL. By a special method of "destructive" distillation a large amount of this motor spirit is obtained. In general, this "destructive" distillation is accomplished by distilling the residue containing the lubricating oils, the paraffin and the tar and coke, under high pressure and therefore at high temperature.

43. Properties of Motor Spirit.—Motor spirit is somewhat lighter than gasoline and has somewhat different properties.

but it has been found to be a very good substitute for gasoline when used as a fuel for gasoline engines. It is said to produce more power per gallon than does gasoline. However, it has an unpleasant odor and is more inclined to produce a deposit of carbon in the cylinder of the engine. At the present time it is being used extensively only in heavy auto trucks and in automobiles used in business. Figure 17 shows the relative amounts of the products obtained from crude petroleum when distilled by the old methods and by the new method.

VIII. OUR SUPPLY OF PETROLEUM

44. The Rise of the Petroleum Industry.—Petroleum was first produced in commercial quantities in the United States in 1858. In 1860 about 2,000,000 bbl. were produced; in 1918 about 356,000,000 bbl. were produced. On the average the production of petroleum in the United States has doubled about every eight years. Figure 18 shows the growth of the petroleum industry and also shows the date at which each new field was discovered.

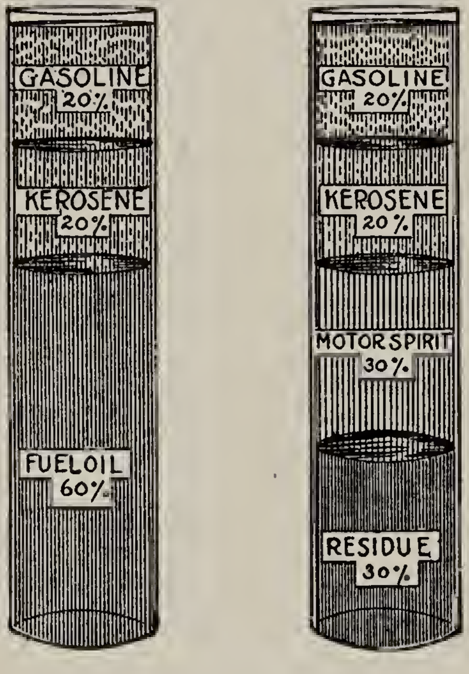

FIG. 17.—Products of petroleum when distilled by the old and by the new methods.

45. The Oil Fields of the United States.—The Pennsylvania fields produced all of the petroleum up to 1886, when the Lima, Ohio, field was discovered. The Indiana field was discovered in 1897; the Texas field, in 1901; the California field, in 1903; the Oklahoma field, in 1905, and the Illinois field, in 1906. Figure 19 shows the best known fields of the United States.

46. How Long Will Our Supply of Petroleum Last?—Experience has shown that the supply of oil in each field is limited. The Pennsylvania field is now nearly exhausted.

All the older fields are rapidly falling off in the amount of oil produced annually. Fortunately, up to the present time, as the older fields began to fail new fields have been discovered. It is thought, however, that most of the oil fields of the United States are now known. It seems nearly certain that before many years the supply of petroleum in the United States will be declining. Oil fields of undetermined productiveness are known to exist in Mexico and South America.

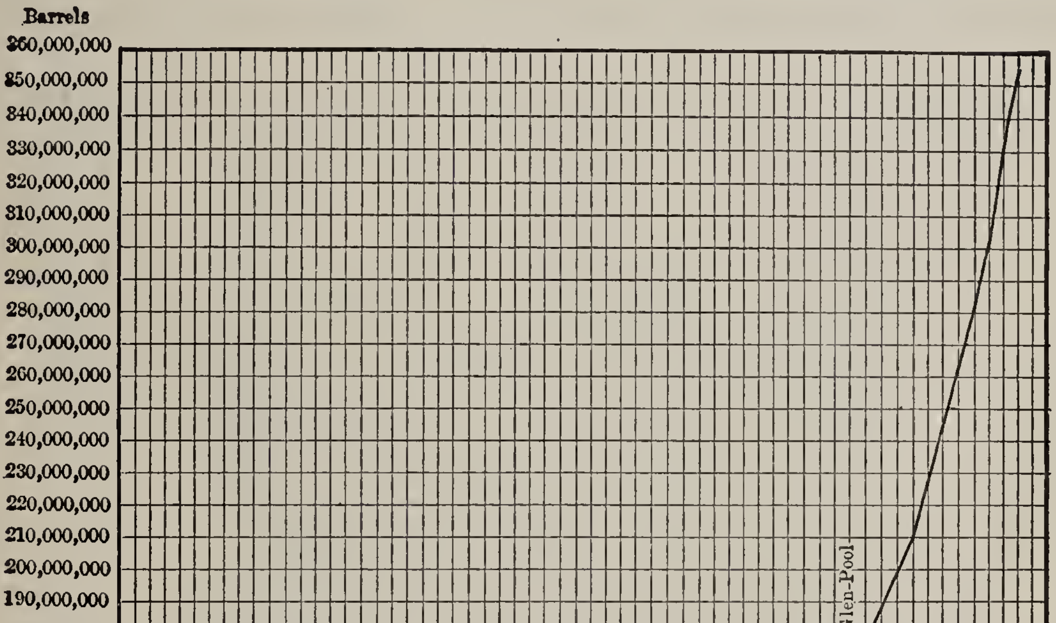

FIG. 18.—Annual production of petroleum, 1859—1918.

IX. ILLUMINATING GAS LIGHTING

47. Illuminating Gas.—By illuminating gas we usually mean either manufactured coal gas or water-gas saturated with oil vapors (Arts. 98 and 99). Whatever the source of illuminating gas, it usually is piped into the house and passes through a meter where its volume is measured. The price paid for it is usually set at a certain sum per 1000 cu. ft.

48. The Gas Meter.—The common gas meter consists of a gas-tight metal case, Fig. 20, which is divided by a metal partition into two compartments. Each of these compartments is again divided into two compartments (A and B, Fig. 21) by a metal disk and leather diaphragm, D, Fig. 20. In the upper portion of the case is a third, gas-tight compartment, VC, Fig. 20, which encloses the valves. The gas enters the meter at the left through the inlet pipe, I, Fig. 20. This inlet pipe leads across the meter to an opening in the floor of the valve chamber. The gas in the valve chamber is always under the same pressure as that in the city mains.

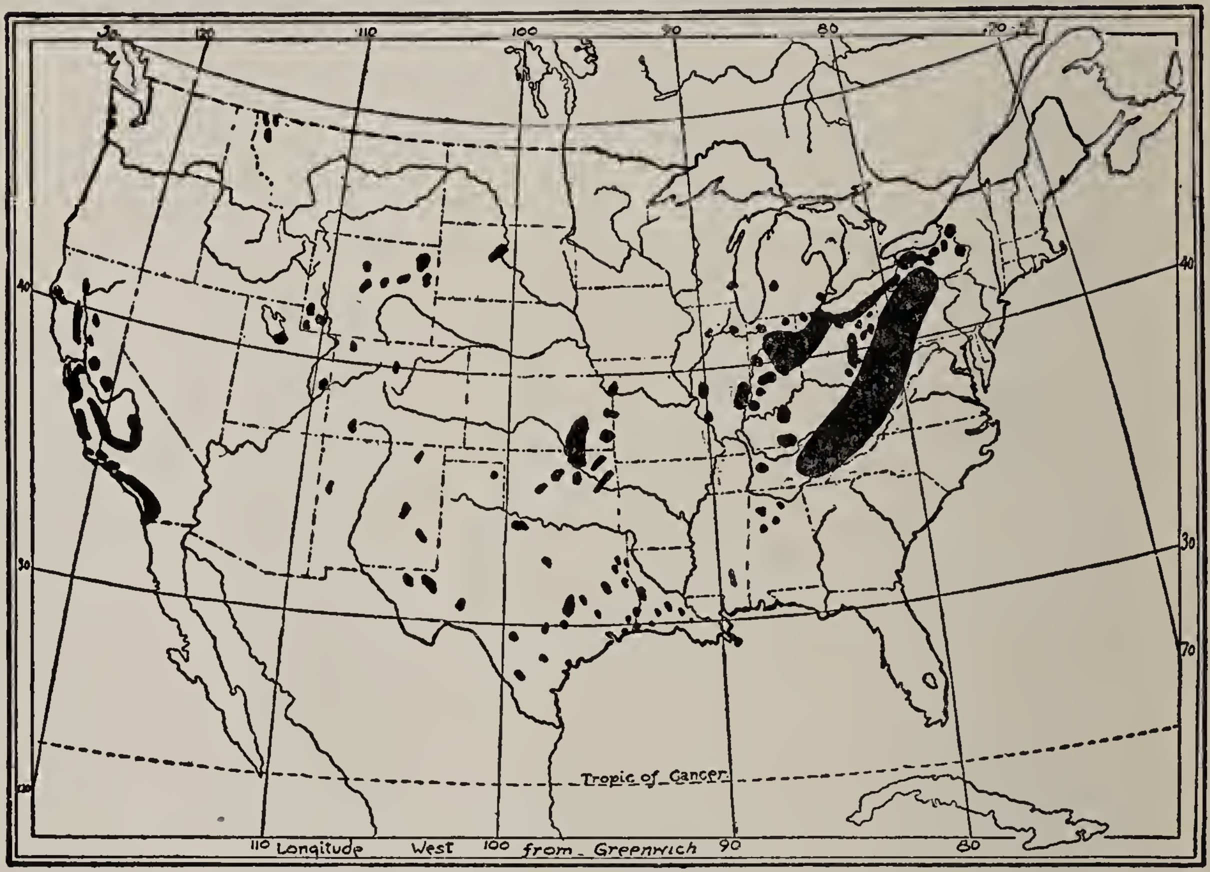

Fig. 19.—The oil fields of the United States.

Beneath each valve are three openings, or ports, Fig. 21. One of these ports opens into chamber A, one into chamber B, and the middle port opens into the outlet pipe, O. When a gas lamp or gas stove is lighted, the pressure on the outlet is reduced. The disk, therefore, has unequal pressure upon its two sides and, as shown in Fig. 21, it is moved, in this case to the left. This movement of the disks is transmitted to the valves and to the recording mechanism. The two disks and the two valves keep moving back and forth as long as gas is being used. In a "5-Light" meter one complete vibration of the disks discharges about ⅛ or ⅑ of a cubic foot of gas.

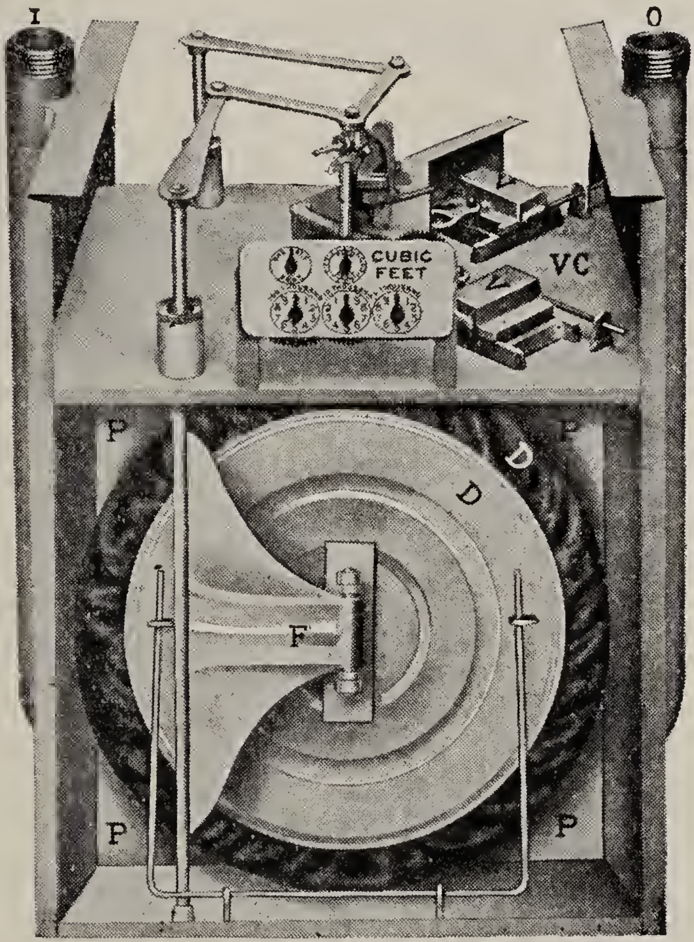

Fig. 20.—5—Lt. consumer's meter with front casing, valve enclosure cover and top cover removed, showing diaphragms, valves and gearing.

This is the size and type of meter generally used by gas companies to measure the gas supplied to the average consumer.

Exercise 20.—To Study the Construction and Operation of a Gas Meter

This exercise may be optional. A discarded meter can usually be secured from the local gas company, probably, if requested, with the casings removed as shown in Fig. 20.

Stand at one end of a meter from which the casing has been removed as shown in Fig. 20. Grasp the two flags, F. Fig. 20, one in each hand. By pressing the disks to right and left alternately you will soon learn so to operate them as to cause the crank always to revolve in the right direction. Watch carefully the movement of the valves and the pointers. Notice that you have to press one disk in as far as it will go before the other disk will move in; that after the second disk has moved in that the first disk can then be pulled out and that the second disk cannot be pulled out till the first disk has been pulled nearly completely out. One disk always moves just one-quarter of a vibration behind the other. Also notice that when one disk does move that the valve on the opposite side also moves so as to open the port and permit the gas to pass into the proper chamber, thus causing the other disk to move.

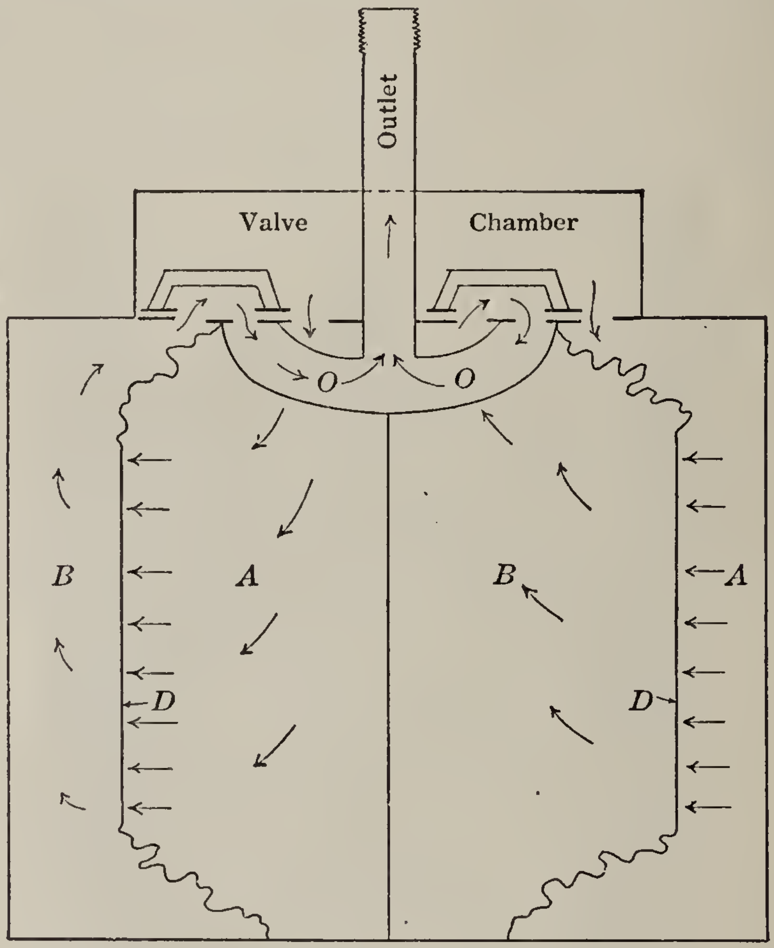

Fig. 21.—This is a diagrammatic cross-section of a gas meter somewhat as it would be seen from the right side of Fig. 20. It shows the relation of the valve chamber, valves, ports and outlet pipe. Inlet to valve chamber is not shown.

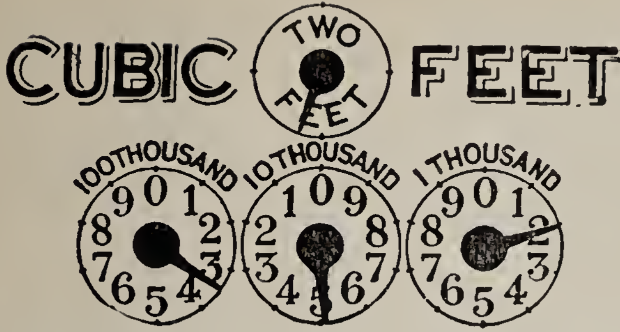

FIG. 22.—This meter reads 35,200 cu. ft.

FIG. 23.—This meter reads 5,700 cu. ft.

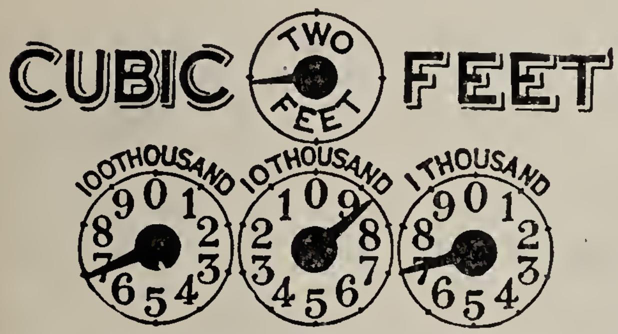

FIG. 24.—What does this meter read? (68,700 or 79,700)

FIG. 25.—What does this meter read? (79,500 or 89,500)

A TYPICAL GAS BILL

Bloomington, Illinois.

John Smith,
505 North Main St.

To the Union Gas and Electric Company, for Gas

From *April 25,* 192 *1,* to *May 24,* 192 *1.*

Present Reading		*6*	*0*	*6*	00	
Last Reading		*5*	*9*	*0*	00	
Consumption of			*1*	*6*	00	cubic feet of gas

at $1.48 per 1,000 cu. ft. *$2.37*
Discount, if paid in 10 days .... *.16*
$2.21

This bill is due *May 29,* 192 *1*
No discount after *June 9,* 192 *1*

49. Reading a Gas Meter.—The small upper dial on a gas meter is the TEST DIAL, OR PROVING HEAD. It is generally used only in testing the accuracy of a meter. The other dials are the ones ordinarily used in reading the amount of gas consumed.

Exercise 21.—To Study the Recording Mechanism of the Gas Meter (Optional)

Notice that the right-hand pointer revolves in a clockwise direction, that the second pointer revolves in a counter-clockwise direction and the third revolves in a clockwise direction. Study the gear wheels to see why this is so.

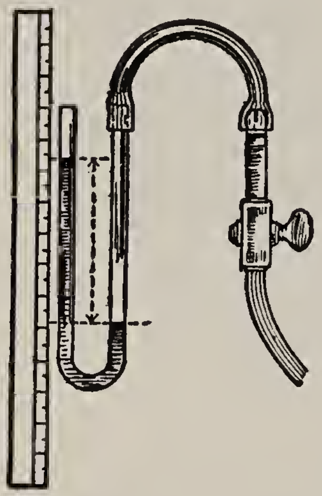

Fig. 26.—Device for determining gas pressure.

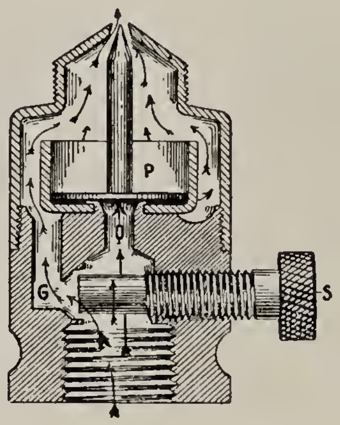

Fig. 27.—Automatic device for regulating gas pressure.

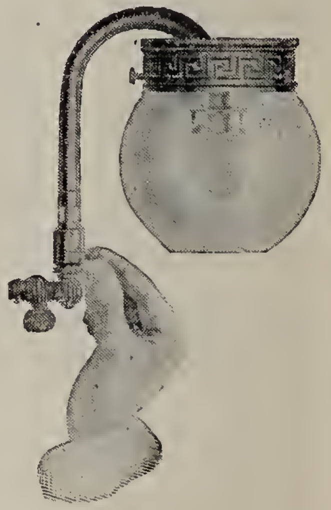

Fig. 28.—An inverted illuminating gas lamp.

The right-hand pointer makes one complete revolution while 1000 cu. ft. of gas is passing through the meter; the second pointer makes one revolution while 10,000 cu. ft. of gas is passing through the meter. The left-hand pointer makes one complete revolution while 100,000 cu. ft. of gas passes through the meter.

It sometimes happens that the hand or pointer is nearly over a figure on the dial. In Fig. 25 you cannot tell whether the left pointer is just past the 8 or just approaching 8. In such cases you have to look at the dial of the next lower denomination.

Read the gas meter at the school, or at home, every day for a week, keeping a careful record of the readings in your permanent notebook.

Exercise 22.—To Measure the Pressure of Gas

Connect a U-tube with the gas jet as shown in Fig. 26. Fill the

U-tube half full of water. Support the apparatus in an upright position. Such a piece of apparatus is called a MANOMETER. Carefully open the gas cock, letting the gas pressure into the manometer. With the ruler read accurately the difference in the level of the water in the two arms of the manometer. If convenient, permit the manometer to remain in position so that you can quickly determine the pressure several times each day for several days. Record often and record the reading together with the date and the hour. If the pressure varies considerably at different hours of the day, how do you account for it?

50. **Gas Burners.**—Illuminating gas may be burned in open jets, "fish tail" burners, or in incandescent burners, that is, within mantles. In the incandescent gas lamp the gas is mixed with the air in a tube below the burner. This tube is therefore the MIXER. The mixture of gas and air passes through a wire gauze at the top of the mixer and is burned within the mantle, there producing a blue, or non-luminous, flame but much heat. The mantle is heated white hot. It, therefore, glows and gives off light just as an iron poker which has been heated white hot glows and gives off light. All burners are supplied with some device for regulating the gas and air supply. Some burners are also supplied with an automatic device for regulating the gas pressure (Fig. 27). Recently several forms of inverted mantle gas lamps have come into common use (Fig. 28).

X. ELECTRIC LIGHTING

51. **Heating Effects of the Electric Current.**—Whenever an electric current passes along a wire, the wire becomes more or less heated. It may not become very hot, but it would if it were not sufficiently large or made of the right kind of material to carry that amount of current. A copper wire will carry, without becoming perceptibly heated, a current of electricity which would heat to a high temperature a wire of iron or German silver of the same size.

Exercise 23.—Heating a Wire by Means of an Electric Current

Scrape the insulation off the ends of some No. 32 German silver wire. Loosen the burr, or nut, on one of the binding posts of a fresh dry cell. Slip one end of the wire under the burr and turn the burr down tight upon it. Be certain that none of the insulation comes between the wire and the binding post and burr. Now loosen the burr on the other binding post. Grasp the loose end of the wire and draw the bared portion under the burr of the second binding post and turn the burr down tight. If the cell is fresh, the wire will become hot; the insulation will begin to smoke and char, and probably will actually burn. The shorter the wire, the hotter it will become (Fig. 29).

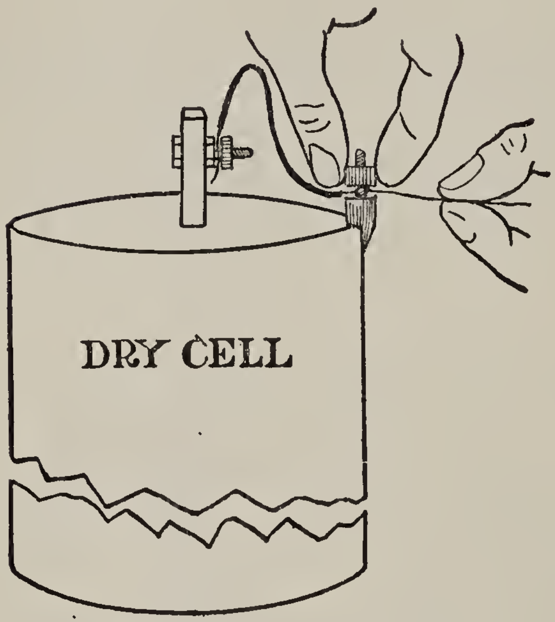

Fig. 29.—Electric current heating a wire.

The over-heating of electric wires sometimes causes fires. If the wires in a building should be too small to carry the current which is sent over them, they may become very hot and set on fire the wood or other burnable material with which they come in contact. For this reason all cities have very strict rules and ordinances governing the wiring of buildings for electric lighting.

52. The Incandescent Lamp.—The incandescent lamp is very simple in principle. It consists of a glass bulb from which practically all the air has been removed. Sealed into the base of the globe are two pieces of platinum wire. The

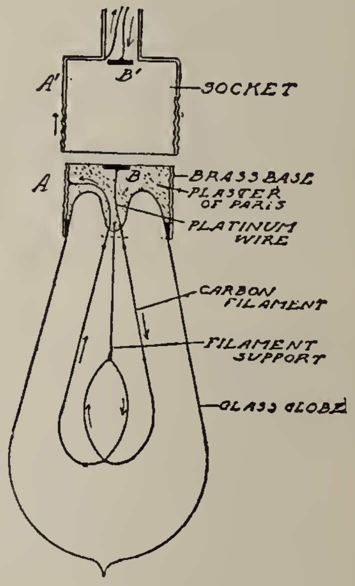

Fig. 30.—Incandescent lamp and socket.

base, or top of the bulb is set by means of plaster of Paris in a brass base which can be screwed into a SOCKET (Fig. 30). One of the platinum wires is soldered to the brass base at *A*, the other is soldered to the plate at the center of the base at *B*. When the lamp is screwed into the socket, *B* comes in contact with *B′* and *A* is in contact with *A′*, completing the circuit. Connecting the two platinum wires within the bulb is a filament sometimes composed of specially prepared carbon. It is really a long thread of carbon. When the current passes through, this filament is heated to a white heat, or becomes INCANDESCENT (Fig. 31). There being no air present, it cannot burn out. If air were present it would be burned up in an instant. In most recent lamps the filament is made of a rare metal called TUNGSTEN (Fig. 32). These lamps give much more light with far less current than the lamps with the carbon filament.

53. The Nitrogen Lamp.—As stated in the last article, incandescent lamps are generally made with all air removed from the bulb. It is not necessary, however, to remove all of the air. It is only one part of the air which causes the filament to burn when heated. Air consists of OXYGEN and NITROGEN chiefly. About ⅕ of the air is oxygen and about ⅘ of it is nitrogen. The nitrogen has no effect on the filament even when it is heated to white heat, at least, the nitrogen does not cause the filament to burn up as oxygen does. In fact, it has been found that if all of the oxygen be removed from the bulb and the bulb is then filled with pure nitrogen that the light given off by the filament when it is heated is whiter, that more light is given off and that the lamp lasts longer. Most of the higher priced lamps, are, therefore, NITROGEN FILLED LAMPS.

Fig. 31.—Carbon lamp.

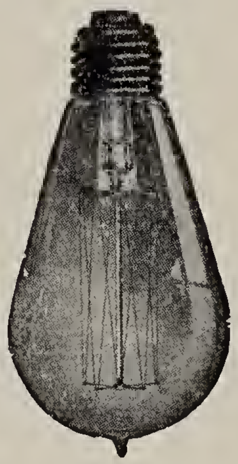

Fig. 32.—Tungsten lamp.

54. **Electric Wiring.**—Electric wiring of buildings must be carefully done by competent electricians. As we have already seen, Art. 51, Exp. 23, electric wires become very hot if they are too small to carry the amount of current sent over them. It is also true that if two wires carrying currents come directly into contact with each other a spark passes between them. Occasionally fires are started by this "crossing" of "live" wires. Most electric wires are of copper and are covered with insulation. This insulation is a thick covering of material through which very little electricity passes. If the wires are not sufficiently large to carry the current required they become so hot as to destroy this insulation. Two of the wires upon which the insulation has been destroyed may come in contact, producing a spark which may set fire to the building.

In the better modern buildings all electric wires are run in CONDUITS. These conduits are simply iron tubes. They are easily bent and are placed in the walls and ceilings of the building when it is being constructed. When it is necessary to turn a corner with a conduit, as in passing from the wall of a room into the ceiling, care is taken to make the turn a curve instead of a sharp angle. When the building is nearly completed a long, flexible steel, resembling somewhat a long, straight clock spring, called a "fishing wire," is pushed through the conduit; the insulated copper wire is attached to the end of the fishing wire and pulled into place in the conduit. The placing of electric wires in conduits not only safeguards the building against fire, but also makes it possible to remove, to repair, or to replace the wiring of the building without injury to the walls or the decorations.

In wiring an old building in which no conduits were placed when the building was constructed, the wires are "fished" through the walls and ceilings, the electricians working through small openings made in the walls, floors, or ceilings. Flexible insulating tubing called LOOM is slipped over the wire till it is completely encased before the wire is drawn into place.

XI. NATURAL AND ARTIFICIAL LIGHTING

55. Importance of Studying the Lighting Question.—Thinking people are rapidly coming to recognize the fact that more attention must be given to the lighting of our houses, our stores, our factories, and especially our libraries and schoolrooms. All who have given this matter special attention agree that too careful consideration cannot be given this lighting problem in this day when we spend so large a portion of our lives in reading and studying or in other occupations requiring close and almost constant use of the eyes. Factory superintendents and school officials are especially active in endeavoring to secure better light for employees and students. Factory superintendents find that it pays financially to provide the best lighting conditions possible for their employees. School officials and parents should give careful attention to securing the best of light in the school and the home.

56. Light Should Come from Above.—Through ages of out-of-door life the eye has become adapted to receiving light from above. The human eye is not adapted to receiving strong light from below or even from a source on a level with the eye. By far the strongest light is received from the sun at midday. But at that hour the sunlight comes from overhead, and even its great intensity is not particularly painful. On the other hand, we are all familiar with the blinding effect of the far less intense rays of the setting sun. When boating, the rays reflected from the water come from below the eye; the effect is blinding and extremely unpleasant. Snow blindness is common in the polar regions, and even uncivilized races have invented devices to protect the eyes against the ill effects of the sun's rays reflected from the snow. Even the reflected light from concrete walks and from light-colored soils is very trying to the eyes because it comes from below.

57. Direct Light and Diffused Light.—The most comfortable light, and therefore the best, is DIFFUSED LIGHT from above. When light comes directly from a luminous body it is said to be DIRECT LIGHT; when such rays are reflected from a smooth surface, such as a mirror or any highly polished surface, they still have the properties of the direct rays. All such rays are parallel to each other or nearly so (Fig. 33). All such direct light, *i. e.*, light with *parallel rays,* is unpleasant and more or less injurious to the eye. Light is said to be *diffused* when its rays are not parallel.

Diffused light is usually obtained by one or the other of the following methods:

First, by causing direct light to be reflected from some uneven or unpolished surface. Examples: (1) Light reflected from a common plastered, or a "white finish" wall; (2) light reflected from a light-colored papered or painted wall (Fig. 34); (3) light reflected from the sky, especially from the portion of the sky opposite the sun, in general, from the northern sky.

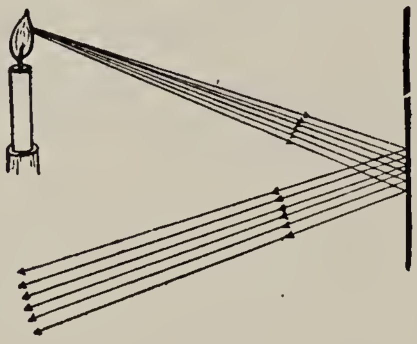

Fig. 33.—Direct light reflected from a polished surface.

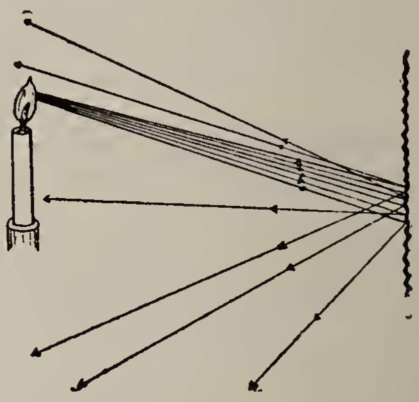

Fig. 34.—Diffused light reflected from a rough surface.

Second, by causing the direct light to pass through some semi-transparent substance or ribbed or fluted glass. Examples: (1) Light which passes through the common white or opalescent globes such as we use on gas mantle burners; (2) light which passes through the frosted tips, or "frosted bowl," of the common tungsten lamps; (3) light which passes through thin cloth such as is commonly used for curtains or light window shades; (4) light which passes through ribbed or frosted glass commonly used in skylights.

58. Obtaining Diffused Natural Light.—Photographers have long recognized the value of diffused light in their work. Most photograph galleries are lighted by means of windows placed in a slanting position and facing the northern sky. Only diffused light from the northern sky can enter these windows. Further to diffuse the light, the windows are often fitted with ribbed glass or glass coated with a thin coat of white paint. Still further to control the light, muslin curtains or light, semi-transparent shades are hung before these windows.

FIG. 35.—Weave shed at a cotton mill, showing the saw-tooth roof. We are looking at the northwest corner of the building; the roof windows face the north.

It is becoming common practice for factories to be constructed with what are known as SAW-TOOTH ROOFS (Figs. 35 and 36). The windows are placed in a slanting position on the north slope of the "saw-tooth" roof, thus admitting only diffused light from the northern sky. By this method of lighting, even large rooms may be evenly and effectively lighted with a soft, mellow light. It is found in factories thus lighted, not only that the employees can do more and better work on account of the better light and lack of shadows, but also that the expense of artificial lighting is greatly reduced.

School officials and schoolhouse architects are beginning to recognize the great value of this method of lighting. Figures 37, 38, and 39 give three views of a schoolhouse thus lighted. Notice that in Fig. 39 all shades are drawn and that most of the light comes from above. Nearly all of the ceiling of the room is fitted with ribbed glass so that none but diffused light from above can enter. It has been found that no artificial lighting is needed in this schoolroom during school hours

Fig. 36.—Interior view of the weave shed. The camera stood in the southwest corner of the room. Note the evenness of the lighting throughout the room. This room is 253 ft. by 140 ft. and contains 648 looms.

at any time during the year, although this particular schoolhouse is located in northern Illinois.

It should always be remembered that direct light produces a glaring effect which is unpleasant and trying to the eye, while diffused light produces a soft, mellow, comfortable effect which is not injurious. It should also be remembered that light should be admitted through the upper portion of the windows if it is impossible to admit it through skylights

Fig. 37.—Exterior of an overhead lighted schoolhouse. (Copyright, 1911, by American Home Magazine Company. By courtesy of *Good Housekeeping* Magazine.)

Fig. 38.—A portion of the roof of the schoolhouse. (Copyright, 1911, by American Home Magazine Company. By courtesy of *Good Housekeeping* Magazine.)

directly above. The common practice of controlling the amount of light by drawing down heavy shades from the top of the windows is bad practice. Much better light can be obtained by providing each window with two light shades, one for the upper and one for the lower sash of the window.

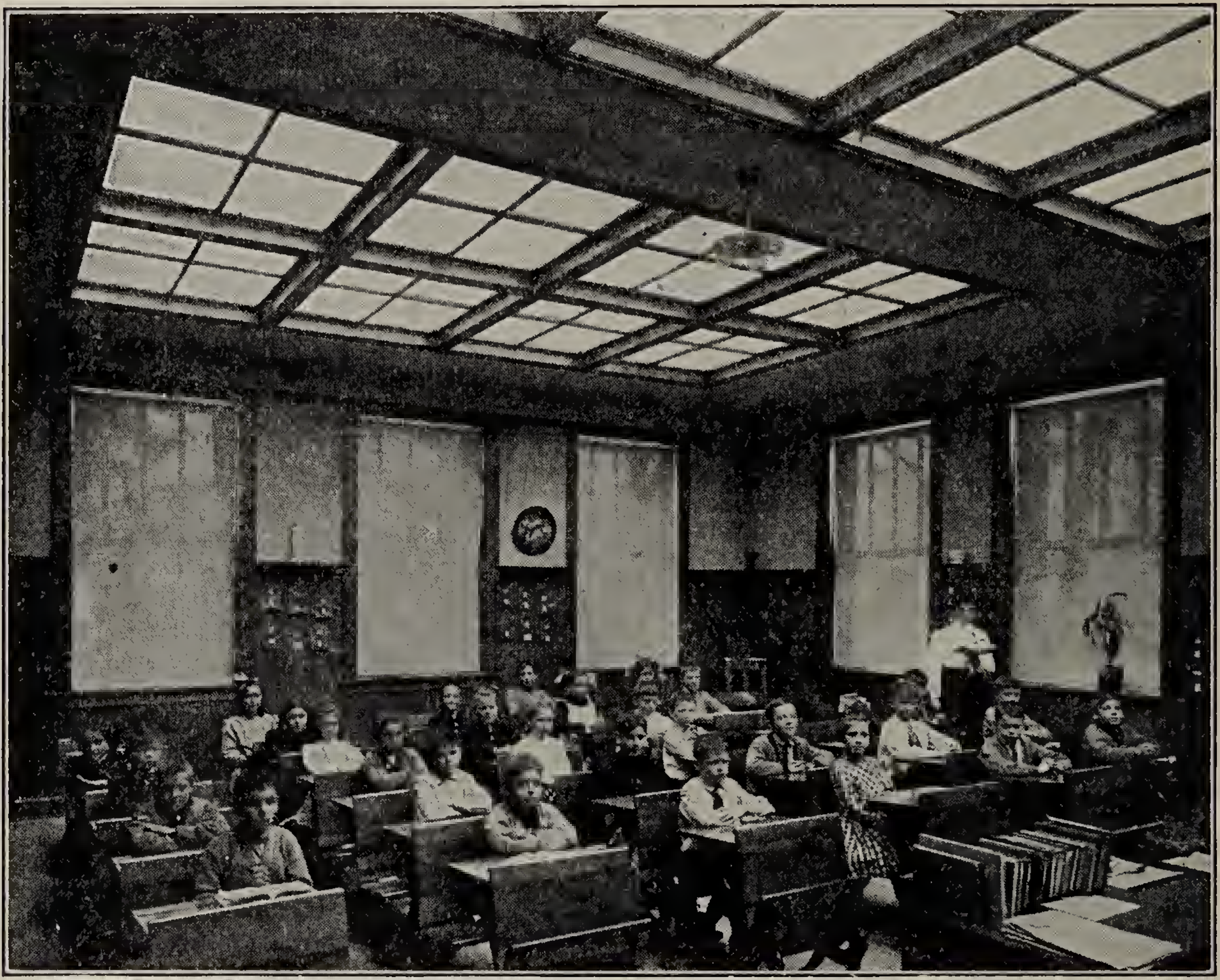

Fig. 39.—Interior view of an overhead lighted schoolroom. Notice that the thin window shades are all drawn down. (Copyright, 1911, by American Home Magazine Company. By courtesy of *Good Housekeeping* Magazine.)

59. Obtaining Diffused Artificial Light.—The *first requirement* in all modern lighting is that the light for the room shall come from several sources, each of moderate intensity, rather than from a single source of great intensity. Figures 40 and 41 are the floor plans of a modern residence, lighted by electricity. These plans indicate clearly the number and location of the lights as placed by an expert lighting engineer. Notice that in the living room there are nine ceiling lights, and four wall lights—thirteen in all. In the dining room there are four ceiling lights and one wall light, besides the central canopy light. The den is lighted by five lights; the hall by three; chambers from three to five.

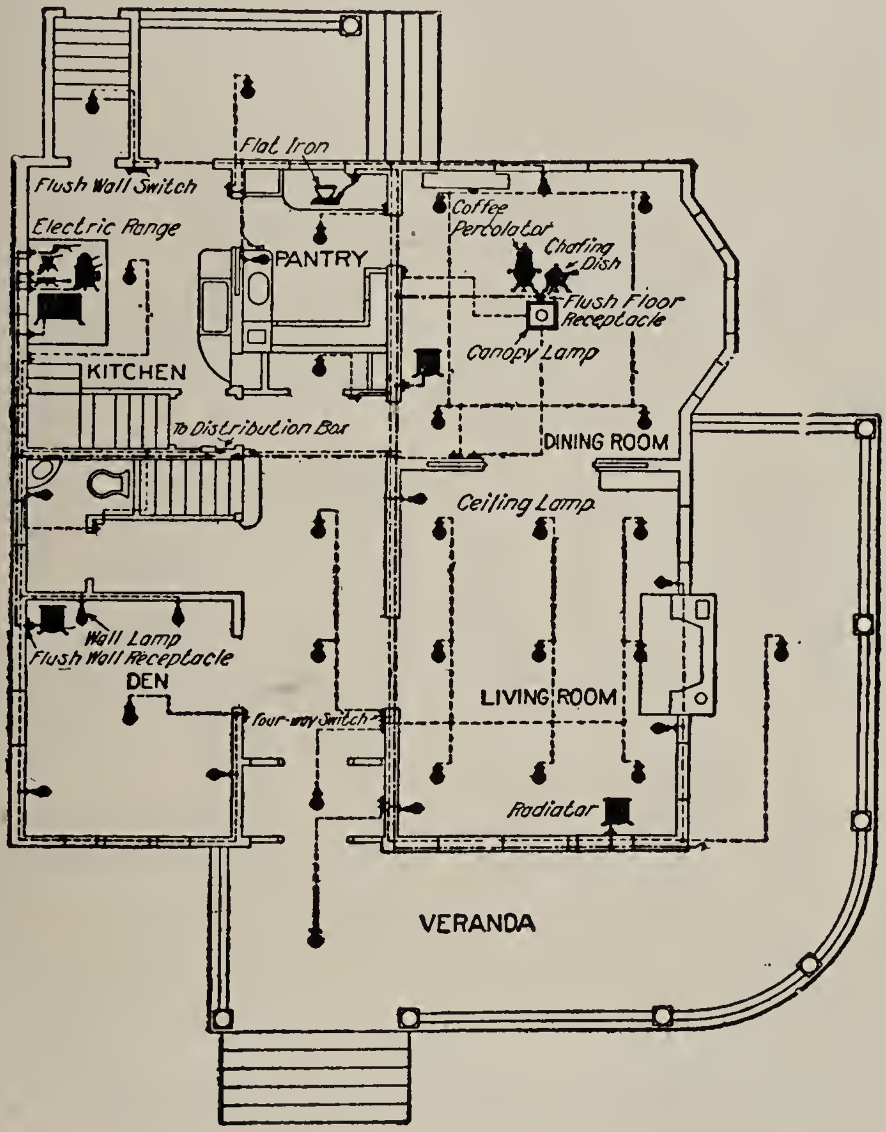

FIG. 40.—Plan of first floor of a modern residence showing system of electric lighting; also other electric appliances.

It is readily seen that, if the light for a room is thus obtained from many sources, much the same effect is produced as by strictly diffused light. The rays from the several different sources are not parallel to each other; moreover, shadows are practically eliminated. The expense of operating the many small lamps to furnish a certain amount of illumination is not materially different from that of operating a small number of large lamps giving the same amount of illumination.

The *second requirement* of modern lighting is that the light shall be diffused. Lamps for use in residences, in schoolrooms, in libraries, and even in factories, are very generally

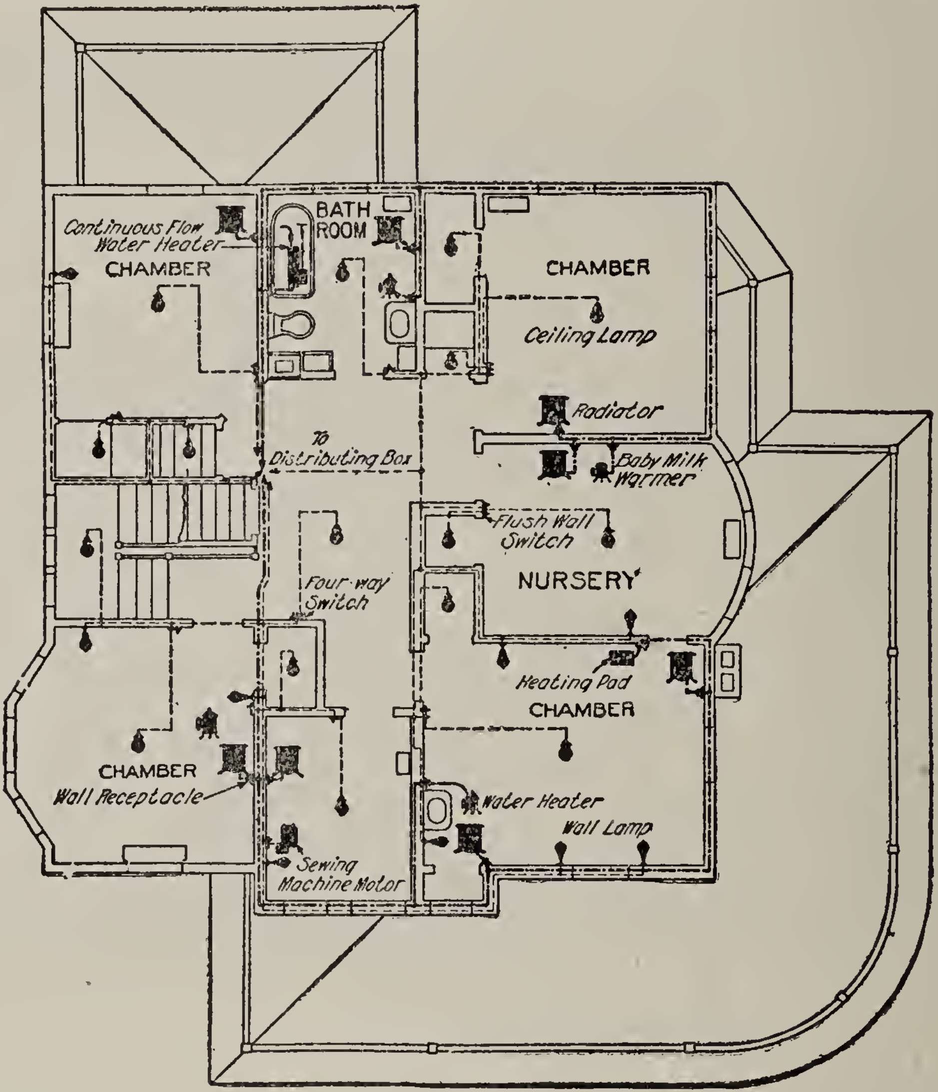

FIG. 41.—Second floor plan of a modern residence showing system of electric lighting; also other electric appliances.

so constructed as to give only diffused light. This is especially true of gas and electric lighting. The gas mantle is often surrounded by a suitable opal glass globe; the lower portion of the electric light globe is frosted, while the upper portion is surrounded by a reflector which diffuses the light. Figure 42 shows how the direct, parallel rays from the tungsten light are diffused by the frosted bowl, and Fig. 43 shows how the direct rays from the gas mantle are diffused by the white glass globe. In each case, the pencil of parallel rays *A* is broken up into the diffused rays *a, a, a,* and *a,* while the pencil of parallel rays *B* is broken up into diffused rays *b, b, b,* and *b.* On the other hand the direct rays *C* pass through the clear glass of the upper portion of the tungsten lamp without being diffused. This direct light from the upper portion of the tungsten lamp is not permitted, however, to escape into the room. The lamp is surrounded by a fluted glass reflector (Fig. 44). This reflector reflects the larger portion of the rays as diffused light, mixing

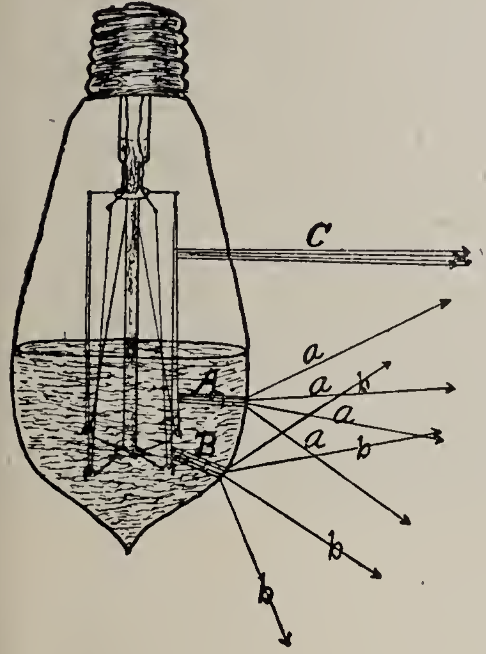

Fig. 42.—Diffused light from the frosted bowl of a tungsten lamp.

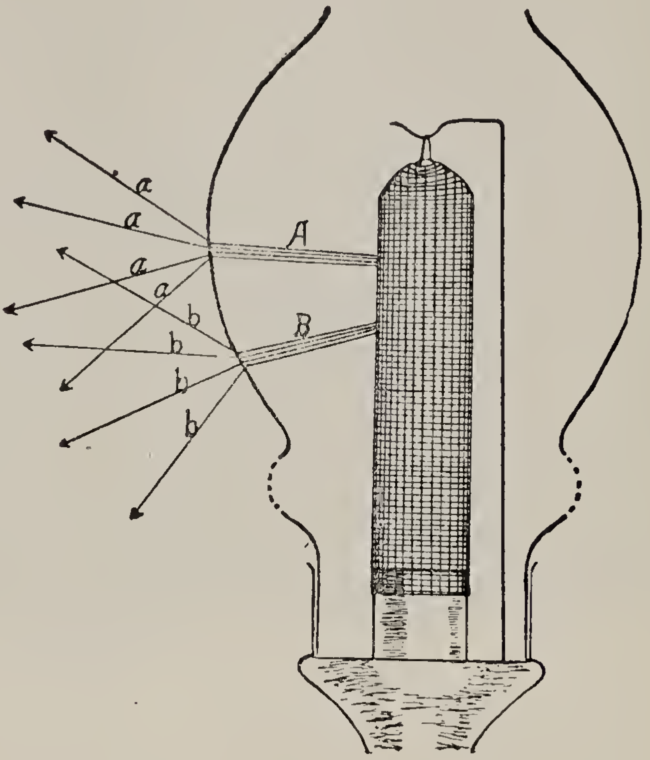

Fig. 43.—Diffused light from the opal glass globe of the gas mantle lamp.

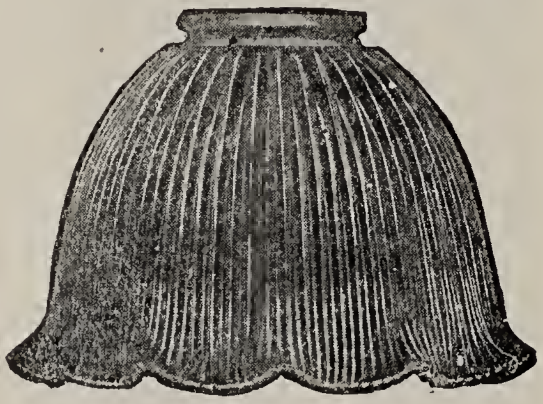

Fig. 44.—A fluted glass reflector. Used on gas and electric lamps.

it with the diffused light which passes through the frosted bowl (Fig. 45 ray *a*, *a*, *a*, *a*, and *b*, *b*, *b*, *b*). A sufficient

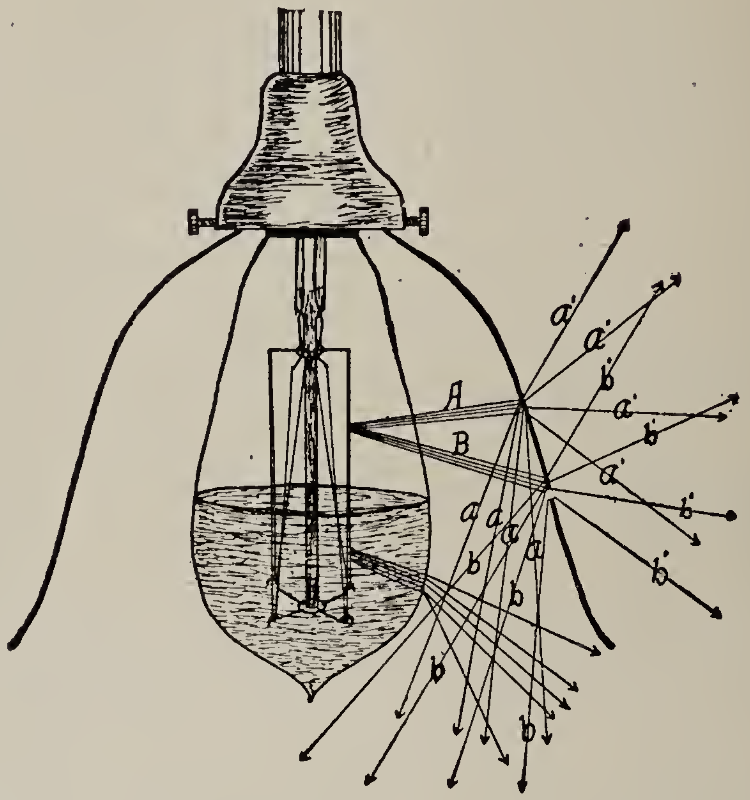

Fig. 45.—Diffused light from tungsten lamp with frosted bowl and fluted glass reflector.

amount of light to illuminate the ceiling of the room passes through the fluted glass reflector. This light is also diffused, *a'*, *a'*, *a'*, *a'*, and *b'*, *b'*, *b'*, *b'*, Fig. 45.

Fig. 46.—Indirect light bowl.

60. Indirect Lighting.—The best artificial lighting is INDIRECT LIGHTING. In the indirect system none of the rays from the light source is permitted to fall directly upon the surface to be illuminated. The lamps are placed within a reflector which diffuses and reflects the light against the ceiling (Figs. 46 and 47), which in turn reflects the light downward to the surfaces which are to be illuminated. The efficiency of such lighting depends

FIG. 47.—A library lighted by indirect lighting.

largely upon keeping the reflector free of dust (Fig. 48) and upon the character and color of the ceiling finish. At best, however, not more than about 70 per cent. of the light is reflected by the ceiling; generally the efficiency of the indirect systems of lighting is much lower than this. Owing to its low efficiency, indirect lighting is frequently regarded as a luxury although its superior quality is recognized by everyone. Bright spots, such as bright, exposed, unshaded lights, have a strong tendency to cause the pupils of the eyes to close, thus, in a measure, shutting out the light and producing the same effect as that due to poor illumination. With indirect lighting all bright spots and glaring

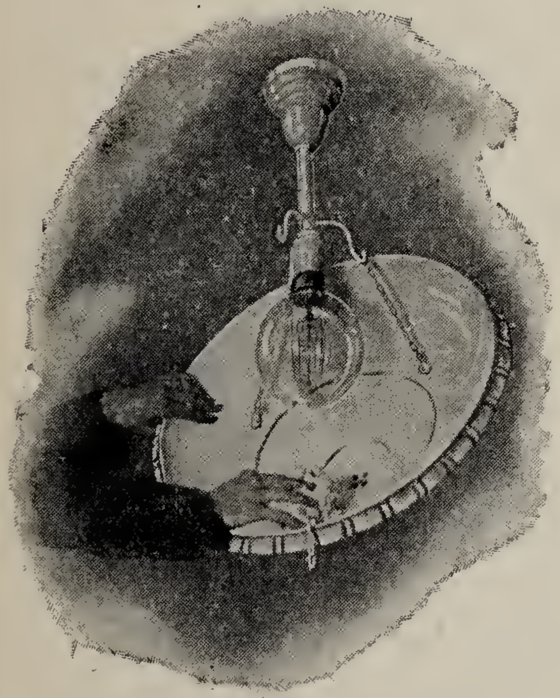

FIG. 48.—Removing the dust from the indirect lighting bowl.

effects are avoided and shadows are few; the diffused light coming from all parts of the ceiling makes this an ideal system of artificial lighting (Fig. 49).

61. Semi-indirect Lighting.—A fairly good substitute for indirect lighting is the *semi-indirect lighting.* A semi-transparent bowl, shaped like the indirect bowl, is used. This bowl is smooth and polished on the inside, or upper side, so as to reflect some light to the ceiling. The glass used is opal glass or it is frosted on the lower side so as to diffuse all light which passes through it.

FIG. 49.—*A.* A bad position and poor light. There is a bright spot before the eye and the light is reflected from the book to the eye. *B.* A good position and good light. The light reflected from the ceiling is diffused light.

62. Amount of Light Which Should be Provided.—It is impossible to give any but very general rules governing the amount of light which should be provided for a room, and therefore the number and size of the lamps which should be installed. The color and the nature of the wall coverings and the character of the furniture and the decorations, as well as the use to which the room is to be put, all have important bearings upon the lighting. A white wall paper or a "white finish" wall will reflect 80 per cent. of the light; a red, dark brown, or dark green wall will reflect only about 15 per cent. A light buff or yellow wall will reflect 45 per cent. of the light; a light apple green will reflect about 40 per cent. The decorations of a room determine largely the illumination of the room with a given amount of lighting.

63. Controlling the Distribution of Light.—It is probable that fully 50 per cent. of the light produced in ordinary residence lighting is wasted. Light is wasted unless it is used to illuminate the surfaces which need to be illuminated. When reading a book or paper, a person needs to have that page illuminated; it is of no benefit to the reader, however, to have the walls and ceiling of the room illuminated to the same extent. In fact, if all other objects in the room were illum-

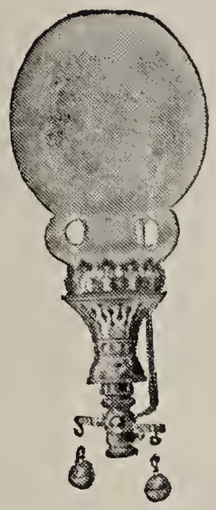

Fig. 50.—Upright gas mantle lamp.

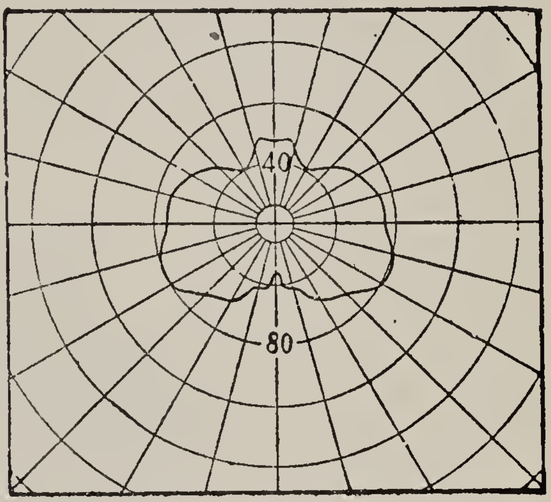

Fig. 51.—The distribution curve for the lamp.

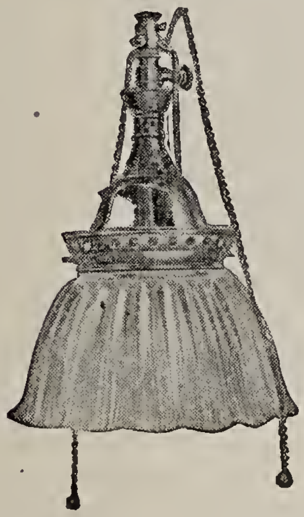

Fig. 52.—A reflex or inverted gas mantle lamp with prismatic glass reflector.

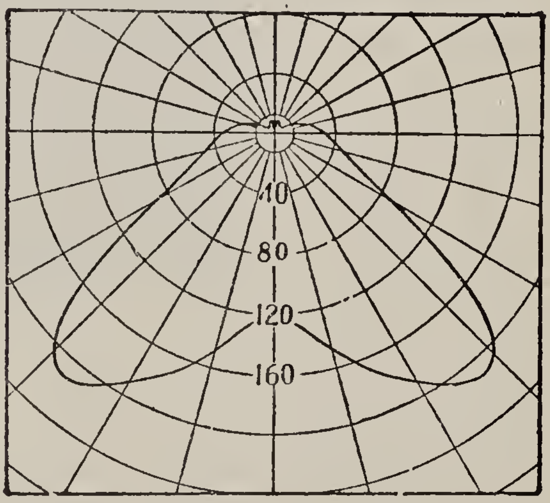

Fig. 53.—The distribution curve for the lamp.

inated to the same intensity as the book, they would tend to draw the attention of the reader from the page. We all know that the attention of the audience in a theater is directed to the players by subduing the light in the body of the house and increasing the light on the stage.

In modern lighting, the choice of fixtures and shades is determined by the use to be made of the light. If the purpose is to supply light for the general illumination of the room, the fixtures and shades will be chosen which will distribute the light with approximately equal intensity in all directions, Figs. 50 and 51. If, on the other hand, it is desired to illuminate a desk or table standing directly beneath the lamp, another style of fixture and shade should be used, Figs. 52 and 53.

During recent years manufacturers of lighting fixtures for both gas and electric lighting furnish the dealer with elaborately illustrated catalogues showing the exact distribution of light from each fixture they make. An intelligent purchaser can, therefore, today choose a fixture exactly suited to furnish the amount and quality of light desired and have that light directed to the point, or points, where it is needed.

64. Relative Cost of Operating Gas and Electric Lights.— *Illuminating gas* is furnished to the consumer under very slight pressure. The price charged varies in different localities but usually ranges between 80 cents and $1.50 per 1000 cu. ft.

Gas may be burned either in the OPEN FLAME jet or in the WELSBACH MANTLE. The open flame jet, or fish tail burner, usually burns about 5 cu. ft. of gas per hour. If gas costs $1.00 per 1000 cu. ft. the cost per hour for gas is about 5 mills for an open flame jet.

When gas is burned in a Welsbach mantle it is generally consumed at the rate of from 3½ to 5 cu. ft. per hour. The cost for gas, is, therefore, from 3½ to 5 mills per hour.

Electricity is sold by the WATT-HOUR or KILOWATT-HOUR. The kilowatt-hour is equal to 1000 watt-hours. The ordinary house meter reads off directly the number of kilowatt-hours of current used. This WATT HOUR-METER, or "WATT-METER," as it is usually but erroneously called, is really little more than a very small and easy running motor (Fig. 54). A very small portion of the current passing through this meter runs the motor which, in turn, operates a chain of gear wheels which turn the hands before the dials (Fig. 54). The usual cost of electric current for lighting purposes is from 8 to 15 cents per kilowatt-hour.

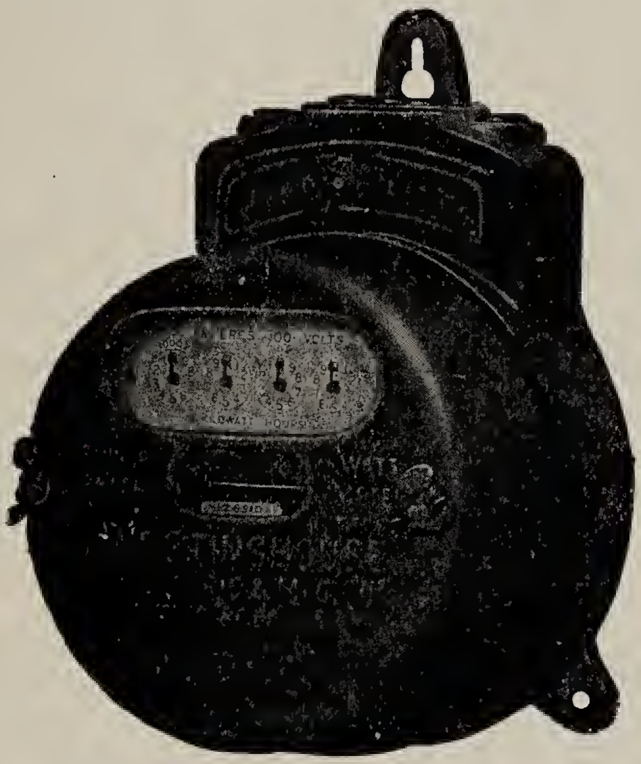

FIG. 54.—A watt-hour meter

The common CARBON FILAMENT lamps are made in several sizes; the sizes most commonly used are the 50-watt lamp and the 100-watt lamp. If electricity sells for 10 cents per kilowatt-hour, the current for the 50-watt lamp costs 5 mills per hour; the current for the 100-watt lamp costs 10 mills, or 1 cent per hour.

The TUNGSTEN FILAMENT lamp is also made in several sizes; the sizes most commonly used for resident lighting are the 25-watt lamp, the 40-watt lamp, and the 60-watt lamp. Therefore, at 10 cents per kilowatt-hour for current, these lamps cost about 2½ mills, 4 mills, and 6 mills, respectively, per hour.

Exercise 24.—Reading the Common House Kilowatt-hour Meter

Study carefully the dial of a watt-hour meter and see how it differs from the dial of the gas meter, Figs. 22, 23, 24 and 25. Notice that the number of cubic feet indicated above each dial on the gas meter shows the amount of gas used *while the pointer has made one complete revolution.* This is not true of the numbers above the dials on a watt-hour meter. The numbers on the watt-hour meter indicate the number of watt-hours of electrical energy used *while the pointer is passing over one of the ten spaces on the dial.*

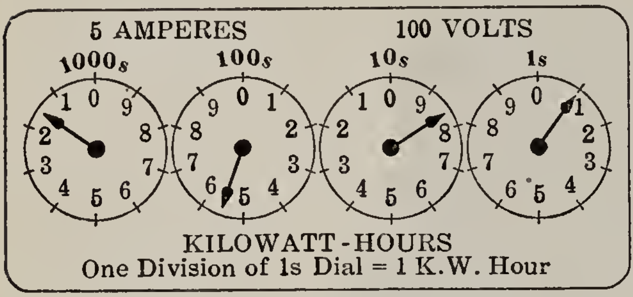

FIG. 55. This dial reads 1581 k.w. hrs.

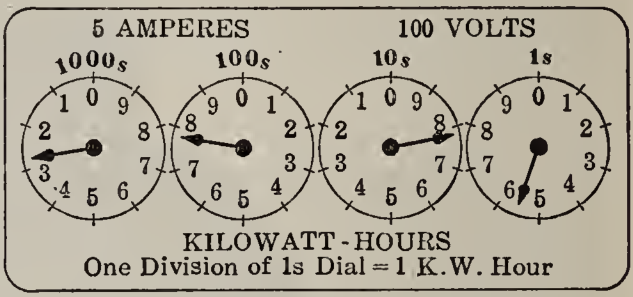

FIG. 56.—This dial reads 2775 k.w. hrs.

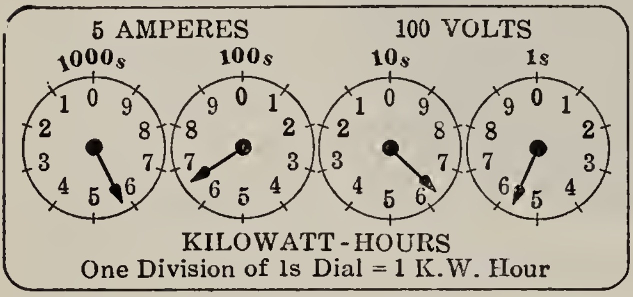

FIG. 57.—What does this dial read? (5665)

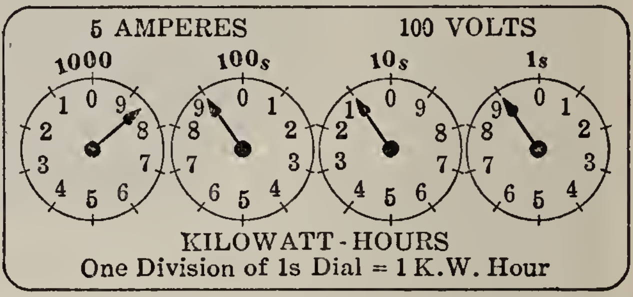

FIG. 58.—What does this dial read? (8909 or 8919?)

If electric current costs 10 cents per kilowatt-hour, what was the cost of the current used between the reading of Fig. 55 and Fig. 56? Between the reading of Fig. 56 and Fig. 57? Between the reading of Fig. 57 and 58?

Although it is probably, as yet, somewhat more expensive to produce a certain amount of light using electric current and tungsten lamps than it is using gas and Welsbach mantle burners, still electric lighting affords so many advantages that it is rapidly displacing gas where both are available. Some of these advantages are: (1) Greater convenience; (2) smaller and more numerous units are easily provided—a very desirable feature; (3) to a certain extent gas lights consume the oxygen in the air and give carbon dioxid; electric lights do not; (4) to a certain extent gas lights tend to blacken the ceiling and walls of the room; electric lights do not; (5) while gas may be put to many uses other than lighting in the home, notably cooking and heating, modern invention makes it possible to use the electric current in the home in a multitude of ways (Figs. 40 and 41).

CHAPTER II

THE PRODUCTION AND USE OF HEAT

I. THE BEGINNING OF WARMTH AND COMFORT

65. Importance of Fire.—Wood has been burned by man ever since the beginning of history. It is impossible even to guess at the time when it was first used as fuel by our ancestors, although there undoubtedly was a time when man did not know the use of fire.

We are so accustomed to fire that we can scarcely realize how much we are indebted to it for the necessities and comforts of life. We forget that, if all the fires in the land should go out, nearly all of the work we see being done about us would cease; that all travel would stop; that, with the coming of darkness all play and pleasure, reading and work would come to an end. We forget that, if we had no fires, we could have no houses to live in, no school buildings to study in; that there would be no street cars, no railroads, no clocks, no watches, no pocket knives—indeed we can hardly mention anything which we enjoy today that we could then have except the fruits, the grains, and the vegetables that grow from the soil. Even then, we should have no tools with which to cultivate the land except such as could be shaped from limbs of trees or from rocks. We should soon all be savages and again live in the woods, sheltered only by rude huts. Our food would be raw meat and such roots, berries, and fruits as we could find.

66. Fires 100 Years Ago.—At the beginning of the 19th century, wood was cheap and labor scarce, and the big fireplace commonly served for both cooking and heating. Hinged to the jamb of the fireplace was an iron crane filled with dangling pot-hooks. It was pulled out so that pots and kettles might be hung upon the hooks, and the crane was then hung back over the blazing fire. Potatoes were baked in the hot ashes. In the wall beside the fireplace was built the brick oven, with its flat bottom and arched top, having an iron door in front (Fig. 59). On baking day, a wood fire was built in the oven, and when it had burned to coals and thoroughly heated the oven, the fire was neatly removed and the bread placed on the oven bottom. In those days, there was usually no attempt to heat other than the living room of the house. The sleeping rooms, in the winter, were damp and bitter cold. The bedstead was surrounded by thick, heavy, bed curtains that hung from the bed frame which reached nearly to the ceiling. Before retiring, the sheets were warmed by means of a warming pan. This consisted of a metal pan

FIG. 59.—An old-fashioned fireplace and oven. (From *Stories of Useful Inventions*. By permission of The Century Company.)

mounted on a handle and having a cover. Live coals were placed in the pan and it was then moved about between the sheets till the chill and the dampness were removed.

In the living room in Whittier's old home, at Haverhill, Massachusetts, can be seen today the fireplace and its old andirons upon which once rested the blazing logs. The crane fastened to the left-hand jamb supports numerous pot-hooks and pots. Two pairs of tongs lean against the jambs. In the wall at the right is the oven with its iron door. Hanging at the left of the fireplace is the warming pan and the lantern. The latter consists merely of a tin can with many small holes punched in its sides and a socket within to hold the candle upright. On the floor beneath them is the foot-warmer. Beyond the door is the flax wheel and the desk at which Whittier wrote all of his earlier poems. The candlesticks and candles are on the desk.

"And for the winter fireside meet,
Between the andiron's straddling feet,
The mug of cider simmered slow,
The apples sputtered in a row."

This old living room has been restored till it accurately represents the home conditions in which the Quaker poet lived and wrote his earlier poems.

For two centuries after the landing of the Pilgrims the people of New England shivered throughout the long, bleak New England winters. Most of the colonists had come from much milder climates and the icy blasts which met them were most trying. In many instances the suffering was intense. In the first place, many of the houses were not well constructed and the cold wind would creep in. In the second place, the huge fireplaces but poorly heated the one room which was supposed to be warmed. Even though Whittier wrote:

"What matter how the night behaved!
What matter how the north wind raved!
Blow high, blow low, not all its snow
Could quench our hearth-fire's ruddy glow,"

it still was true that a short distance from the fireplace the room was so cold as to be quite unendurable to us today. There are plenty of records to show that it was not uncommon for ink to freeze upon the pen even as the recorder wrote his diary at the chimney side. "One noted, that when a great fire was built upon the hearth, the sap which was forced out of the wood by the flames froze into ice at the ends of the logs." "President John Adams so dreaded the bleak New England winter and the ill-warmed houses that he longed to sleep like a dormouse every year, from autumn to spring." (*Home Life in Colonial Days*, Earle.)

FIG. 60.—A winter's service at church.
(Copyright, 1900, by Curtis Publishing Company, and reproduced by courtesy of the *Ladies' Home Journal*.)

All through the days of the colonies and for a half century following the Revolutionary War, the churches of New England were entirely without heat. The men sat throughout the long forenoon and afternoon services wrapped in overcoats and wearing their warmest mittens and footwear. The women and children were provided with foot warmers, sheet-iron boxes containing live coals (Fig. 60).

67. The First Stove.—The first stoves ever used by our American forefathers were made about 40 or 50 years before the Revolutionary War. The stove was merely a cast-iron box with a door in one end and an opening in the upper side through which the smoke could escape. The back or side of the fireplace was removed and this box was slipped into the space beneath the chimney. A very peculiar thing about this stove, as it seems to us, is the fact that the end containing the door was left on the outside of the house. What we should call the back of the stove projected into the room and the operator was obliged to go out of the room into the wood house to feed it. It was, however, a great improvement over the open fireplace because it overcame the strong draft, which, in the open fireplace, sent most of the heat up and out of the chimney.

68. Franklin's Stove.—In 1742 Benjamin Franklin invented his ''Pennsylvania Fireplace.'' He called it ''an open stove for the better warming of a room.'' It was really an open stove which was placed within the old fireplace. The air of the room became heated when it came in contact with any portion of the stove. Franklin said: ''The use of these fireplaces in very many houses, both in this and neighboring colonies, has been and is a great saving of wood to the inhabitants. Some say it saves five-sixths, some say three-fourths, others much less. I suppose two-thirds or one-half is saved; my room is twice as warm with one-fourth the wood formerly used.''

As a means of securing comfort, Franklin's invention, without doubt, was the greatest single step ever made in perfecting heating devices. With this stove it became possible to heat most of the rooms of a house so that they were fairly comfortable. Such stoves would hardly be considered of great value today for heating purposes, but at the time of the Revolutionary War they were the kings of heaters. In fact, there was no very great improvement over the Franklin stove for a century. In this line of advancement, as well as in many other lines, the world must ever recognize in Benjamin Franklin one of its greatest benefactors.

Today we have heating devices much more complicated than Franklin's stove. These include, beside the improved and modern stove, the warm air furnace, steam and hot water heaters, gas heaters, and electric heaters. These modern heating devices require much less attention and insure greater comfort to the inhabitants of the house than did Franklin's stove. All of these heating arrangements, mentioned above, with the exception of the electric heater, make direct use of fire for the production of heat, hence it is fitting that just here we study what goes on in a fire and how it may be controlled.

II. THE CHEMISTRY OF FIRE

69. Fire was a Riddle to the Ancients.—Fire was long a riddle to the ancients, and even to people of more recent times. It was not until after the close of the Revolutionary War that the true explanation of fire was brought out by Lavoisier (Lä″vwä″*syé*) a French chemist. His explanation was (1) that the fuel which is burned is composed of certain fuel elements, namely, carbon and hydrogen; (2) that the air contains a third element called oxygen; (3) that burning consists of the chemical union of the fuel elements, carbon and hydrogen, with the oxygen of the air; and (4) that this combination of carbon and hydrogen with oxygen produces heat and light. This explanation of fire by Lavoisier is still accepted today.

This explanation immediately calls for further explanations of what is meant by "chemical element," "chemical union," "fuel elements," "oxygen," "carbon," and "hydrogen." These will be discussed in turn next.

70. Chemical Elements.—Carbon is called a CHEMICAL ELEMENT because no other kind of matter has yet been obtained from it alone. Carbon, alone, can produce only carbon. So it is with oxygen and with hydrogen. Substances that have, so far, defied all attempts on the part of man to change them into simpler substances are called CHEMICAL ELEMENTS. About 80 chemical elements are known. The following is a list of the common chemical elements.

Aluminum
Calcium
Carbon
Chlorine
Copper
Gold
Hydrogen
Iron
Iodine
Lead
Magnesium
Mercury
Nickel
Nitrogen
Oxygen
Phosphorus
Potassium
Silicon
Silver
Sodium
Sulphur
Tin
Tungsten
Zinc

It is from the chemical elements, in various combinations, that the many, many different substances known on the earth are derived.

71. Chemical Union.—This is the process by which the different chemical elements, or the compounds derived from them go together to make various combinations called CHEMICAL COMPOUNDS. Chemical union resulting in the formation of a chemical compound is illustrated in the following exercise using the elements copper and sulphur.

Exercise 25.—Union of Elements to Form Compounds

Clean a piece of copper foil with emery or sand paper until the surface of the metal is bright. What is the color of the copper? Now hold the cleaned foil with a pair of tongs and sprinkle a thin layer of powdered sulphur on the surface of the copper. What is the color of the sulphur? Are the substances copper and sulphur elements or compounds? (See Art. 70, list of chemical elements.) The copper and sulphur are undergoing chemical change at ordinary temperatures, but very slowly. The rate of union may be increased by heating them. By means of the tongs hold the copper and sulphur in the flame of the burner and watch changes. If too much sulphur has been used, it may be burned off from the surface of the metal. Remove the foil from the flame and examine the surface of the copper. What is its color now? This is a new substance produced by the union of the copper and the sulphur. It is known as COPPER SULPHID. Possibly not all of the copper was used in the change. Only that portion on the outside, and next to the sulphur really underwent chemical change. Heat was liberated as the elements united but it was not noticeable in the flame.

72. **Discussion of the Exercise.**—This experiment illustrates chemical union. The pair of elements, copper and sulphur, illustrate many such pairs that might be made to go into chemical union. Thus copper and oxygen combine to form copper oxid, carbon and oxygen unite and form carbon dioxid, silicon and oxygen make silicon dioxid, or sand, sodium and chlorine will combine to make sodium chlorid, or common salt. The number of such combinations of two, and even more than two, elements to form compounds is very large indeed. It is the compounds resulting from such combinations of which the earth and the things thereon are made.

The student should be careful not to confuse CHEMICAL COMPOUNDS with MIXTURES. The making of a chemical compound involves a much deeper process than making a mixture. When two elements are merely mixed, each of the elements, if they are solids, not liquids or gases, may still be seen, if not with the eye, then with the aid of a microscope. We may mix, for instance, powdered copper and powdered sulphur, and a careful examination will still show copper particles and sulphur particles. But when we cause the two to unite chemically we have a substance, called copper sulphid, in which no amount of examination will show any copper or sulphur. Copper and sulphur, as such, have disappeared and they have been merged into one substance, copper sulphid, which is something entirely different from the elements of which it is made. So it is with all compounds with reference to the elements from which they are made. Moreover, a chemical compound always contains a certain percentage of each of the elements composing it, whereas a mixture may contain the elements in varying percentages.

73. **Fuel Elements.**—These are the chemical elements commonly found in fuels and upon which the fuel depends for its ability to burn. These fuel elements are carbon and hydro-

gen. While there are many forms of fuel, such as solid fuels, including wood and coal; and liquid fuels like kerosene, gasoline, and alcohol; and gaseous fuels such as coal gas, gasoline gas, and other gases, it is found that the ability of these fuels to burn is dependent on the presence of one or both of the fuel elements, carbon and hydrogen.

We shall next study carbon and hydrogen, together with the oxygen upon which the burning of the fuels depends.

74. **Carbon.**—This is a solid, black in color except in case of the diamond which is crystallized carbon. Charcoal is composed chiefly of carbon, while the so-called lead of the lead pencil is a mixture of a form of carbon, called graphite, and clay.

75. **Oxygen.**—This is a colorless gas. It is one of the constituents of the air. The other chief constitutent of the air is another gas called nitrogen. It will be remembered that nitrogen, as well as oxygen, is a chemical element (Art. 70). These gases are mixed together in the air. They are not in chemical union. The air also contains the compounds carbon dioxid and water vapor, both of which are colorless gases. The following table gives the constitutents of the air out of doors.

Oxygen, 21 volumes in 100 volumes of dry air.
Nitrogen, 78 volumes in 100 volumes of dry air.
Water vapor, variable within wide limits.
Carbon dioxid, 3 volumes in 10,000 volumes of dry air.

Now the burning of fuels requires oxygen and produces carbon dioxid and water vapor. It is evident then, that combustion will tend to change the proportions of the constituents of the air. Why the oxygen is not all used up and why the volume of the carbon dioxid does not largely increase in amount will be explained in Arts. 310 and 374.

Since oxygen is commonly found mixed with the other substances in the air we wish to get it in a pure, or nearly pure, form so that it may be studied better. There are many compounds of oxygen which may be made to give up a part or all of their oxygen by heating or by other means. One such compound is potassium chlorate, a white crystalline compound composed of potassium, chlorine, and oxygen. When it is heated, it liberates its oxygen. If it is mixed with manganese dioxid, it liberates oxygen, at a much lower temperature.

Exercise 26.—The Preparation and Properties of Oxygen

Set up the apparatus as shown in Fig. 61. Remove the test tube, fill it about one-third full of potassium chlorate; then place about an equal amount of manganese dioxid in the tube. Close the tube with the hand and shake it until the chlorate and the dioxid are well mixed. Replace the stopper in the apparatus, making sure that the stopper fits tightly. Apply gentle heat to the mixture in the tube, beginning at the end which has the stopper, but do not heat the stopper, for it may catch fire and make serious trouble. As the oxygen is given off, gradually and carefully extend the heat toward the closed end of the tube. At no time should so much heat be applied that the escaping gas carries the oxygen-producing

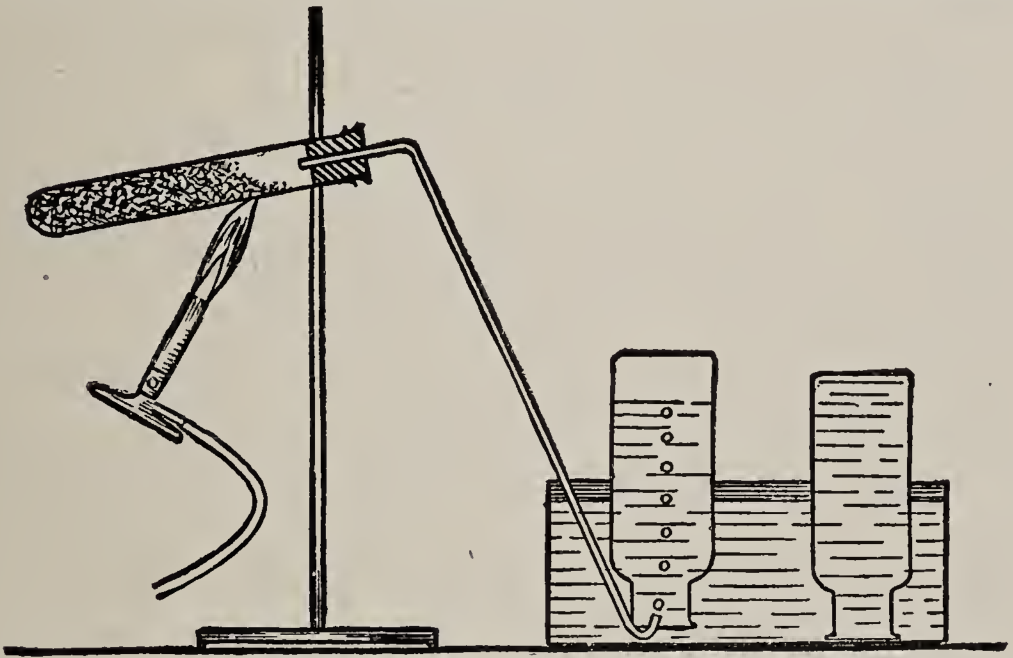

Fig. 61.—The preparation of oxygen. Potassium chlorate and manganese dioxid are placed in the test-tube and heated and the oxygen is collected in bottles. Be careful to see that the delivery tube extends entirely through the rubber stopper. Do not allow the delivery tube to become clogged.

mixture along with it bodily, thus tending to clog the delivery tube and to prevent the escape of the gas. Fill wide-mouthed bottles with the gas produced. To do this, submerge the bottle in the water in the pan, seeing that all of the air is expelled from the bottle by the water; then, keeping the mouth of the bottle beneath the surface of the water, invert the bottle and place it over the end of the delivery tube. As the oxygen escapes from the delivery tube, it bubbles into the bottle of water and crowds the water out. When the first bottle is full, place another bottle over the end of the delivery tube just as the first one was placed. Set the full bottles on the top of the table, keeping them inverted. The water around the mouth of the bottle will keep the oxygen from getting out. When you have driven as much oxygen as possible from the mixture in the tube, remove the end of the delivery tube from the water; then remove the flame from the test tube.

Study the oxygen obtained as follows:

(*a*) *Effect of Pure Oxygen on a Burning Splinter.*—Place a splinter of wood in a bottle of oxygen to see that the wood does not burn in oxygen at ordinary temperatures. Now heat the splinter, that is, "set it on fire," and thrust it into a bottle of oxygen. What is the result? In which, gas, oxygen or air, does the wood burn more rapidly? Why? Ignite another splinter and blow out the flame leaving the splinter merely glowing. Hold it in the air for a moment to see whether it will again burst into a flame. If it does not, place the glowing splinter in a fresh bottle of oxygen and observe the result. How do you explain it?

(*b*) *Effect of Pure Oxygen on Smoldering Substances.*—Repeat the latter part of (*a*) using a piece of smoldering candle wicking or a piece of burning punk and a fresh bottle of oxygen.

(*c*) *Effect of Pure Oxygen on Glowing Charcoal.*—Wrap a small wire around a piece of charcoal the size of a lead pencil and an inch in length. Heat the charcoal in the flame until it glows. Quickly lower it into another bottle of oxygen and notice what takes place. When the charcoal ceases to burn, remove it from the bottle and close the mouth of the bottle. Compare the rate at which the charcoal burns in the oxygen with that in the air. Charcoal is chiefly carbon, and the compound resulting is carbon dioxid, a gas, which remains in the bottle. CAUTION.—*Quench the charcoal by putting it into water. If left burning it might set the building on fire.*

(*d*) *Effect of Pure Oxygen on a Burning Candle.*—Twist a small wire around a short piece of candle or taper, light the candle and observe the rate at which it burns in the air; then plunge it into a fresh bottle of oxygen. Observe the rate of burning in the oxygen.

(*e*) *Burning Iron in Oxygen.*—Slightly unravel the end of a piece of iron picture wire. Heat the unraveled end in the flame; then quickly dip it into a little powdered sulphur and at once plunge it into a bottle of oxygen. Does the iron burn? It may be necessary to make several trials before the iron burns brilliantly. Do not use too much sulphur, just enough to kindle the iron. Can you make iron burn in the air?

(*f*) *The Limewater Test for Carbon Dioxid.*—Place a tablespoonful of fresh, clear limewater in each of the bottles used above. Place the palm of the hand over the mouth of each bottle in turn and shake well. In which case does the limewater become milky in color and in which does it not? There may be several dark-colored specks in some of the bottles, but disregard them. The milky color of the limewater is a test for carbon dioxid.

76. Discussion of the Experiment.—The union of oxygen with the substances burned in this experiment is termed OXIDATION. The products arising from the union of the oxygen with the elements burned are called OXIDS. Thus the carbon in the wood, candle wicking, charcoal, and candle united with the oxygen to form carbon dioxid. The hydrogen in the wood, the candle wicking, and the candle united with the oxygen to form water. This was in the form of steam when made. The iron of the picture wire formed iron oxid.

Carbon dioxid causes limewater to become milky. Oxygen does not change limewater.

77. Temperature and Oxidation.—A factor which influences the rate of oxidation is TEMPERATURE. At ordinary temperatures the rate of oxidation is very slow for most materials. Wood and many other fuel materials decay at ordinary temperatures. They are really undergoing what is called SLOW OXIDATION. At higher temperatures the rate is much more rapid. For each substance that burns, there is a temperature at which it burns rapidly in the air. This temperature is called the KINDLING TEMPERATURE. When a fire is kindled, the aim is to heat the fuel to be burned by burning the kindling, the kindling having a lower kindling temperature than the fuel. Thus sulphur is used to kindle the iron; kerosene, paper, or shavings are used to kindle the coal or wood because these kindling agents have lower kindling temperatures than the fuel which is to be burned. When the fuel is once ignited, it then liberates heat fast enough to keep itself at the kindling temperature and so the fire continues as long as the concentration of the oxygen is sufficient. Wet fuels often require so much heat to dry them that the burning portion can not supply heat enough to dry the unburned portion and to raise it to the kindling temperature. Hence the fire goes out. Water is thrown on a fire to cool the burning material below its kindling temperature. Also the steam arising from the water serves to dilute the air and thus to lower the concentration of the oxygen so that the fire goes out.

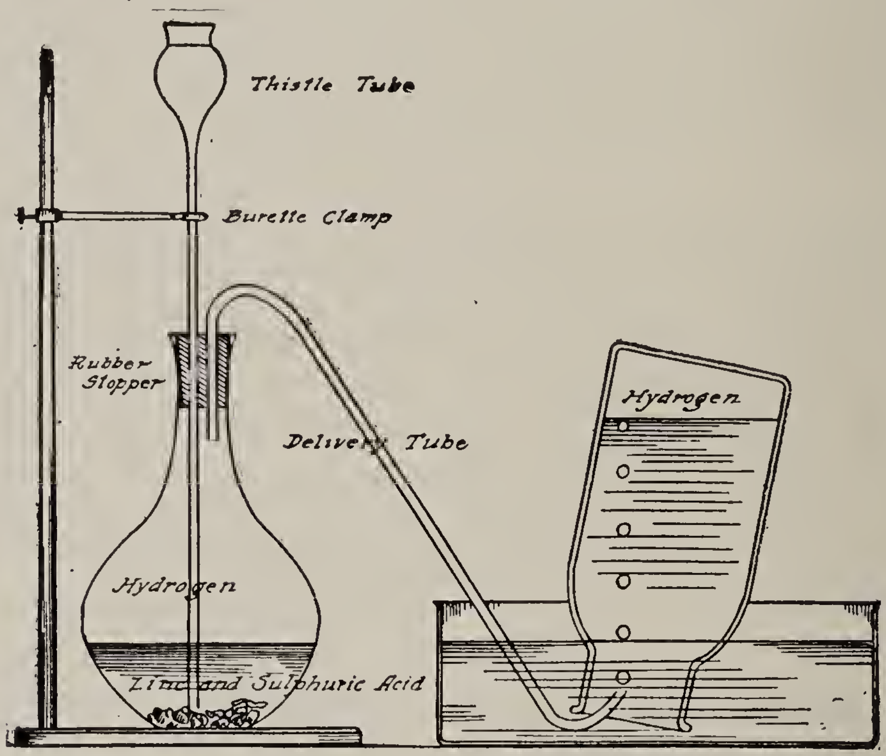

Fig. 62 — Apparatus for generating hydrogen.

78. **Study of Hydrogen.**—Hydrogen is the second of the fuel elements. It is to be prepared and studied.

Exercise 27.—The Preparation and Properties of Hydrogen

Set up the apparatus as shown in Fig. 62. Cover the bottom of the flask with granular zinc, replace the stopper and see that all joints of the apparatus are tight. Prepare to collect the gas, hydrogen, just as oxygen was collected. Do not have any flames closer than 4 ft. from the hydrogen generator. Pour water down the thistle tube until the bottom of the flask is well covered and the lower end of the thistle tube is submerged; then pour in concentrated sulphuric acid slowly until the action between the zinc and the acid is rapid. Do not spill the acid on the hands, clothing, or desk. Allow the hydrogen to escape from the delivery tube for about one minute; then collect the gas over water in wide-mouthed bottles. Fill one bottle *half full* of the gas. Finally remove the delivery tube from the water, wipe it dry, and allow the gas to flow into a *dry* bottle containing air. Cover this bottle as well as possible. Take the hydrogen generator apart, fill the flask with water to dilute the acid and stop the action. Pour the dilute acid into the sink, rinse the unused zinc with fresh water and save the metal for future use.

Study the hydrogen as follows:

(*a*) *The Burning of Hydrogen.*—Light a splinter of wood. Lift one of the full bottles of hydrogen from the water, and, keeping the mouth of the bottle down, bring the flame of the splinter to the mouth of the bottle. Pay no attention to the noise, but look for the flame of burning hydrogen playing about the mouth of the bottle where it is uniting with the oxygen of the air. The experiment may be repeated with other bottles of the gas.

(*b*) *The Burning of a Mixture of Hydrogen and Air.*—Prepare another burning splinter. Lift from the water the bottle which was filled half full of hydrogen, keeping the mouth of the bottle down. What enters the bottle as the water runs out? Allow the air and hydrogen a few seconds in which to mix; then ignite them by means of the flame. The result illustrates the burning of a mixture of hydrogen and air. The noise is due to the sudden rush of the products of the burning from the bottle. The outrush is due to the heat generated by the combustion. Such a mixture is said to be EXPLOSIVE. Such mixtures should be ignited only in bottles having wide mouths to allow the easy escape of the products of the burning.

(*c*) *The Product Formed When Hydrogen Burns in Air.*—Prepare another burning splinter of wood. Take the *dry* bottle containing the mixture of air and hydrogen, and keeping it mouth downward, ignite the mixture. After the combustion is over carefully examine the inside of the bottle. Do you find any moisture on the walls? Where did this come from? What then is the product arising from the burning of hydrogen in air? Why was it necessary to use a dry bottle for this part of the experiment?

79. Discussion of the Exercise.—When hydrogen burns, it unites with oxygen, liberating much heat and producing water, in the form of vapor, as a product. This vapor condenses to water when it is cooled. Hydrogen is the lightest known substance. It is much lighter than air, and hence the bottles containing hydrogen are kept inverted so that the hydrogen will not run out. Mixtures of hydrogen and air containng more than 5 per cent. by volume of hydrogen and less than 72 per cent. are explosive. That is to say, a mixture of 95 cu. ft. of air and 5 cu. ft. of hydrogen will explode; so will other mixtures containing relatively less air and more hydrogen until a mixture of 28 cu. ft. of air and 72 cu. ft. of hydrogen is obtained, beyond which the mixture is no longer explosive.

80. Hydrocarbons.—

Exercise 28.—Burning Compounds of Hydrogen and Carbon

(*a*) Light the Bunsen burner and hold over the flame an inverted, dry, cold tumbler. What substance appears on the inside of the glass? Pour a tablespoonful of limewater into the tumbler, cover it and shake it. Notice the change in the limewater. What two substances were formed by burning the gas?

(*b*) Repeat (*a*) but use a candle flame instead of the gas flame. Study the products arising from the burning of the candle.

(*c*) Repeat (*a*) using a kerosene lamp flame, studying the products of the combustion.

What products of combustion may we expect when fuels containing hydrogen and carbon are burned?

HYDROCARBONS are compounds of hydrogen and carbon. Petroleum is a very complex mixture of hydrocarbons. Some of the hydrocarbons of petroleum are gases at ordinary temperature, some are liquids, and some are solids (Chap. I, Sec. IV). The liquids form the largest portion. By distillation, the gaseous, liquid, and solid hydrocarbons are separated. Gasoline and kerosene are common liquid hydrocarbons, while the paraffin of which the candle is made is a solid hydrocarbon. There are not large amounts of uncombined hydrogen in nature, but the compounds of hydrogen and carbon known as hydrocarbons are abundant, and in these, the hydrogen and carbon are combustible.

81. The Burning of Fuels Produces Energy.—It is well known to everybody that heat is produced when a fuel burns. Now heat is one of the forms of energy. "*Energy is work or anything that may arise from work or be converted into work.*" We readily see then, that heat is energy because we have seen heat doing work in pulling the train or running the automobile. The locomotive of the train or the engine of the automobile is the machine in which heat is produced and converted into work. Electricity is another form of energy. It may do work for us or it may produce light or heat. Fuels possess a kind of energy called CHEMICAL ENERGY, because the energy is set free when the fuel undergoes a chemical change called burning. In this ability of fuels to burn and liberate energy we find the real reason for burning them. We may want the energy in the form of heat to warm our houses or to cook our food. We may want the energy of the fuel to do work for us by pulling the train or running the automobile. Now we can begin to see why it was said at the first chapter that to take fire away from man would soon cause him to become a savage having no machinery, tools, nor implements, and living in caves and eating his food uncooked. Thus we see that the discovery of fire by primitive man back sometime in the dim past was one of the most important discoveries he ever made. It has enabled him to pass from savagery to civilization.

82. Summary of Section II. The Chemistry of Fire.—(1) Fire is the chemical union of the oxygen of the air with the fuel elements, carbon and hydrogen, of the material burning. (2) The fuel elements and oxygen are three of the eighty or more known chemical elements. (3) When carbon unites with oxygen in the burning process a gas, carbon dioxid, is formed, while hydrogen uniting with oxygen produces water vapor, another gas. These two gases, carbon dioxid and water vapor, are the common gaseous products arising from fire. (4) In order that oxygen may unite with the fuel elements the temperature of the fuel must be at least as high as a certain temperature called the kindling temperature. (5) When the fuel burns it produces energy which appears as heat or light. Man has learned to put this energy to various uses to serve his purpose.

III. BURNING OF WOOD AND COAL

83. The Burning of Wood.—Wood is composed chiefly of carbon, hydrogen, and oxygen. These elements are present in various compounds which make up the wood. When the wood is heated to the kindling temperature in the presence of the air containing oxygen, a complicated series of changes take place which may be understood in part at least, by means of Exs. 29 and 30.

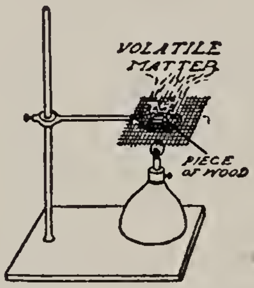

FIG. 63.—Burning wood on gauze.

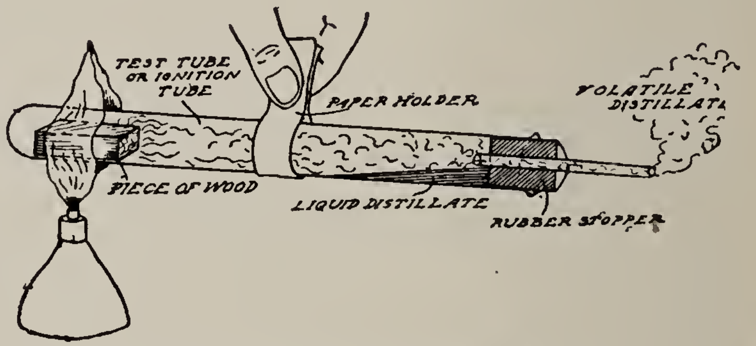

FIG. 64.—Distillation of wood.

Exercise 29.—Heating Wood in the Air

Place two or three thicknesses of wire gauze on a ring attached to a ring stand and lay a piece of wood about ½ by ½ by 1 in. in size on the gauze. By means of a flame apply heat to the wood from beneath the gauze. If the flame from the burner passes through the gauze, more thicknesses of the gauze must be used. While the wood is smoking strongly, remove the flame and apply a lighted match to the escaping smoke. Does the smoke catch on fire? (Fig. 63.) How high above the wood can you cause the smoke to ignite?

This smoke consists of VOLATILE MATTER produced by the action of the heat on the wood. The volatile matter consists in part of hydrocarbons, and in part of water, acids, and wood alcohol. It is the burning of the volatile matter which causes the flame when wood is burned.

The black material, left on the gauze after the volatile matter is removed, is called WOOD CHARCOAL. Place it on the edge of the gauze so that the end of the stick of charcoal extends beyond the gauze and heat the charcoal strongly by means of a flame. Does the charcoal get red hot? Does it burn after the flame is removed? Does the charcoal burn with a flame? Does it give off much heat? Do you find any ash remaining after the charcoal has burned? The glowing embers of a wood fire are due to the burning of the wood charcoal after the volatile matter has been removed and burned.

Caution.—Be sure to quench the glowing charcoal lying on the gauze by throwing it into water. Why? (c Ex. 26.)

Exercise 30.—The Distillation of Wood

Select a piece of wood about 1 in. long and of such a size as will slip into a test tube. Close the test tube with a one-hole stopper through which passes a short glass tube (Fig. 64). Heat the test tube as shown in the figure, carefully observing what takes place. Does smoke appear? Try lighting it as it comes from the small tube. Does liquid appear in the tube? Keep the tube inclined so that the liquid will stay near the stopper. If you allow it to run back and meet the hot glass it will probably break the tube. When the wood ceases to give off smoke, cool the tube, remove the stopper and pour the liquid into a shallow vessel. What is its color, odor, and appearance?

84. Discussion of the Exercise.—The liquid distilled from the wood is known as PYROLIGNEOUS (pī″rō-lig′nē-us) ACID (*pyro* meaning fire, and *ligneus* meaning woody). It is therefore, acid obtained from woody substances by means of fire. It is composed largely of water but it also contains acetic acid (the acid of vinegar) and wood alcohol and other substances of commercial value. When wood is burned in a stove or grate these substances, except the water, together with the gases which escaped from the tube are all consumed in the flames, while the charcoal remains on the grate to be slowly oxidized to carbon dioxid, producing much heat but little or no flame.

85. A Study of Flame.—It has been seen that it is the vapor of the candle, of the gasoline, and of the kerosene that burns. The hydrogen has been seen to burn with a flame. The illuminating gas burns with a flame. The volatile matter from the wood burns with a flame. In every case a flame is produced by a burning vapor, or gas. Those fuels that are gases or that may be changed into vapors, or gases, by means of heat burn with a flame. Four conditions are necessary in order that a flame be produced: (1) The material must be in the form of a vapor or gas; (2) this vapor or gas must be mixed with oxygen; (3) the mixture of oxygen and vapor or gas must have concentration within certain limits (Art. 77); (4) the mixture must be heated to the kindling temperature. If one or more of these conditions are wanting there can be no flame.

86. Blowing Out a Flame.—A common expression is that of ''blowing out'' a flame. Candle flames, lamp flames, and even the flame of a fire just started may be blown out. However, if the fire is well started, it may be impossible to blow it out, but rather the blowing only serves to make the fire burn faster. From what has been given in Art. 85, on flames, it is evident that the effect of blowing into a candle flame or a lamp flame is to scatter the particles of vapor or gas and thus reduce their concentration (Art. 77) to such an extent that there can be no flame. Moreover, the cold blast of air entering the flame serves to cool the burning materials below their kindling temperature (Art 77). With a solid fuel such as charcoal, however, the case is different.

Exercise 31.—Effect of Blowing upon Glowing Charcoal

Place a piece of charcoal upon the gauze and heat it with a flame until it glows. Now blow gently upon the glowing portion. Does the blowing cause it to burn more or less rapidly? Can you blow it out? *Caution.—Quench the charcoal in water when through with it.*

It is evident that one can not blow hard enough on the charcoal to scatter the particles as the gas particles are scattered and thus stop the burning. Rather, the blowing serves to bring in fresh oxygen and to remove the carbon dioxid resulting from the burning thus favoring the burning.

87. Luminous and Non-luminous Flames.—In will be recalled that the flames of the candle, of the kerosene lamp, and of the burning wood are yellow or red in color and give much light. Such flames are said to be LUMINOUS. The hydrogen flame, the gasoline flame as commonly used in stoves, and the illuminating gas flame as used in stoves or within Welsbach mantles are blue. Such flames are said to be NON-LUMINOUS. The heat of the flame causes the mantle of a gas lamp to become very hot and thus to give light. The light producing ability of the flames of the candle, or kerosene, and of wood is due to the presence of red- or white-hot particles of carbon. The carbon has been separated from the fuel burned by the action of the heat on certain compounds in the fuel. This carbon is heated by the burning of the hydrogen in the fuel and thus gives light. The carbon finally meets oxygen and it too burns liberating heat. If anything interferes with the burning of the carbon, a black smoke composed of unburned carbon particles results (Ex. 4).

88. Incomplete Combustion.—

Exercise 32.—Causing a Flame to Smoke

Light a candle flame. Can you see any unburned carbon escaping from the flame? Now introduce some cold object, as a glass tumbler, into the flame. What is the result? What do you find is being deposited upon the cold surface? Why did it not burn?

Light a kerosene lamp and replace the chimney. Turn the wick higher until the lamp smokes. What is the smoke? Why does not this smoke burn? Why does not the flame smoke when the wick is turned lower as it should be (Art. 8, Ex. 4)?

DISCUSSION OF EXERCISE 32.—The fuels burned in the above exercise were hydrocarbons. We have just seen that the fuel suffers decomposition or a breakdown into its elements, hydrogen and carbon, as it burns. These elements then burn separately. If there is a lack of sufficient oxygen, or if the fuel and oxygen are not properly mixed, or if the carbon is cooled below its kindling temperature before it has a chance to meet oxygen, then there will be more or less unburned carbon and the flame will smoke, due to the escape of this unburned carbon. Now it happens that the volatile matter from wood contains some oxygen in addition to what may mix with it from the air, and consequently wood ordinarily burns without black smoke. It is therefore said to be a cleaner fuel than soft coal which ordinarily burns with a black smoke.

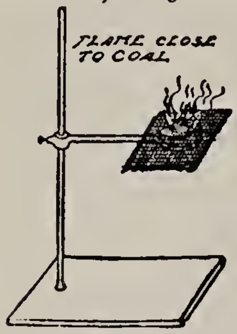

Fig. 65.—Burning the volatile portion of coal in air.

89. Burning Coal.—Soft or bituminous coal is the name applied to most of the coal mined in the United States, except that which is mined in the eastern half of Pennsylvania. To this latter the name hard or anthracite coal is applied.

Exercise 33.—How Soft Coal Burns

Place two or three thicknesses of wire gauze on a ring attached to a ring stand and lay a piece of soft coal about the size of a marble on the gauze. Heat the lump strongly by means of a flame. Does the coal produce any smoke? Remove the flame (Fig. 65). Can this smoke be ignited? How far above the coal are you able to ignite the smoke? The smoke, or volatile matter, consists of water and various hydrocarbons arising from changes in the coal, due to the heating. After all of the volatile matter of the coal has been driven off, remove the flame and examine the part which remains. It is called coke. What is the name of the corresponding material obtained by heating wood? See if you can ignite the coke as the charcoal from wood was ignited. Coke is much used as fuel, especially in obtaining metals from their ores.

Exercise 34.—How Hard Coal Burns

Repeat the preceding experiment using a lump of hard coal instead of the soft coal. Can you heat it hot enough to drive off enough volatile matter to support a flame? What can you say about the relative amounts of volatile matter in the two kinds of coal?

Exercise 35.—Distillation of Soft Coal

Arrange to distill soft coal just as wood was distilled (Ex. 30) except that the test tube is filled about one-thirds full of fine soft coal. The liquid which collects in the test tube is called COAL TAR, the gas which burned is the COAL GAS, while the solid portion left from the coal is the COKE.

90. Familiar Facts about the Burning of Wood and Coal.—Wood and soft coal burn with long red flames because they contain so much volatile matter, while hard coal, because it contains so little volatile matter, does not produce such flames. Wood and hard coal make but little smoke because they are completely burned, including whatever volatile matter they contain, while soft coal, because it contains so much volatile matter, produces more or less black smoke. Hard coal and wood produce light fleecy ashes, while those from soft coal often melt together in the fire, causing clinkers. For starting a wood or a soft coal fire, a rather small amount of kindling is needed, since these fuels catch on fire easily because of their large amounts of volatile matter which easily ignites. Hard coal, because it contains so little volatle matter, requires more kindling and a hotter fire to start it.

91. The Composition of Common Solid Fuels.—In our study of fuels it is important that we understand the behavior of the fuel when heated. The following table gives: (1) The percentage of carbon that does not pass away as volatile matter, known as charcoal, coke or fixed carbon; (2) the percentages of volatile matter which is produced by the fuel when it is heated; (3) the percentage of water; (4) the percentage of ash.

In the construction of stoves and furnaces in which the various fuels are to be burned, the manufacturer must keep in mind these facts of composition. The customer who buys a stove or furnace must know in general what kind of fuel is to be burned. Even with all of these conditions in mind, it is yet a difficult matter to burn soft coal, which produces much volatile matter, in such a way as to avoid serious loss.

TABLE II.—COMPOSITION OF SOLID FUELS

Substance.		Coke or fixed carbon, per cent.	Volatile matter, per cent.	Moisture, per cent.	Ash, per cent.
Wood, dried		20 to 30	55 to 65	15 to 20	1 to 3
Peat, dried		25 to 35	25 to 50	20 to 35	2 to 7
Coal	Lignite	40 to 70	23 to 48	4 to 40	3 to 20
	Cannel	30 to 40	45 to 55	1 to 4	6 to 12
	Bituminous	40 to 75	20 to 50	3 to 10	2 to 10
	Semi-bituminous	70 to 80	10 to 20	1 to 5	4 to 10
	Semi-anthracite	80 to 90	5 to 10	1 to 3	3 to 7
	Anthracite	85 to 93	3 to 6	1 to 3	3 to 5
Coke		85 to 95	none	1 to 5	2 to 12

IV. SMOKE; ITS CAUSE AND PREVENTION

92. The Cause of Smoke.—Because of the high percentage of volatile matter in soft coal, it is likely to produce much black smoke unless precautions are used to prevent it. The principles concerned in smoke production are identical with those explained in connection with the smoking candle and the oil lamp. Hydrocarbons produced by the heated coal are decomposed more or less completely into hydrogen and carbon. Failure of the carbon to meet a sufficient supply of oxygen at or above the kindling temperature of the carbon, causes more or less of the carbon to be carried up the chimney unburned, making its appearance as black smoke. Even though the temperature of volatile matter is kept sufficiently high until it meets oxygen, if the supply of the latter is insufficient, the carbon will be incompletely burned at best. It may be burned to CARBON MONOXID instead of CARBON DIOXID. This means a loss of heat, since less than one-third of the energy of the carbon is liberated as heat if it is burned to carbon monoxid instead of carbon dioxid.

93. Some of the Evils of Smoke. The Smoke Nuisance.—The production of black smoke means, not only poor combustion of the coal and hence a loss of heat, but also injury to health and property. People who are compelled to live and work in a smoky atmosphere are liable to injury to their health. Moreover, the smoke and its accompanying dirt have a depressing effect on people. They are liable to become despondent and unhappy. This in turn may affect their health. Smoke makes necessary the more frequent painting of buildings. Stone buildings become dingy and the owners are sometimes put to the expense of washing the entire outside of the building. White clothing becomes soiled because of soot. Furnishings and draperies in houses are injured. Goods on the dealer's shelves are injured because of soot. Our waste due to poor combustion of soft coal runs into millions of dollars annually.

94. How Can This Waste be Prevented?—Of course, the prevention is by causing more perfect combustion of soft coal. Did you ever follow the changes that take place when fresh, soft coal is thrown into a stove containing a bed of hot coals? When the coal first meets the hot bed of coals the volatile matter of the coal begins to distill off. If the temperature in the stove is fairly high, this volatile matter may undergo more or less complete decomposition into carbon and hydrogen. The hydrogen burns if the oxygen supply is somewhat limited, while the carbon, which requires a greater concentration of oxygen, is burned incompletely or not at all. Black smoke results. If the temperature in the stove is rather low, the volatile matter may not be decomposed so much. A bluish-gray smoke results. At all events the drafts of the stove are generally not able to supply enough oxygen and maintain at the same time a temperature high enough to burn the volatile matter immediately after throwing fresh coal into the fire. Consequently smoke issues from the chimney as long as there is much volatile matter being produced from the coal. After the volatile matter has been set free, smoke ceases to escape from the chimney until a fresh charge of coal is thrown into the stove. If smaller amounts of coal could be thrown in at shorter intervals of time, it might be that the drafts of the stove would be able to supply enough oxygen to burn the volatile matter as fast as it is produced by the coal. Since it is not convenient to place frequent small charges of coal in the stove, the other method commonly resorted to in smokeless combustion is the gradual and slow distillation of the volatile matter in the soft coal, so that the drafts can furnish oxygen fast enough to consume the volatile matter completely.

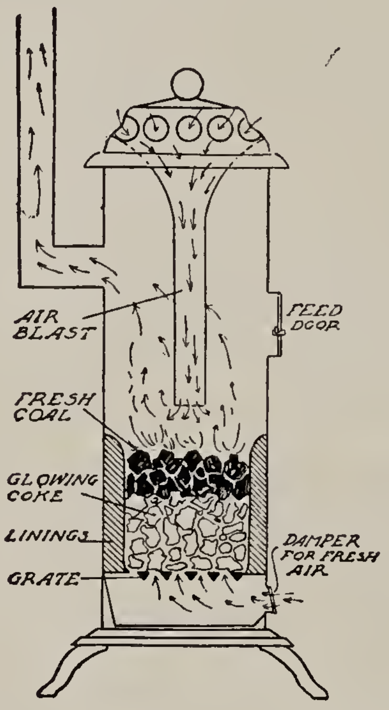

Fig. 66.—Stove with air blast.

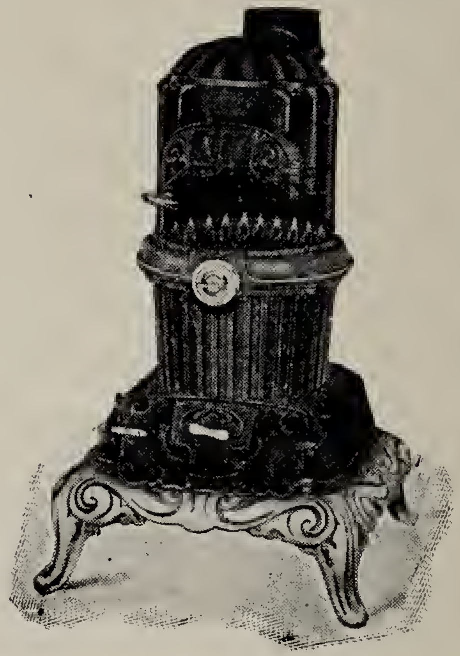

Fig. 67.—Another form of air blast.

95. How Some Stoves and Furnaces are Constructed to Prevent Smoke.—A common device is the HOT BLAST stove. In this stove the air for the oxygen supply is admitted from above instead of from beneath the grate as in most stoves. By the top-draft arrangement, the volatile matter has a better chance to meet oxygen and hence its complete combustion is more readily accomplished (Figs. 66 and 67).

In some furnaces the coal is first thrown into a COKING CHAMBER which is heated by the fire in the fire pot. Here slow

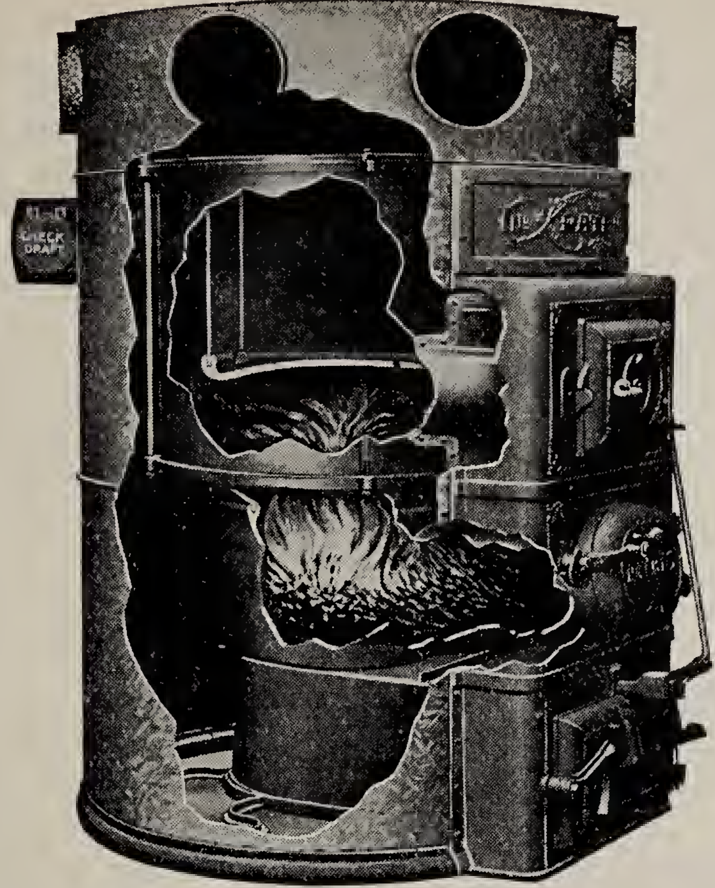

FIG. 68.—A furnace with a coking chamber.

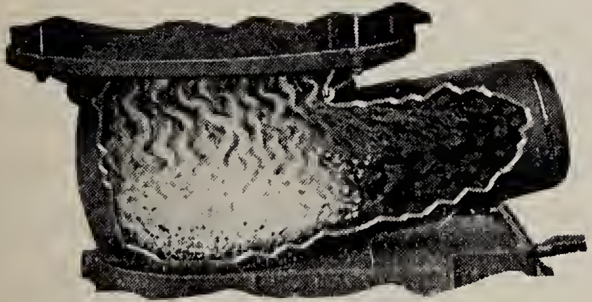

FIG. 69—Coking chamber of a side-feed furnace.

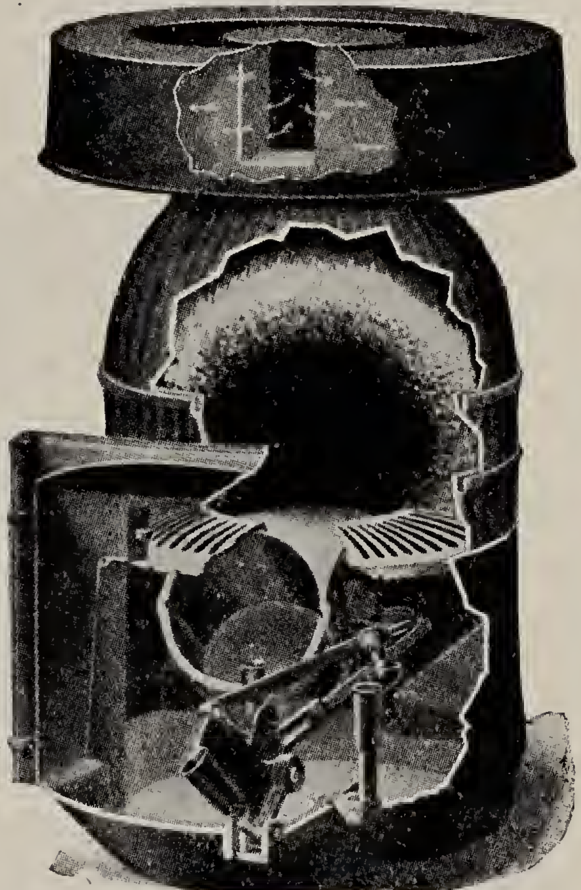

FIG. 70.—An underfeed furnace.

distillation of the volatile matter takes place. By means of a damper in the coking chamber door, sufficient air can be admitted and a sufficiently high temperature may be maintained in the combustion chamber to burn the volatile matter completely (Figs. 68 and 69).

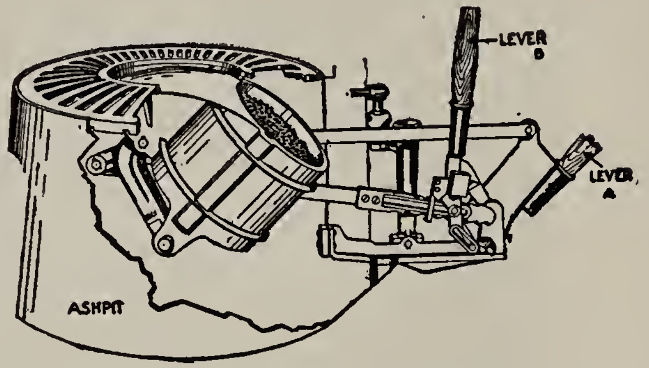

Fig. 71.—Showing the feed cylinder tilted forward and filled with coal. The apron closes the opening in the center of the grate through which the coal is forced upward into the fire box.

In the underfeed furnace, fresh coal is introduced at the bottom of the fire bed. Distillation of the volatile matter takes place therefore at the bottom of the fire, where the oxygen supply may be more abundant than on top of the fire, and hence it is more completely burned (Figs. 70, 71, and 72). Moreover, in passing through the glowing coke above, the volatile matter is sure to be heated to the kindling temperature.

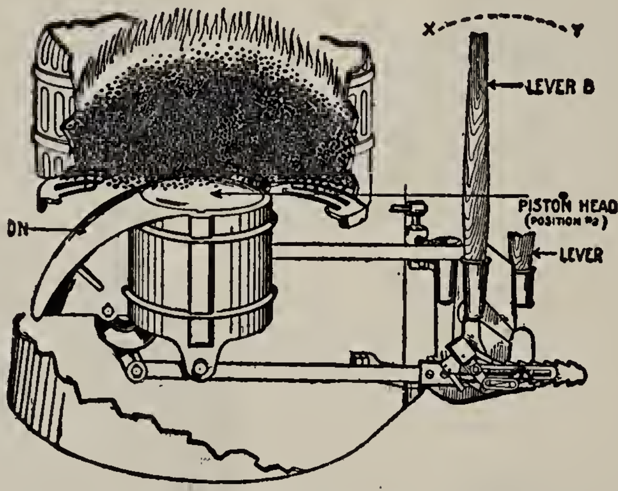

Fig. 72.—Showing the fresh coal forced into the fire box and the burning coal resting on the top of the fresh coal.

In steam boiler plants MECHANICAL STOKERS are often employed. With the mechanical stokers, the aim is to feed the fuel to the fire gradually by some device. In the stoker shown (Fig. 73), which is a chain grate stoker, the coal is fed continually by being carried into the furnace on the grate. As the fresh coal approaches the zone of combustion, the volatile matter is gradually distilled from the coal. There is also provision for a supply of air ample to burn the volatile matter as well as the fixed carbon or coke.

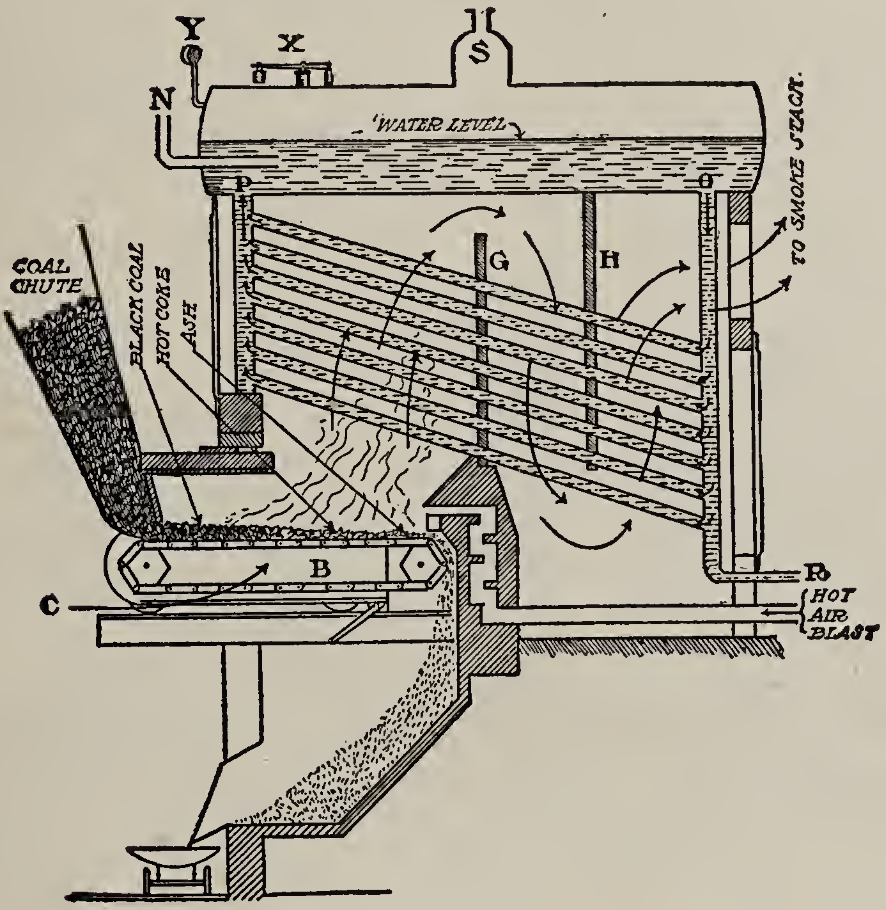

FIG. 73.—Mechanical stoker and a water-tube boiler. *B,* Chain grate. *C,* Fresh air. *G, H,* Baffle plates. *N,* Water feed pipe. *R,* Blow off. *S,* Steam dome. *Y,* Pressure gage. *X,* Safety valve.

V. LIQUID FUELS

96. The Burning of Liquid Fuels.—The burning of kerosene and of gasoline has already been studied. It will be remembered that, in each case, the liquid is first converted into a vapor, and then the vapor is burned, using an adequate supply of air. The same principle is used in burning liquid fuels generally. Crude petroleum is burned by vaporizing it by means of a jet of air or steam, after which the vapors are burned in the proper supply of air. The gasoline in the automobile is vaporized and mixed with the proper amount of air in the carbureter, after which the mixture is drawn into the cylinder, compressed to increase the rate of combustion, and finally burned within the cylinder (see Gas Engines, Chap. XI).

VI. GASEOUS FUELS

97. Gaseous Fuels.—These have long been a favorite kind of fuel. Their use in the home and in various industries has gradually increased. Gaseous fuels are commonly transmitted from producer to consumer in pipes. The cost of pipes makes it unprofitable to transmit the fuel long distances. Some gases, as acetylene, are transmitted under pressure in metal tanks. The material for making acetylene, calcium carbide, may be transmitted long distances profitably.

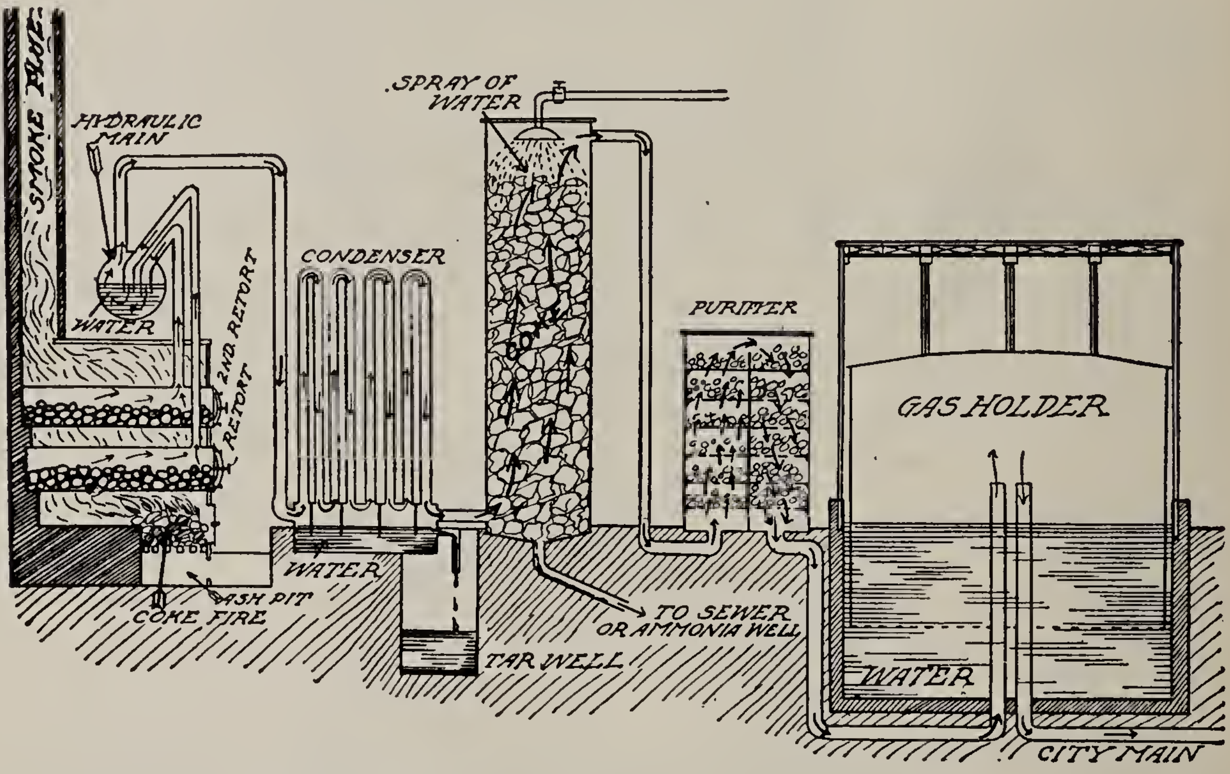

FIG. 74.—An illuminating coal gas plant.

98. Coal Gas.—COAL GAS was the first manufactured gas.

It was used for lighting the streets of London and Paris more than 100 years ago. In 1817, the city of Baltimore began to use it for street lighting. The gas is made by distilling soft coal in air-tight retorts (Fig. 74). The coal contains many hydrocarbons which leave it when the coal is heated. The hydrocarbons at the same time are broken down into simpler compounds. The gas also contains hydrogen and carbon monoxid. Because of the hydrocarbons in coal gas it burns with a luminous flame. The manufacture of coal gas has gradually declined of late owing partly to the fact that but few kinds of coal are suitable for use in making it and these are becoming more expensive, and partly to the decrease in the cost of electricity.

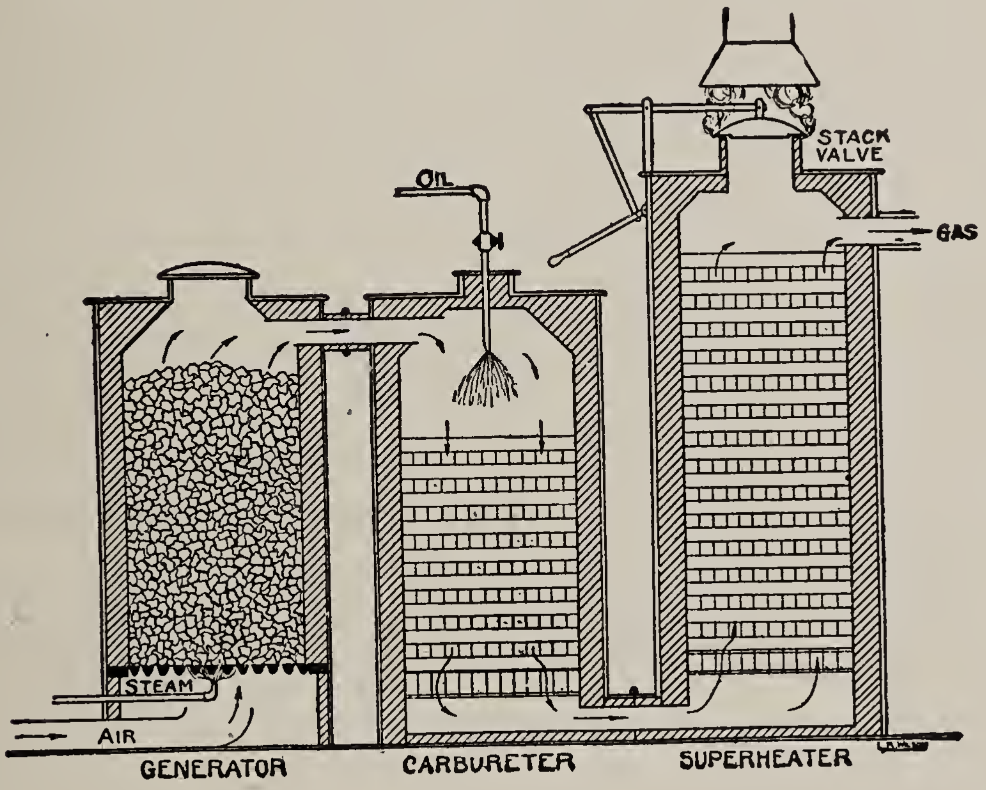

Fig. 75.—Water-gas apparatus.

99. **Water-Gas.**—Water-gas has come to replace coal gas in many cities. When steam is passed over red-hot carbon, the former is decomposed into hydrogen and oxygen. The carbon then unites with the oxygen from the steam to form carbon monoxid or carbon dioxid depending upon conditions,

while the hydrogen from the water is set free. By proper control of conditions, carbon monoxid rather than carbon dioxid may be formed, which, with the hydrogen set free, makes a mixture of highly combustible gases. The mixture is called WATER-GAS. During the chemical reaction of the steam and the hot carbon, heat is absorbed, and consequently the carbon soon cools to a temperature at which the reaction stops. The carbon is then heated again by blowing air through the furnace, called the GENERATOR (Fig. 75), in which it is contained. When the carbon again becomes hot enough, the air is shut off and steam is again admitted. Since the carbon monoxid and the hydrogen burn with a blue flame, it becomes necessary to introduce some substance that will render the flame of water-gas luminous. This is done by introducing into the gas vaporized, or gasified, hydrocarbons derived from crude petroleum. The petroleum is sprayed into a CARBURETER which is heated to a very high temperature. Here the petroleum hydrocarbons are broken down into simple hydrocarbons which remain as gases. These are mixed with the water-gas and the mixture is passed through the SUPERHEATER. Such a mixture is known as CARBURETTED WATER-GAS.

100. **Gasoline Gas.**—Gasoline gas is simply air and gasoline vapor mixed in such proportions as to be non-explosive. Air containing less than 1.5 per cent. and more than 6.4 per cent. of gasoline vapor, by volume, when 88°B. gasoline is used, is non-explosive, while a mixture containing between 1.5 per cent. and 6.4 per cent. of gasoline is explosive. There are two general processes used for vaporizing the gasoline. One, known as the COLD PROCESS, is described in Art. 39. For this, a light oil (88°B.) *must* be used. The other process, known as the HOT PROCESS, uses heat to vaporize the gasoline. This makes possible the use of a heavier, and hence a cheaper, grade of gasoline. In each of these systems, it is expected that the air will carry from 12 to 20 per cent. of gasoline vapor. Gasoline gas is almost always used with a mantle when used to produce light. It may be used in ranges for cooking. The

production of gasoline gas offers a convenient means of producing gas in small amounts for home or school use in places inaccessible to a city gas supply.

TABLE III.—COMPOSITION OF GASEOUS FUELS (APPROXIMATE)

Kind of gas	Combustible constituents			Non-combustible constituents		B.t.us. per cubic foot (see Art. 102)
	Hydrogen per cent.	Hydrocarbons, per cent.	Carbon monoxide, per cent.	Carbon dioxide, per cent.	Nitrogen.	
Natural gas	0.0	99.0	0.4	0.3	0.2	900
Coal gas ..	41.3	49.0	6.4	2.0	1.0	600
Water-gas .	38.0	19.0	33.0	4.0	5.0	600
Gasoline gas	0.0	15.0	0.0	0.0	68.0	570

VII. THE MEASURE OF HEAT

Our fuels are burned for the production of heat or light. A fuel intended for the production of heat is more or less valuable depending on the amount of heat that can be obtained from it when it is burned.

101. Distinction Between Heat and Temperature.—We have learned that temperature refers to the hotness or coldness of a body (see Art. 14). Temperature is measured by means of a thermometer. Two bodies may have the same temperature but may contain vastly different amounts of heat. A pint of water may have the same temperature as the average temperature of a large body of water like Lake Michigan, yet it will possess very little heat compared with that in the lake. The lake influences the climate of the surrounding states, but the influence of the pint of water on the temperature of objects around it will amount to almost nothing. It is apparent that the weight of the body has a great deal to do with the heat it contains at a given time. Then, too, the amount of heat a body contains also depends upon the material of which it is made. Two objects of the same weight but of different materials may be changed in temperature an equal number of degrees, and yet the amounts of heat required to produce the change in temperature may differ greatly. One pound of water in being raised in temperature 10°C. will require more than 32 times as much heat as will be required by 1 pound of lead raised a like amount in temperature. Other substances require still different amounts of heat for a like temperature change.

DEFINITION.—*The heat capacity of* 1 *gram of a substance while being raised* 1°*C. is called the* SPECIFIC HEAT *of that substance.*

So it is evident that the heat an object possesses depends upon three factors: (1) Its weight; (2) its temperature; (3) the material or substance of which it is composed.

102. Units of Heat Quantity.—

DEFINITIONS.—1. *One unit is the amount of heat necessary to raise* 1 *gram of water* 1°*C. It is called the* LESSER CALORIE *and this is usually abbreviated thus:* 1 *cal.*

2. *A second heat unit is the amount of heat necessary to raise* 1000 *grams, or* 1 *Kg., of water* 1°*C. It is called the* GREATER CALORIE *and is usually abbreviated thus:* 1 *Cal. This is the unit generally used by European engineers in calculating all large quantities of heat, such as are required in heating buildings.*

3. *A third unit is the amount of heat required to raise the temperature of* 1 *lb. of water* 1°*F. This is called the* BRITISH THERMAL UNIT. *In writing it is usually abbreviated, thus:* 1 *B.t.u. This is the unit commonly used by British and American engineers.*

TABLE IV.—HEAT VALUE OF FUELS (APPROXIMATE)

	Greater Calories per pound	B.t.us. per pound
Carbon	3,672	14,544
Hydrogen	15,664	62,032
Wood, Ash	2,141	8,480
Wood, Beech	2,161	8,591
Wood, Oak	2,100	8,316

	Greater Calories per pound	B.t.us. per pound
Wood, Pine	2,311	9,153
Wood, Elm	2,150	8,510
Charcoal	3,227	12,780
Peat	1,800 to 2,300	7,200 to 9,000
Lignite	1,800 to 3,000	7,200 to 11,700
Coal, Bituminous	3,000 to 3,600	11,700 to 14,400
Coal, Semi-anthracite	3,000 to 3,600	11,700 to 14,400
Coal, Anthracite	3,400 to 3,900	13,500 to 15,300
Coke	3,450 to 3,700	13,700 to 14,500
Petroleum	about 5,000	about 20,000

VIII. OUR COAL SUPPLY

103. Development of Coal Production.—The first coal produced in the United States was mined and marketed in 1820. The records show that 365 tons, an average of 1 ton per day, were produced that year. For many years the production of coal increased slowly. During past years the increase in production of coal has been very rapid, till in 1918 about 580,000,000 tons were mined and used. The diagram, Fig. 76, shows that until 1907 the production of coal in the United States has doubled about every ten years. If this rate of increase in the use of coal were to continue in the future, we should consume in 1920 about 1,000,000,000 tons; in 1930 about 2,000,000,000 tons; in 1940 about 4,000,000,000 tons, and so on. At this rate of increase, how many tons will we require in the year 2000? How many tons in the year 2040? Is it probable that this rate of increase will continue?

104. Waste in Mining of Coal.—In mining coal, it has generally been found necessary to leave large columns of coal to support the roof of the mine. In the anthracite fields of Pennsylvania more than one-half of the coal is thus left in the mine—only about 40 per cent. is removed. The remaining 60 per cent. of the coal is left in such shape that it can probably never be recovered. This means that for every ton of anthracite coal which has been mined about 1½ tons have been forever lost to the use of mankind. In the bituminous fields, there has been less waste. For every ton of bituminous coal mined about ½ ton has been left in the mine.

105. How Long Will Our Coal Supply Last?—Government officials have made careful estimates of the number of tons of coal in all known coal deposits of the United States. Accepting this estimate and supposing that the consumption of coal will continue to increase at the same rate in the future as it has in the past, it has been shown that our available coal supply will be exhausted in about 120 years, or about the year 2030. We therefore see how necessary it is that we avoid as far as possible all waste of coal.

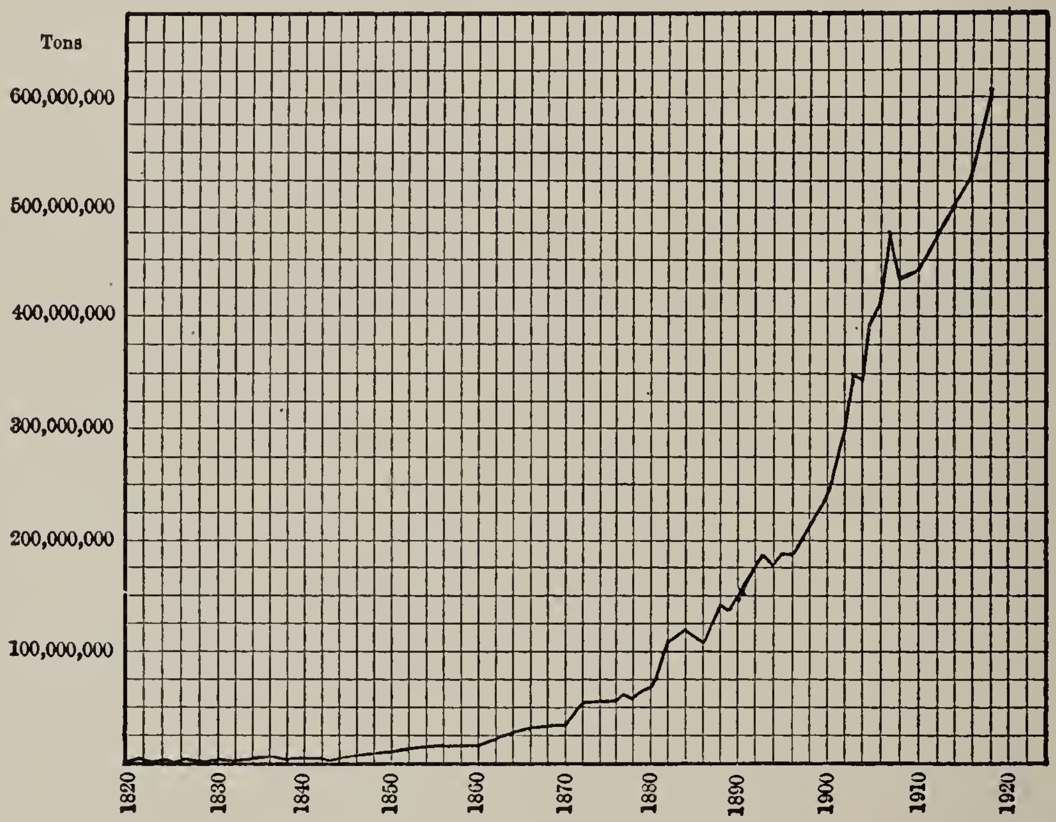

Fig. 76.—Annual production of coal in the United States, 1820—1918.

At the present time a much larger portion of our coal is being wasted than is being used for the benefit of mankind. The two chief sources of loss are:

1. Only about one-half of the coal is being removed from the mine; the other half is being left in such a condition that it probably can never be recovered.

2. We have seen in the preceding pages of this chapter, that only a small portion of the energy in the coal burned is now being utilized.

106. The Coal Fields of the United States.—The map, Fig. 77, shows the location of the more important coal fields of the United States. The large eastern field extending from Pennsylvania to Alabama yields chiefly anthracite, semi-anthracite and semi-bituminous coals. The central fields, consisting of the Illinois, Indiana, Kentucky, Iowa, and Missouri fields yield chiefly bituminous and cannel coals. The large northwestern field of the Dakotas, Montana, and Wyoming yields bituminous and lignite coals. The fields of Colorado yield bituminous and semi-anthracite coals (see Table II, Art. 91, Composition of Solid Fuels, for the distinction in different kinds of coals).

FIG. 77.—Distribution of coal fields in the United States.

IX. DEVELOPMENT OF HOUSE HEATING

107. The Roman Hypocaust.—The houses of the Romans were heated by hypocausts. These were fire rooms constructed in the cellars (Fig. 78). From these rooms clay pipes led to various rooms of the house above. Through these pipes all of the smoke and heat from the burning wood passed to the rooms above. This method of heating would seem very disagreeable to us, especially when the volatile matter was distilling from the wood. Crude as this method of heating was, it was the best method known until comparatively recent times. The use of the hypocaust perished with the civilization of Rome.

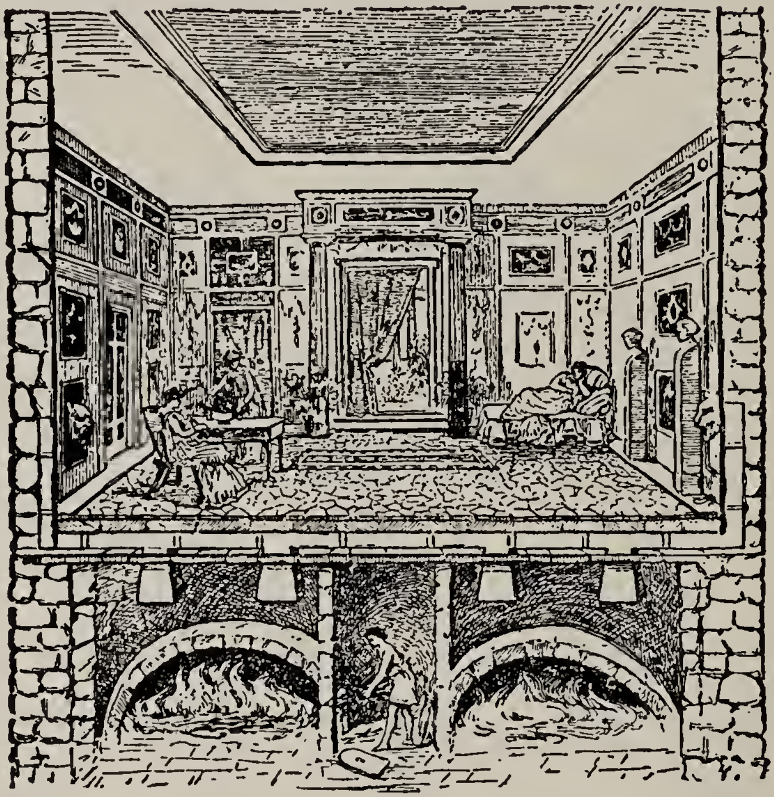

FIG. 78.—A Roman hypocaust. (From *Stories of Useful Inventions.* By permission of The Century Company.)

108. The Fireplace and the Early Stoves.—Mention has already been made of the use of the fireplace in house heating and cooking, and of Franklin's invention of the stove. Stoves did not come into general use in the United States until after 1825. Wood was used as the fuel and the stoves were but little more than open, iron fireplaces standing out in the room. Between 1825 and 1835, the first stoves for burning hard coal were made. Some of these were fairly successful but all have been greatly improved since that time.

109. The Invention of the Chimney.—It is recorded that the invention of the chimney was the result of war. At the time of the Norman conquest of England in 1066 the Britons heated their houses by means of fires built on the floor at the center of the house. The smoke was permitted to escape through a hole in the center of the roof. But the smoke so bothered the Britons as they fought from the house roofs that the custom arose of building a fire at one side of the room and providing for the escape of the smoke through an opening in the side wall. To cause the smoke to escape more readily through the opening, a hood was built into the room over the fire. From this crude beginning chimneys finally developed.

CAUSES OF CONVECTION CURRENTS

110. Some Common Observations.—You have very likely noticed many times that when a fire in the stove is first lighted the draft is not strong for a minute or so. As soon as the fire is really burning well, the draft becomes strong. When we first light a bonfire the feeble flame is blown about in all directions by the breezes. When the fire gets to burning fiercely, all these conditions change. Instead of being carried off by the wind, the smoke and burning embers are swept swiftly upward, rising in a vertical, tapering column to the height of 20, 30 or perhaps, 50 ft. If we notice carefully now, we shall see that the wind blows into the fire at the ground from every direction. The rising column of air is called a CONVECTION CURRENT. We shall be able to understand this better if we learn what effect the heating of air has upon its volume.

111. Effect of Heat upon the Volume of Air.—

Exercise 36.—Air Expanded by Heat

Fit a 10- or 12-in. glass tube into the stopper and the stopper into the flask. Be sure that the apparatus is air-tight (Fig. 79). Invert the flask so that the end of the tube dips into the water in a vessel. Gently apply heat to the flask, constantly turning it so as to heat it evenly on all sides. Do bubbles of air escape from the tube? Heat the flask quite hot; then remove the flame and allow the flask to cool.

What happens? What portion of the air was forced out of the flask?

When air is heated, it always expands. When a certain volume of air at the temperature of freezing water is heated to the temperature of boiling water, it increases nearly $\frac{1}{3}$ in volume. If it is heated but 1°C., it increases exactly $\frac{1}{273}$ part of itself. This fact was discovered by a Frenchman named Charles in 1787. He discovered that this was the rate at which all gases expand when heated. This fact is called CHARLES' LAW and is stated thus: *Pressure remaining constant the volume of a given portion of gas increases* $\frac{1}{273}$ *part of its volume at zero centigrade for each rise of* 1°C. *above that temperature, and it decreases* $\frac{1}{273}$ *of its volume for each fall of* 1° *below that temperature.*

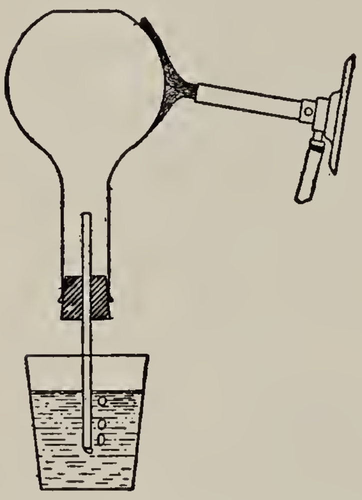

FIG. 79.—Effect of heat upon volume of air.

112. **Application of Charles' Law.**—It is not probable that in any two lamps we might examine we should find that the gases within the chimney are heated to exactly the same temperature. But we are probably not far from the truth if we say that the gases within the ordinary lamp chimney are so heated that they are expanded to twice the volume they had when they entered the bottom of the burner. Every cubic inch of air which enters the burner leaves the top of the chimney as 2 cu. in., if this be true. The same thing takes place in the bonfire. As soon as the fresh air reaches the heated portion of the fire it is greatly expanded. The coal in the stove or furnace produces a still higher temperature. The air passing up through the bed of glowing coke is so heated at that moment that it is increased to *three or possibly five times its volume* as it enters the damper. It is this heating of the air and the consequent expansion, or increase in volume, which produces CONVECTION CURRENTS. Just why and how this is so we must learn.

113. Floating Bodies and Buoyancy.—We all know that a cork or a piece of wood weighs less than a piece of iron of the same size. We also know, that if we place the cork or piece of wood in water, it will float, while if we place the iron in water, it sinks. What makes the cork float? Just why does the iron sink? Does the iron have any *tendency* to float? Answers to these questions will help us to understand CONVECTION CURRENTS.

Exercise 37.—Floating Bodies and Buoyancy

(*a*) Place a cork in a basin of water. Does it float entirely upon the surface? If any portion of the cork is below the surface of the water, about how much of it is so? Does "floating upon the water" mean that all of the body is above the level of the water? Does the cork have any *tendency* to sink?

(*b*) Set a small pail in an empty basin. See that the pail is exactly level. Fill it exactly full of water. Take care that no water runs over into the basin. Now tie a cord securely around a stone. Weigh the stone by means of a spring balance. While the stone is still suspended from the balance, lower it into the pail of water till it is entirely covered by water. At the same time the stone must not touch the bottom of the pail. See how much the stone now seems to weigh (Fig. 80). How much has it lost in weight?

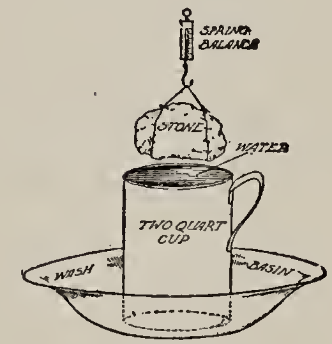

Fig. 80.—Buoyancy.

(*c*) Carefully remove the stone from the water. Remove the pail from the basin. You now have in the basin the water which ran over when the stone was immersed in the pail. Empty the water out of the pail and pour the water from the basin into it. Weigh the pail and this water. Now empty out this water and weigh the pail. The difference in these last two weights gives you the weight of the water which ran over when the stone was immersed in the water. The difference between the two weights of the stone gives the loss of weight which the stone seemed to suffer upon being immersed. How does this loss of weight compare with the weight of the water which ran over? What is now your answer to the question: Does the stone have any *tendency* to float when immersed in water? To what extent does the water lift or hold up the stone? Repeat the experiment.

(*d*) Fill the pail partly full of water again. Now hold the cork down near the bottom of the water and release it. What happens? To what extent does the water lift, or force up, the cork? If you had a body exactly as dense as water, *i.e.,* which weighs exactly the same per cubic inch, would it float or sink? What would it do?

114. Archimedes' Principle.—In performing part (*c*) of the preceding experiment, a student got the following results:

Weight of the stone in air	46 oz.
Apparent weight of the stone immersed in water	30 oz.
From which we get the loss in weight	16 oz.
Weight of pail and water which ran over	23 oz.
Weight of the pail empty	7 oz.
From which we find the weight of water	16 oz.

From this experiment the student concluded that the loss of weight by the stone when immersed in water was equal to the weight of the water displaced.

This truth was first stated by a Greek philosopher named Archimedes who lived about 25 years before Christ in ancient Syracuse. He was a close friend of King Hiero; his life was spent in the study of mathematics and science. He was the most profound student of these subjects in his day. It is said that his friend, King Hiero, ordered from his goldsmith a crown of pure gold. When the crown was completed, however, the king suspected that it was not pure gold. He summoned Archimedes and instructed him to ascertain the truth without injuring the crown. Archimedes was pondering over this question as he went to his daily bath. Noticing, as he entered the full bath, that the water was lifted and ran over the edge of the tub just in proportion as his body was immersed, and also that his own weight was decreased at the same time, he leaped from the bath and ran to his home shouting, "Eureka, Eureka," which means "I have found it, I have found it." Pure gold is a little more than nineteen times as heavy as water, where silver is but ten and one-half times as heavy. If the crown had been pure gold it should have lost one-nineteenth of its weight when immersed in water. He found that it lost more than one-nineteenth of its weight, so he concluded that silver had been used in its construction.

Archimedes' principle may be thus stated: *Whenever a body is immersed in a fluid (liquid or gas) it is buoyed up with a force which exactly equals the weight of the fluid displaced.*

When the cork was immersed in the water (*d*, Ex. 37), it was being pushed upward with a force equal to the weight of an equal volume of water. Since the weight of the cork was less than this force, it was pushed to the surface of the water and partly out of it. As it floated upon the surface of the water, it was displacing an amount of water which exactly equaled it in weight. The stone, on the other hand, sank to the bottom because it was heavier than an equal volume of water; its weight was therefore greater than the buoyancy of the water. That it was buoyed up to a considerable extent, was shown by the balance.

115. Convection Currents Caused by the Buoyant Effects of the Air.—The solid portion of the earth is covered by an ocean of air many miles, probably some hundreds of miles, in depth. This air has weight, just as water has weight. In fact, it is much heavier than we usually suspect until we have weighed some of it. A box 2 ft. by 2 ft. by 3 ft., or 12 cu. ft., holds 1 lb. of air. A common schoolroom 30 ft. by 30 ft. by 10 ft. therefore holds 750 lbs. of air.

All bodies here on the earth's surface are being buoyed up by this air exactly as the stone and the cork were buoyed up by the water. A stone will fall through the air and rest at the bottom of the atmosphere exactly as it fell through the water and rested at the bottom of the pail. Even the cork is so much heavier than the air that it, too, sinks to the bottom of the atmosphere. There are some substances lighter than the air. Hydrogen weighs but about one-fifteenth as much as the air. A balloon is a bag filled with this very light hydrogen or some other light gas. Whenever the bag and the hydrogen which it contains weighs less than the air it displaces, the surrounding air buoys it up with a force greater than its weight and it floats. Instead of using hydrogen, heated air is often used in toy balloons. The toy Fourth of July balloon consists merely of a sack of light, nearly air-tight material, usually paper. The bag is inverted and its lower end is somewhat open (Fig. 81). A burning candle is suspended in the open mouth of the sack. The heat from the candle keeps the air in the balloon warm. As long as this air is sufficiently heated, the balloon continues to float. The important thing to notice is this: *The heated air would be buoyed up, pushed upward, just the same if it were not enclosed in a sack.* From this fact we see that *convection currents are always produced when any fluid is heated more at one point than at surrounding points.*

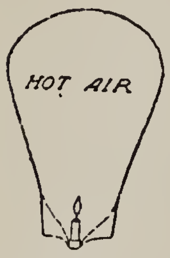

FIG. 81. Hot-air balloon.

We shall find convection currents of great importance in the study of the weather, Chap. III.

APPLICATION OF CONVECTION CURRENTS TO CHIMNEYS

116. The Draft in the Chimney.—The current of air, or draft, in the chimney is caused by the column of air within the chimney becoming either warmer or cooler than the surrounding air. If the air within the chimney is warmer, the draft will be upward. Why? When there is a fire in the furnace or stove, the air within the chimney will be heated and the draft will be upward. It is now evident that the draft is not strong when we first light a fire in the stove because the air within the chimney has not yet been heated.

CONCLUSION.—*There is nothing mysterious about the draft of a chimney. A chimney will "draw" if the laws of physics have been regarded in the construction of the chimney and in the operating of the stove. A column of heated air is lighter than a column of cold air and will, therefore, be pushed up through and out of the top of a chimney, unless there is some other force opposing its motion.*

Application of Convection Currents to Room Heating

117. Convection Currents in a Room Heated by Means of a Stove.—Convection currents play an important part in all heating of rooms by means of stoves. The movements of air in a stove-heated room can easily be determined by experiment.

Exercise 38.—Air Currents about a Stove

Close all windows and doors. Light some punk or a piece of cotton cloth and test the currents of air by holding the torch in the following positions and observing the movement of the smoke: First, above the stove; on each side of the stove, level with the top of it; on each side of the stove and about 6 in. from the floor. Second, hold the torch 6 in. or 1 ft. from the ceiling and about half way from the stove to the window or outside wall; do this on each side of the room. Third, hold the torch about 3 ft. from the floor and about 6 in. or 1 ft. from the window or outside wall. Fourth, hold the torch 6 in. from the floor and half way from the outside walls to the stove. Show by means of a sketch the air currents as you found them. If some of the walls of the room are inside walls, the circulation will hardly be as perfect as it would be if they were all outside walls.

The general circulation about the stove in a room having all four of its walls outside walls is very simple. There is a rising column about and above the stove. As this column pours upward against the ceiling, it spreads out in every direction toward the outside walls. The outside walls, and especially the windows, are cold, consequently the air is here chilled. It therefore becomes heavy and drops to the floor. Across the floor from every side of the room the cold stream of air passes back to the stove. As a person sits facing the stove in such a room there is sure to be a stream of cold air blowing against his back and past his feet. This is especially true if the stove is not large enough to heat all the air in the room. These returning currents of air are often mistaken for cold, outside air which is supposed to have crept in through cracks and crevices about the windows and in the outside wall. If the walls of the room were air-tight these currents would still exist.

The Setting of Furnaces

118. The Furnace.—The Furnace for house heating is little more than a large stove of simple construction inclosed within a sheet-iron jacket or surrounded by brick walls.

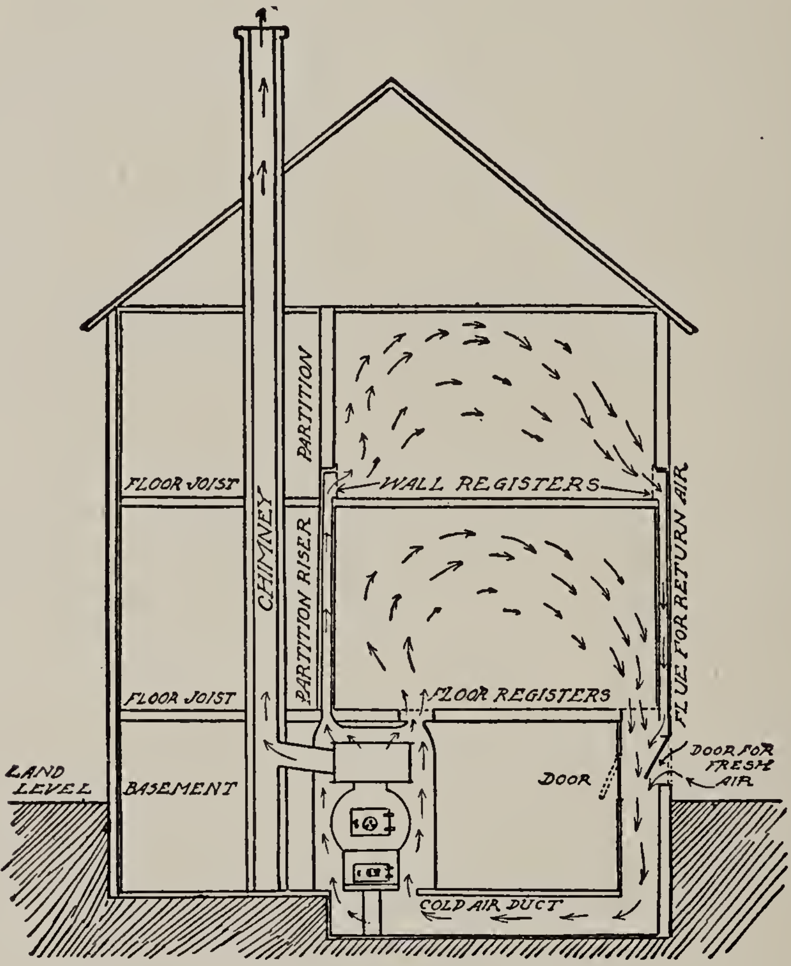

Fig. 82.—Furnace and air supply.

When the iron jacket is used it is said to have a portable setting; when the brick walls are used it is said to be a brick set furnace. The furnace is set in the basement or cellar. The air to be heated is led to the bottom of the space inclosed by the jacket by means of sheet-iron pipes running through the basement, or better still, by means of large tile or cemented brick passages beneath the basement floor. The heated air is led upward from the top of the jacket to the rooms above, which are to be heated.

119. Air Supply for the Furnace.—The cold air supplied to the furnace is often taken from within the house; a more sanitary method is to supply the furnace with pure, fresh air from without the basement wall. When the second plan is followed, the furnace becomes, not only a heating plant, but also an excellent means of furnishing ventilation as well. By this plan, a considerable stream of fresh air is coming into the house at all times. This is, of course, quite impossible unless some opening is provided to allow an equal amount of air to escape. The ordinary house is often too well built to permit this amount of air to escape through cracks and crevices. The exit may be provided by partly opening a window; it is better, however, to provide fireplaces with flues extending above the roof. Many people do not yet appreciate the great importance of proper ventilation for their homes and therefore they provide for taking the cold air supply only from within the house. This practice is a saving of fuel, for none of the air within the house is very cold at

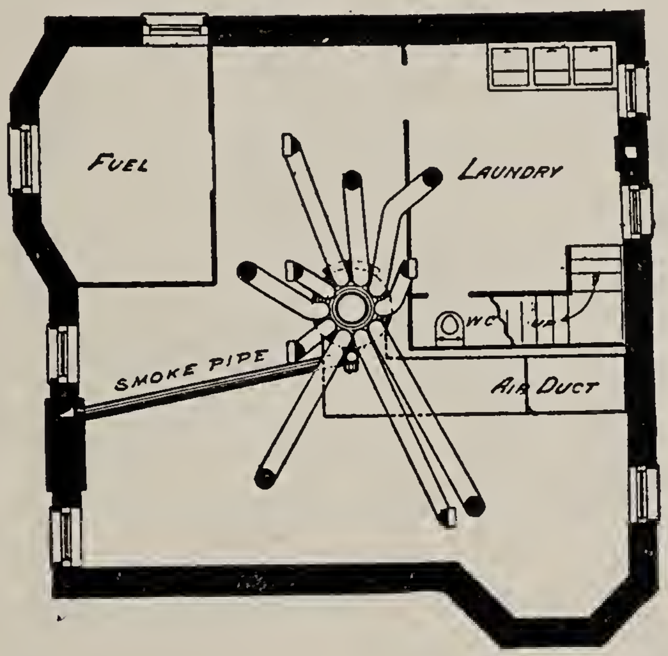

FIG. 83.—Basement plan for setting a furnace.

any time. A common practice, which can be made to meet the wishes of all, is so to construct the COLD AIR DUCT, as it is called, that the air may be taken either from within the house or from the outside as is desired (Fig. 82).

120. Placing the Registers and Risers.—The pipes which lead up from the furnace open into the rooms by means of REGISTERS, open frameworks of iron. The pipes leading from the furnace to the second floor or higher are made of tin, are rectangular in shape and usually about 3½ in. by 12 in. so as to be easily placed within a 4-in. wall. These hot air pipes are called RISERS, or STACKS.

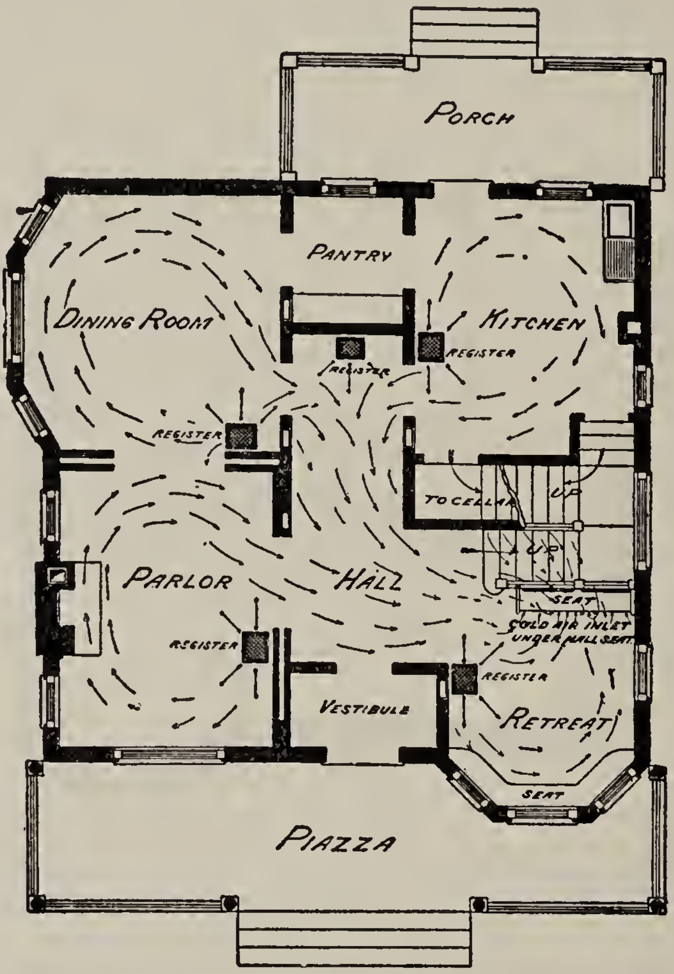

FIG 84.—First floor plan for setting a furnace.

One general rule should be followed: *All heating pipes should be as short as possible; all risers should be placed in inside walls; and all registers should be placed as far as pos-*

sible in the warmest portion of the room. The reason for this rule is easily seen. Just as the tallest chimney produces the best draft because it contains the longest column of heated air, so the upward current of air through the furnace, through the riser which leads from it and into the room above will be strongest if the air is well heated throughout its entire course. By placing the riser in inside walls and the register in the warmest portion of the room, which is usually also near an inside wall, a column of heated and consequently *light* air, of the greatest possible length is assured. Were the register placed at the coldest point in the room, the upper portion of the column would be cold air, and consequently heavy air, and the movement of the air through the furnace and the riser would be slow and sluggish. *A strong and reliable circulation of air is the keynote to success in furnace heating.*

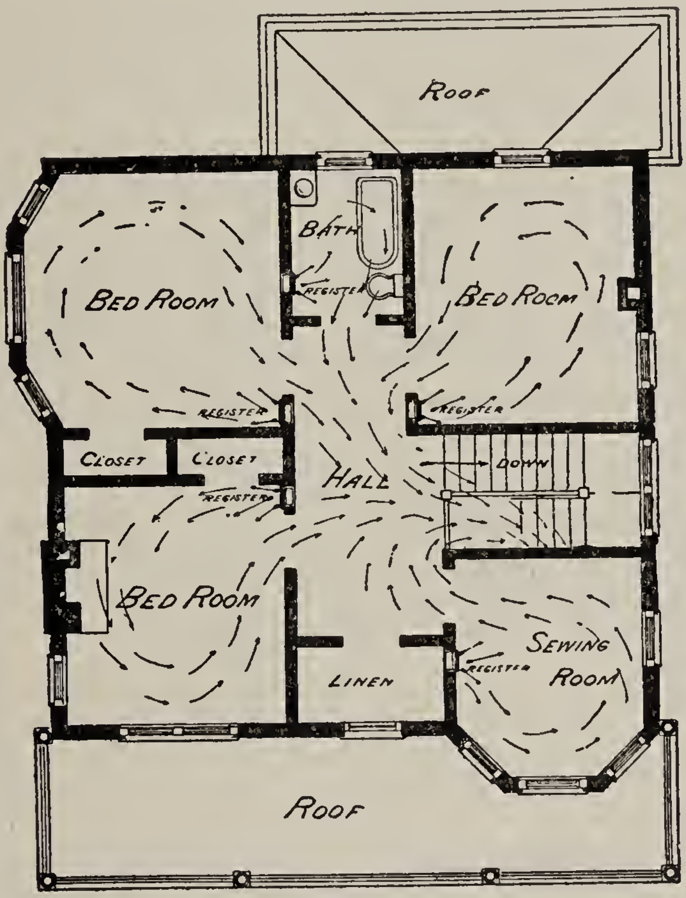

Fig. 85.—Second floor plan for setting a furnace.

In Fig. 82 the circulation of air from a furnace is made clear. It will be noted that floor registers are used for the first floor rooms and all wall registers for the second floor rooms. In some houses each room on the second floor is provided with a flue for the return of cold air to the furnace, if INSIDE CIRCULATION is the system to be used. These are not often provided, however. A good circulation is secured by permitting the cold air to return down the stairway (see plans, Figs. 83, 84 and 85).

121. **A Successful Furnace.**—To be a success, the furnace should be so constructed and so set as to accomplish the following results:

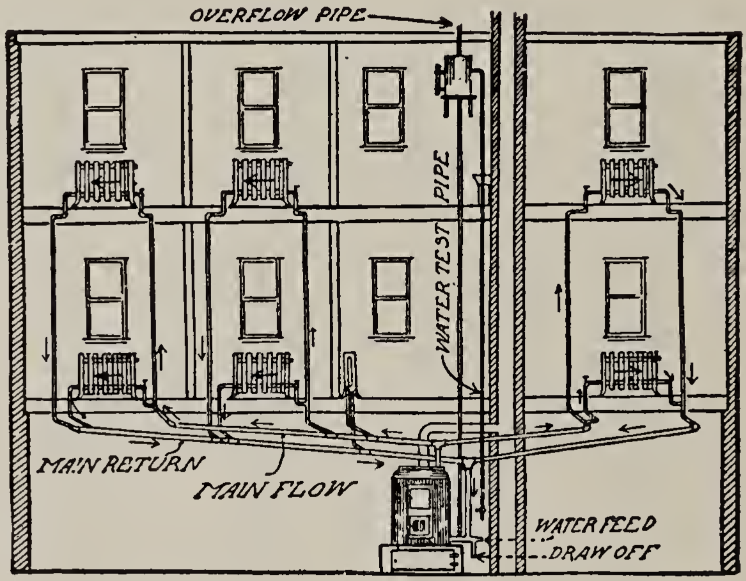

Fig. 86.—A hot water system.

1. There should be a large volume of moderately heated air passing through the furnace and into the rooms to be heated at all times. A small volume of highly heated air is not only uncomfortable but unhealthful as well.

2. There should be no cross-currents of air. The cold air from all parts of the house should join in a single current when returning to the furnace. (Study Figs. 84 and 85.)

3. The heated air should enter at the warmest portion of the room and the cold air should be drawn out from the coldest portion.

4. All of the air in all of the rooms to be heated should be

in constant circulation, and all of the air should be heated to a comfortable temperature.

5. A successful furnace does not overheat the basement. A furnace should have such a perfect circulation that the jacket never becomes very hot. The purpose of the furnace is to send heated air into the rooms above and not to heat the basement.

Hot Water Heating

122. Principles of Heating by Hot Water.—In heating houses by means of hot water, we depend largely upon the same principles as in furnace heating. In the furnace we depend upon the heating of the air and the consequent expansion of it to produce the circulation; so here also we depend upon the heating of the water and the consequent expansion of it to produce the necessary circulation.

The WATER HEATER is usually placed in the basement (Fig. 86). The hot water flows from the highest point of the heater through the MAIN FLOW PIPES to the radiators placed in the various rooms. From the radiators, the cold water returns through the RETURN FLOW PIPES to the bottom of the heater. In passing through the radiators, the water heats them and they in turn heat the air in the rooms, producing convection currents precisely as the stove does.

The water cannot be kept in circulation without some active force to keep it moving. It is easily seen that we have vertical pipes filled with hot water, and others filled with cold water. The cold water being the denser and therefore the heavier, and the pipes being connected both at the top and the bottom, the cold water is certain to fall to the bottom of the system and crowd the heated water to the top. This means that the cold water sinks into the heater and that the hot water is forced up into the radiators. The water in the radiators soon becomes cool and the water in the heater soon becomes heated, thus the circulation is maintained. Notice the slope, or PITCH, as it is called, in the case of the horizontal pipes. Why should these pipes slope as they do?

123. Essential Features of Any Hot Water Heating System.—1. In any system of hot water heating, the circulation of the water depends upon the unequal weight of two columns of water, one heated and one cold. The heater, the piping, and the radiators must be placed with this thought in mind

2. Since water expands when heated and contracts when cooled, every hot water heating system must be provided with an EXPANSION TANK. This tank is to give the water a chance to expand when heated without bursting the pipes. (See Art. 15, Ex. 11.)

3. Care must be taken that every portion of the heater, the pipes, and the radiators can be drained completely when not in use; this will prevent freezing and bursting of pipes.

4. Care must be taken that the water in the expansion tank and in the pipe leading to it does not freeze when the heater is in use; otherwise a severe explosion may occur. Why is this so?

124. Advantages of Hot Water Heating.—Many people regard the hot water system of heating as superior to any other system. When well installed and properly operated, it doubtless is cheaper to operate and gives a milder, and more even heat than is usually obtained from other systems. It is also possible so to install this system of heating as to give ample ventilation, but in such a case it is doubtful if it is less expensive to operate than a good furnace system providing equal ventilation. This will be explained in Chap. V. The first cost of a hot water system of heating is considerably greater than that of furnace heating and slightly greater than that of STEAM HEATING, which will soon be considered.

SENSIBLE AND INSENSIBLE HEAT

125. The Factors of Heat Quality.—We are all more or less familiar with heat changes. If we place a hot iron in a pail of cold water, the water becomes heated and the iron cooled. The temperature of both the iron and the water soon become the same. All of the heat which goes out of the iron goes into the water. The change in temperature in each case *indicates* the change in heat quantity. But we know that, if we use more of the water the change in temperature of the water will be less; or, if we use a larger piece of iron and heat it to the same temperature before placing it in the water, the water will be heated to a much higher temperature. The fact is that heat quantity is made up of three factors. Usually these factors are: (1) Change in temperature; (2) quantity of matter involved; (3) kind of matter (Art. 101). We shall see, however, that the three factors may be: (1) A change in the form or state of the matter; (2) quantity of matter; (3) kind of matter.

126. Sensible Heat.—When the three factors involved in the heat quantity are change in temperature, quantity of matter, and kind of matter we say the heat is SENSIBLE HEAT, because it may be perceived by the senses. The heat units are based upon the measurement of sensible heat. Define 1 B.t.u. and show that the last statement is true, likewise show that it is true by defining a Cal. or a cal. (Art. 102).

127. Heat Necessary to Turn a Liquid into a Vapor.—We have seen that by applying heat to the paraffin in the candle wick, to the kerosene in the lamp, to the alcohol and water in the distilling flask we changed these liquids into vapors. In each case we put heat, a certain number of calories, or B.t.us. of heat, into the liquid to turn it into vapor. It takes a large amount of heat to turn water into vapor after it has been heated to the boiling temperature. We can get a fairly good idea of the amount required by performing an experiment.

Exercise 39.—Amount of Heat Required to Vaporize Water

Weigh a tin quart cup or small tin basin. Fill the cup half full of water and crushed ice or snow. Weigh again. Stir the water until the ice is just melted. The water should now be at 0°C. Quickly place the cup over a flame and note the exact time by the watch. The height of the flame must not be changed during the experiment. Watch the water till it begins to boil. Note the exact time again. Record the number of minutes required to bring the water to the boiling point. Allow the water to continue boiling about twice as long as was required to bring it to the boiling point. Now remove the flame and record the exact time. Weigh the vessel and contents again.

Record your results as in the table below.

Discussion of Exercise 39.—A student performing this experiment got the following record:

Weight of 1-qt. tin basin	86 grams
Weight of basin and water	309 grams
Weight of the water alone	223 grams
Began heating the water at	2–33–30
Water began boiling at	2–42–40
Time required to boil the water	9 min. 10 sec., or 550 sec.
Let the water boil till	3–1–40
Water boiled for	19 min., or 1140 sec.
Weight of the basin and water after boiling	219 grams
Therefore, weight of the water vaporized	90 grams

From this record we see that it required only 550 seconds to raise 223 grams of water from 0°C. to 100°C.; but that it required 1140 seconds, while applying the same heat, to vaporize 90 grams of water. Now 90 grams was but $^{90}/_{223}$ of the whole amount of water or 0.403 of it. To have evaporated all of the water would have required 1140 seconds ÷ 0.403 or 2828 seconds. From this experiment we conclude that it requires $^{2828}/_{550}$ times, or 5.14 times, as much heat to vaporize a certain quantity of water as is required to raise that quantity of water from the freezing point to the boiling point.

Very careful experiments repeated many times have proved that these figures should be 5.36. Heat which is used thus to change the state of matter without changing its temperature is called insensible heat. When used to change a liquid to a vapor, it is called HEAT OF VAPORIZATION. When used to change a solid into a liquid, it is called HEAT OF FUSION. *We now see that the heat of vaporization of water is* 5.36 *times the sensible heat of raising the same amount of water from the freezing point to the boiling point.*

STEAM HEATING

128. Principles of Steam Heating.—We saw in Arts. 20 and 21 that the temperature of steam arising from boiling water is nearly the same as that of the water. It is also known that as long as the pressure remains constant the temperature of the steam remains the same. In Art. 127, Ex. 39, we saw that a large amount of heat must be put into water to turn it into steam. When the steam is again turned into liquid, *i.e.*, liquefied, exactly the same amount of heat is given off as was absorbed in the vaporizing. Steam heating depends upon an application of these principles.

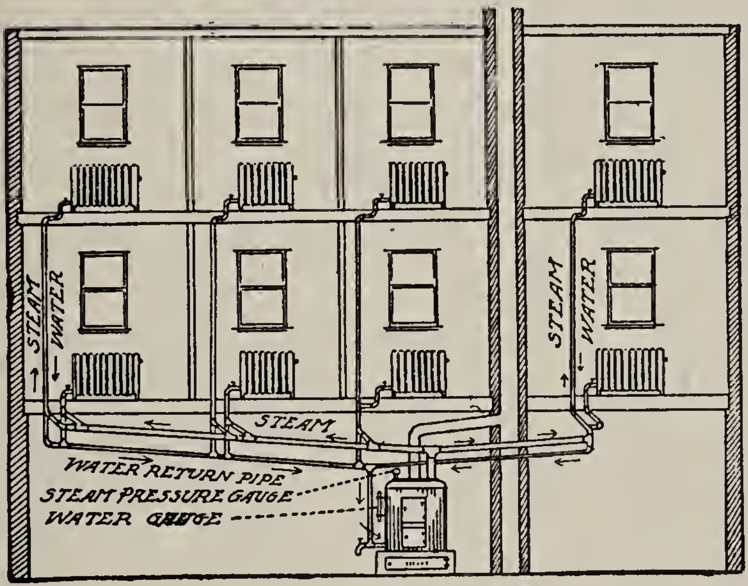

FIG 87.—System of piping for steam heating.

129. Equipment for Steam Heating.—As in the case of hot water heating, the equipment consists of a HEATER, generally called BOILER, of connecting pipes, and radiators (Fig. 87). In fact, a plant for hot water heating may be, and sometimes is, used for steam heating with but slight modification.

This is so, notwithstanding the fact that the two systems are very different in principle.

130. Hot Water and Steam Systems Contrasted.—The two systems may be contrasted as follows:

1. In the hot water system, the radiator is heated by receiving the SENSIBLE HEAT given off by the water as it is cooled in passing through the radiator.

In the steam system, water is turned into steam in the boiler. The steam then passes up through the pipes to the radiator and is there condensed, giving off its HEAT OF VAPORIZATION. This is the source of the heat which keeps the radiator hot. The hot water, condensed steam, returns to the boiler, often at 100°C.

2. In the hot water system, the water is kept in circulation by its own unequal density. The hot water, being lighter, is pushed upward into the radiator while the colder, heavier water sinks into the heater, crowding the hot water upward.

In the steam system, the steam is forced upward into the radiators by the unequal pressure upon it. In the boiler, more water is constantly being changed into steam, *tending thereby to increase the pressure.* In the radiator, the steam is constantly condensing into water, *tending thereby to decrease the pressure.* This means that there is always a lower pressure in the radiator than in the boiler, and consequently, steam is constantly being forced from the boiler into the radiator.

3. In the hot water system, the heater, the pipes and the radiators are always completely filled with water.

In the steam system, the boiler is but partly filled with water.

4. The ordinary hot water system is never closed but always open at the expansion tank.

The steam system is always closed but the boiler must be provided with a safety valve (Art. 134).

5. Hot water heating and furnace heating are generally used in small or medium sized buildings where all of the

rooms to be heated are above the heater or furnace and not far removed from it. They do not give good results when long horizontal pipes must be used.

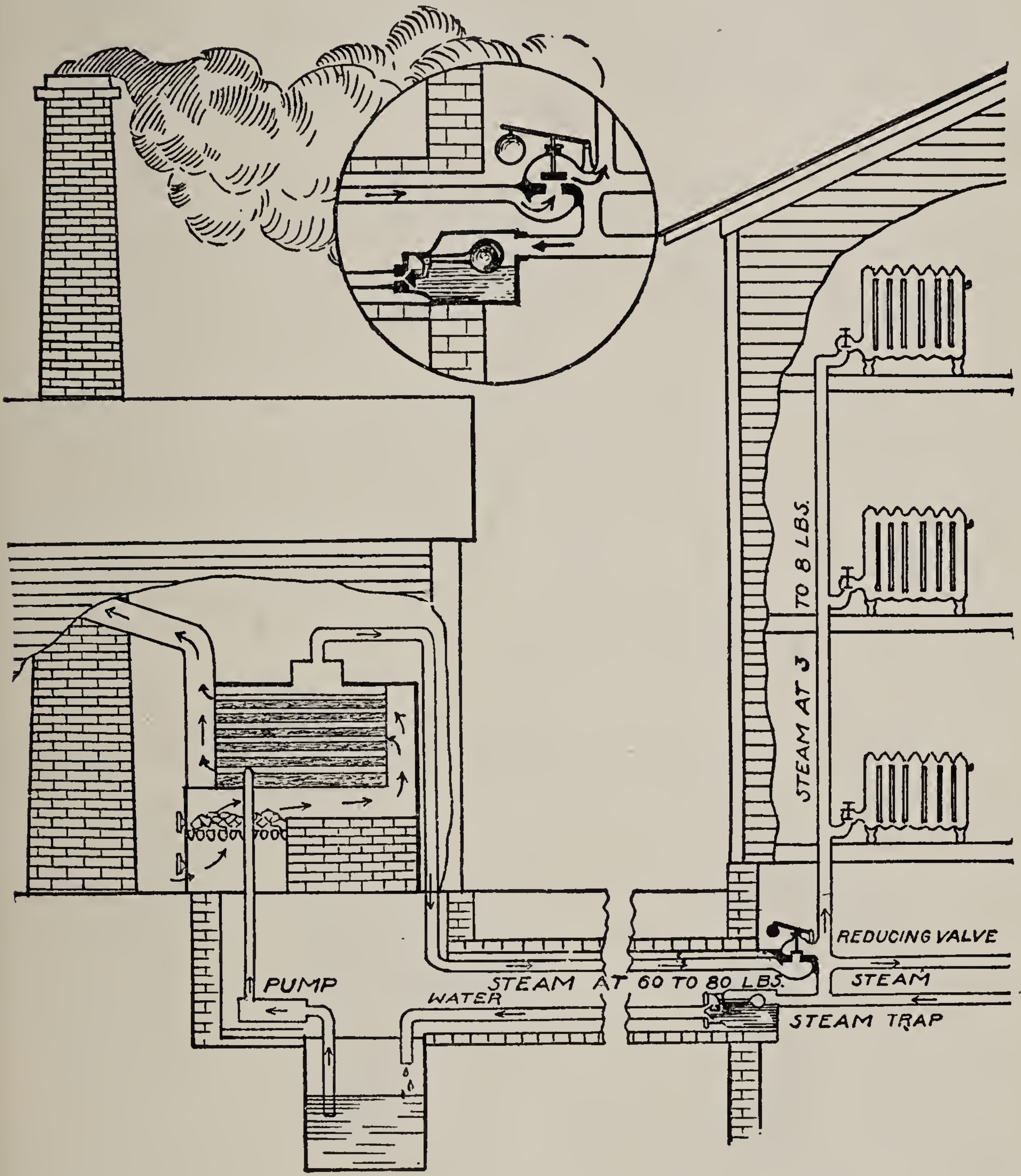

Fig. 88.—A steam heating plant. The steam trap and reducing valve are enlarged.

131. A Steam Heating Plant.—Steam heating is especially adapted to the heating of large buildings and rooms which are considerably removed from the boiler (Fig. 88). In many cities large, central steam heating plants are constructed.

Steam pipes extend from the plant throughout large portions of the city. These pipes are supported within brick conduits beneath the surface of the street. Smaller SUPPLY PIPES lead from the MAINS to the business blocks and the residences on either side of the street. Steam heat is then sold to customers just as gas (Art. 48) and water (Art. 502) are sold.

Exercise 40.—A Study of Fig. 88

The boiler is a FIRE-TUBE boiler. Compare this boiler with that shown in Fig. 73. How do the two boilers differ? At what pressure does the steam pass from the boiler to the REDUCING VALVE? Under what pressure is the steam in the RADIATORS? The radiators are usually of cast iron and are not made strong enough to stand safely high pressure. Examine carefully the reducing valve and explain how it works. What would be the effect of moving the iron ball farther out on the lever? Study carefully the picture of the STEAM TRAP and explain how it works. The ball within the trap is hollow and very light. What happens as the water accumulates in the trap? Just what is the purpose of the steam trap? What would happen if no steam trap were used?

132. Safety Devices on Steam Boilers.—All steam boilers are equipped with three safety devices, a pressure gage (Art. 133), a safety valve (Art. 134), and a water gage (Art. 135), for it is necessary, first, that the operator shall be able to see at once what pressure the boiler is carrying, second, that under no condition shall the steam pressure become greater than that which the boiler is intended to carry, and third, that the water in the boiler never gets below a certain level.

133. The Pressure Gage.—The purpose of the pressure gage is to indicate the steam pressure on each square inch of the boiler. Its essential parts are: (1) A curved, somewhat flexible, metallic tube, *A*, Fig. 89; this tube is connected by a small pipe to the boiler; (2) hinged to the free end of the curved tube is a short connecting rod, *B*; the other end of the rod is hinged to one end of the lever *C*; the opposite end of the lever *C* carries a circular set of cogs; (3) these cogs on the end of the lever *C* mesh into the cogs on the cog wheel, *D*, which carries the pointer or index.

As the steam pressure rises within the boiler, the pressure tends to cause the curved tube to straighten out. The tube then pulls up on the rod. The rod lifts the right-hand end of the lever. The cogs at the other end of the lever cause the cog wheel to rotate clockwise. The index points to a scale printed on the face of the gage. There is always 1 atmosphere of pressure on the exterior of the boiler. Now the pressure gage indicates the excess of pressure, *i.e.*, the pressure over and above 1 atmosphere, on the inside of the boiler.

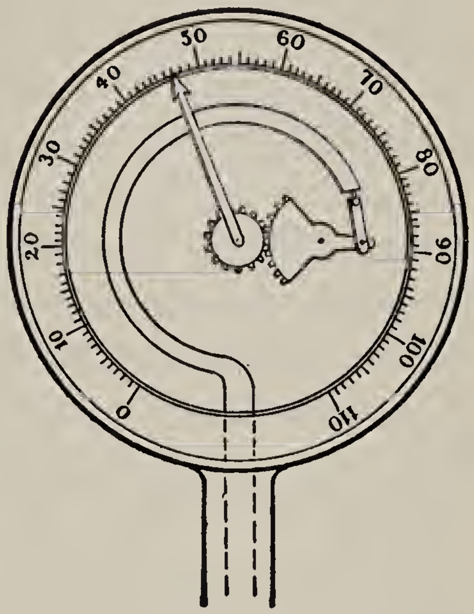

Fig. 89.—The pressure gage.

134. The Safety Valve.—Safety valves are of two types: The BALL AND LEVER TYPE and the POP VALVE TYPE. In the ball and lever type, Fig. 90, the valve is held down by the weight of the ball upon the lever. The pressure is increased by slipping the ball farther out on the lever. Explain why.

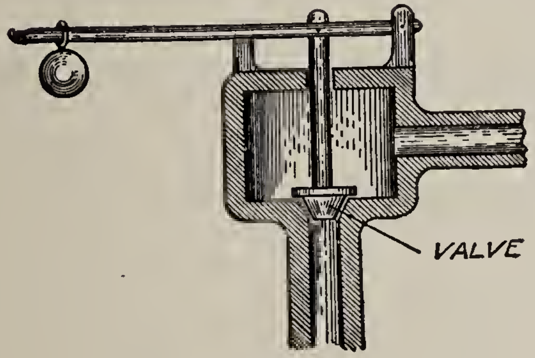

Fig. 90.—Ball and lever. safety valve.

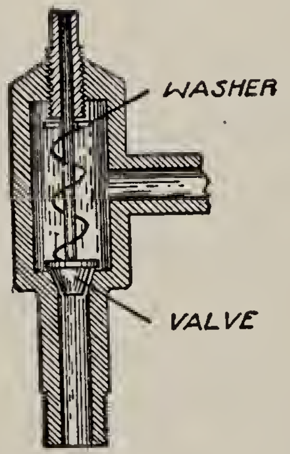

Fig. 91.—Pop safety valve.

The principle of the pop valve is shown in Fig. 91. The valve in this case is held down by a spiral spring. The top of the spring rests against a metal washer. This plate may be forced farther down by turning down the screw. The spring then holds the valve down against a greater pressure. In each type, the valve opens and allows some steam to escape as soon as the pressure within the boiler exceeds the amount for which the valve is set.

135. The Water Gage.—The purpose of the water gage is to enable the operator or engineer to see exactly how high the water stands in the boiler. The gage is merely a strong glass tube mounted on the side of the boiler at the height at which the water should stand. This glass tube is so connected at both its top and its bottom that the water stands within it at the same height as it stands within the boiler. This gage is of the greatest importance, for the person in charge must never permit the water within the boiler to get lower than the bottom of the gage. The danger from an explosion is very great if the water is permitted to get too low in the boiler. Point out the water gages on the boilers shown in the illustrations (Figs. 88 and 309 and 310).

THE OPEN GRATE

136. The Low Efficiency of the Old Fireplace.—The old colonial fireplace was of immense size, often 6 or 8 ft. in width, and consumed immense quantities of fuel. Still the room was but poorly heated. The burning logs resembled a huge bonfire and the draft up the chimney was intense. To replace the large amount of air which passed up and out of the chimney, a blast of cold air poured in at every crack and crevice. A cold current was always crossing the room from the outside wall to the chimney. Probably nine-tenths of the heat was swept up and out of the chimney without warming the room at all. Only a little of the heat passed back into the room, and that was by RADIATION. It is an old saying that the old-fashioned fireplace roasted one side of a person while the other side froze. (Art 66).

137. The Common Modern Grate.—The common grate of today is not used extensively in the northern states for heating purposes. It is generally regarded as a secondary heating plant to be used in the fall and spring or in conjunction with some other system of heating in the winter. In the southern states, where little artificial heat is needed, it is often the only heating plant.

The modern grate consumes but little fuel compared with the old-time fireplace. The flue is much smaller and the amount of air passing up the chimney far less. The ''roasting and freezing'' effect is not nearly so marked as in the case of the old-fashioned fireplace. Still the efficiency is very low. Usually not more than 12 or 15 per cent. of the heat generated is utilized in heating the room in which the grate is placed. But even then, this common grate is invaluable from a sanitary point of view as will be shown later when considering ventilation (Chap. V).

X. DEVELOPMENT OF COOKING DEVICES

Stoves and Ranges

138. Cooking Before the Days of Stoves.—Throughout the 18th century and until well into the 19th, cooking stoves were unknown in America. Most of the food was cooked by boiling in pots which hung suspended from the swinging crane in the fireplace. Some articles of food, such as apples and potatoes, were roasted in the coals upon the hearth. Meats were generally roasted by being suspended by means of a cord or wire before the fireplace. In order that the meat be made to roast evenly it had to be turned almost constantly. This was usually a child's task in the private family. In many inns, where much meat had to be roasted, it was often mounted upon a SPIT, or sharpened stick of wood, in such a manner that it could be kept turning constantly, often by means of a tread mill operated by a dog. Figure 92 shows an ingenious device used in the London Club House, a fashionable hotel in London. The fire was built on a series of grates standing in front of a wrought-iron water heater. Before the several grates were horizontal spits upon which the meats to be roasted were placed. These spits were caused to revolve by the "smoke jack," a small metal wind mill mounted in the chimney flue.

One of the most frequently used utensils for cooking was the REFLECTOR. It was a semi-cylindrical box made of bright tin and so mounted that it lay upon one side (Fig. 93). Generally it was equipped with a grate-like shelf upon which the meat could be placed, the juices dripping through into the bottom of the reflector below. The reflector was placed upon the hearth before the fire and was used, not only for cooking meat, but for baking as well. A modified form of the

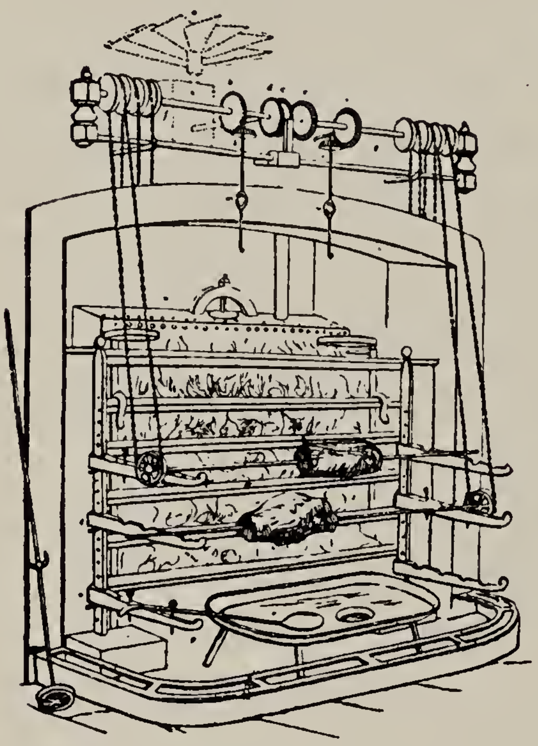

Fig. 92

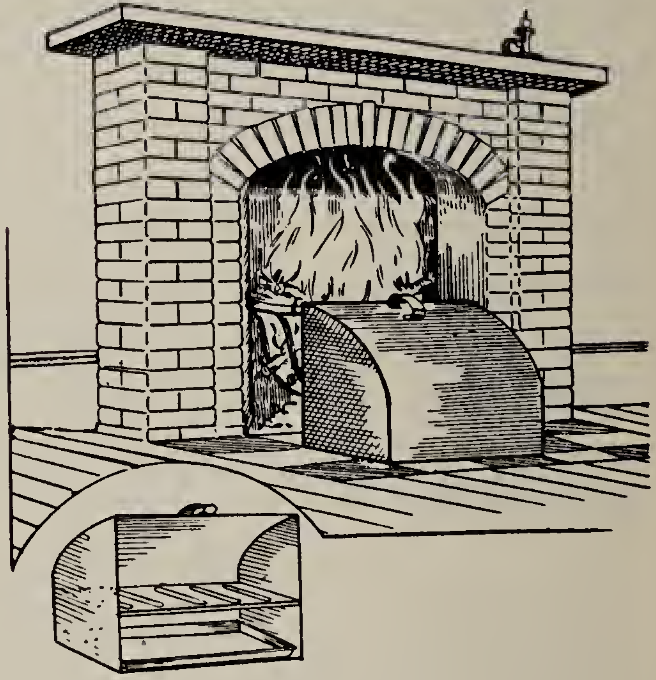

Fig. 93

Fig. 92.—The kitchen fireplace at the City of London Club House, Broad street, London. Reproduced from an old wood cut. The "spits" upon which the joints of meat were mounted before the fire were kept revolving by a "smoke jack," a small windmill, mounted in the chimney flue.

Fig. 93.—Reflector formerly used for roasting and baking in the home.

reflector is shown in Fig. 94. A coiled spring in the box on the top of the reflector was wound up. The uncoiling of the spring was regulated by a sort of clock work. As the spring uncoiled, it revolved the spit upon which the joint of meat was mounted.

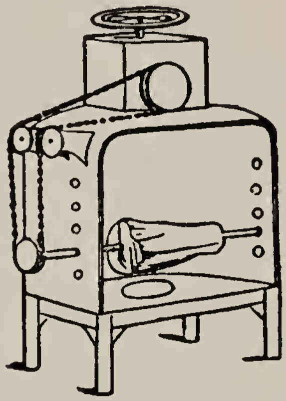

Fig. 94.—A reflector for home use in which the "spit" upon which the joint of meat was mounted was kept constantly revolving by a coiled spring in a box on top of the reflector.

The old BRICK OVEN built into the side of the fireplace, Fig. 59, is known to every one, and has a permanent place in our mental picture of an old-fashioned kitchen. As a matter of fact, however, it usually was heated and used one day in the week. A flue led from this oven into the chimney. On baking day, a wood fire was built in it and when it was sufficiently heated, the coals and ashes were raked and swept out and the week's baking placed in it.

139. The Early Cook Stoves.—The first American stoves intended especially for cooking were made about 1820. The CONANT STOVE, made at Brandon, Vermont, was one of the first (Fig. 95). It was a cast-iron stove with firebox at the bottom. The oven was above the firebox and had doors opening both at the front and the rear of the stove. The smoke pipe went up through the oven. On each side of the stove was a projection which held a cast-iron kettle whose bottom was exposed to the heat of the fire. Most of the food was cooked by boiling in these kettles, although some baking was done in the oven. The stove had an ample hearth, and roasting was accomplished by opening the firebox door and placing the old style reflector upon the hearth.

The STANLEY ROTARY STOVE was made at Troy, New York, about 1835 (Fig. 96). It also had an ample hearth. Its top revolved by means of a crank and cogs. It carried five griddles of varying sizes. By revolving the top, any one of these griddle holes could be brought over the hottest part of the fire or placed in a cooler position as desired. The directions for using the stove read: ‘‘Roasting is done in the best manner by reflection in the tin oven under the stove (where it is to stand) and may at the same time be done on the front part of the stove in the common reflector which most families have.’’

Another early stove was the ‘‘YANKEE NOTION’’ (Fig. 97). This was also a cast-iron stove. There were griddle holes on the top for kettles. At the rear of the stove arose a large, strong cast-iron pipe supporting the oven. The smoke and the products of combustion passed through flues around the oven and joined on top to enter the smoke pipe.

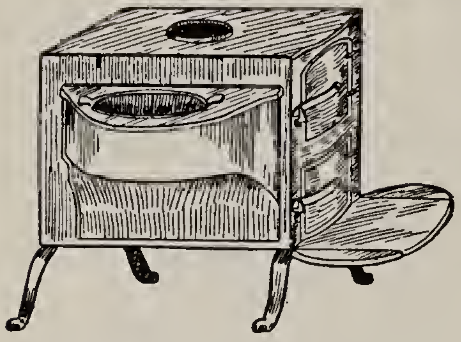

FIG. 95.—The Conant stove; made at Brandon, Vt., 1820.

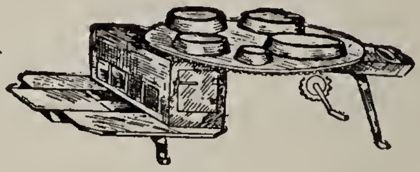

FIG. 96.—Stanley's rotary stove; made about 1835.

While these stoves appear to us to be crude and very unpromising as cooking stoves, we should remember that they were considered very excellent by our grandmothers.

140. Modern Cook Stoves for Coal and Wood.—The modern cook stove for wood or coal differs from these early stoves in having its oven directly behind the fire-pot. Behind and beneath the oven is a DIVING FLUE. This space is really divided into two flues side by side connecting at the front. When the OVEN DAMPER is *up* as in the cut (Fig. 98), the smoke and the products of combustion must pass downward behind the oven, forward beneath the oven, around the end of the partition, thence backward again and upward to the pipe. This heats all around the oven except the two sides. Usually there are doors in both sides of the oven. When the oven damper is *down,* the products of combustion pass directly from the fire-pot over the oven and up the pipe. Examine a stove carefully to note the flues and see how they may be cleaned.

141. **The Range.**—A stove which was so *arranged* as to fit easily into a fireplace was called a RANGE. This term is still applied to a stove which has one of its long sides for the front and the other for the back. In the range, the oven flues are usually so constructed that the products of combustion pass downward at the side of the oven, then circle beneath the oven and up to the pipe which is connected at the center of the back of the range. The oven is thus heated on all sides but the front. Examine a range carefully to note the flues and see how they may be cleaned (Fig. 99).

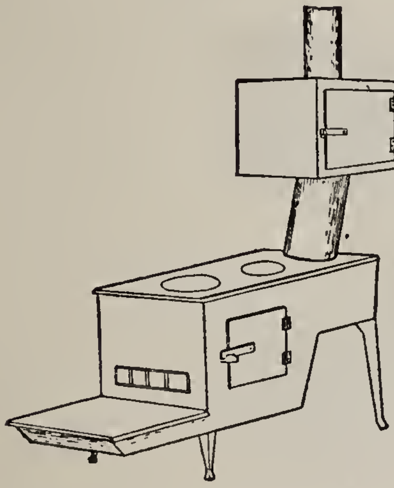
FIG. 97.—The Yankee notion; about 1835.

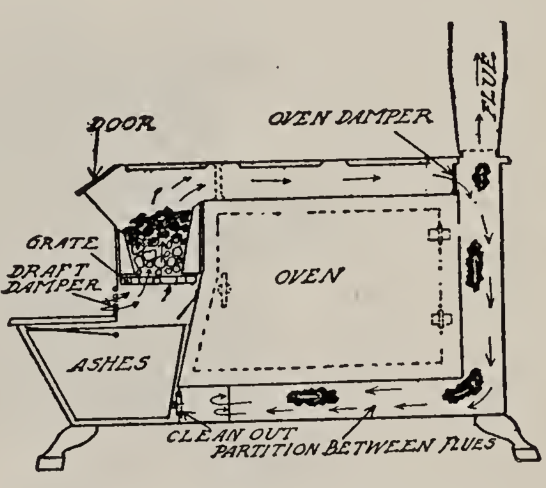

FIG. 98.—Common cook stove.

142. **The Gas Range.**—The gas range is a stove constructed to burn natural gas, coal gas, water gas or other gaseous fuels. Since the object is to burn the gas under such conditions as to produce heat and not light, the flame must be non-luminous. This means that the gas must be mixed with air in a MIXER before it enters the burner, just as the gas must be mixed with a sufficient amount of air in the mixer of the incandescent gas lamp (Art. 50). Therefore, on every gas stove or gas range there is a mixer into which the gas passes on its way to the burner. The mixer is supplied with some device for

controlling the amount of air which enters and mixes with the gas.

Exercise 41.—Regulating the Air Supply of a Gas Stove

Examine a gas stove carefully, noting the AIR REGULATOR usually at the front of each burner. Note carefully how the supply of air is regulated. Shut off the air supply from one burner. What is the effect upon the flame? Why does it become a luminous flame? Reopen the damper slowly, noting just the amount of air necessary to produce a non-luminous flame. Notice that more air is required to produce a non-luminous flame when the gas is turned on full strength than is required when the gas is partly turned off.

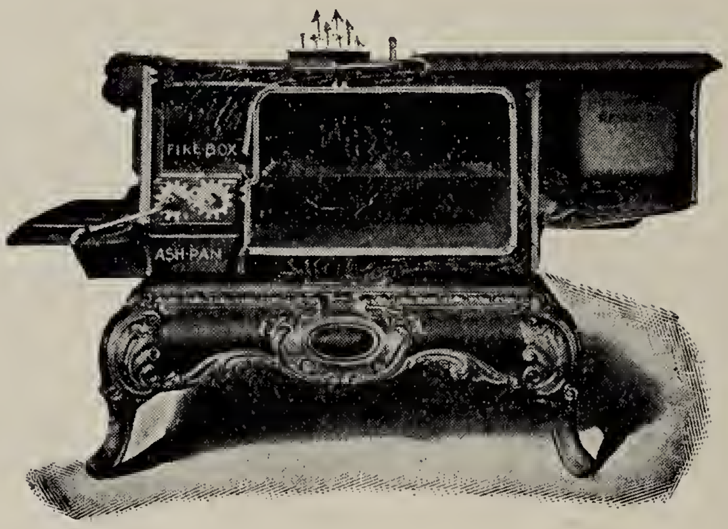

FIG. 99.—A range.

The most intense, *i.e.*, the hottest, flame is secured when the damper is so set that there is just a sufficient amount of air to produce a non-luminous flame. An excess of air not only reduces the intensity of the heat, but it also tends to cause the flame to "strike back," *i.e.*, to burn down in the burner instead of above the burner as it should. If the supply of air is insufficient, the flame will be luminous and smoky.

The air supply on a gas stove should be carefully watched and frequently regulated to secure the best results.

FIRELESS COOKERS

143. Cooking Temperatures.—The cooking of foods is accomplished by raising them to a certain temperature and then maintaining that temperature for a certain length of time. Both the temperature required and the time required vary, first, with the nature of the food to be cooked, and second, whether it is to be cooked wet, *i.e.*, STEWED or BOILED, or cooked relatively dry *i.e.*, BAKED. "Stewing" and "boiling" usually require a temperature near the boiling point of water, or from 180° to 212°F. Baking requires a much higher temperature. Bread is commonly baked at about 375°F.

144. Conductors and Non-conductors.—If it were possible to discover a device which would *entirely prevent the loss of heat,* it is evident that it would be necessary only to bring the food once to the proper temperature; if no heat were lost, the food would then remain at that temperature indefinitely or until cooked. Unfortunately we know of no means of preventing heat from escaping through the walls of any vessel we can construct. Heat passes through every known material. However, it passes through some materials much more readily than through other materials. Materials through which heat passes readily are said to be GOOD CONDUCTORS OF HEAT; materials through which heat passes less readily are said to be POOR CONDUCTORS OF HEAT. All metals

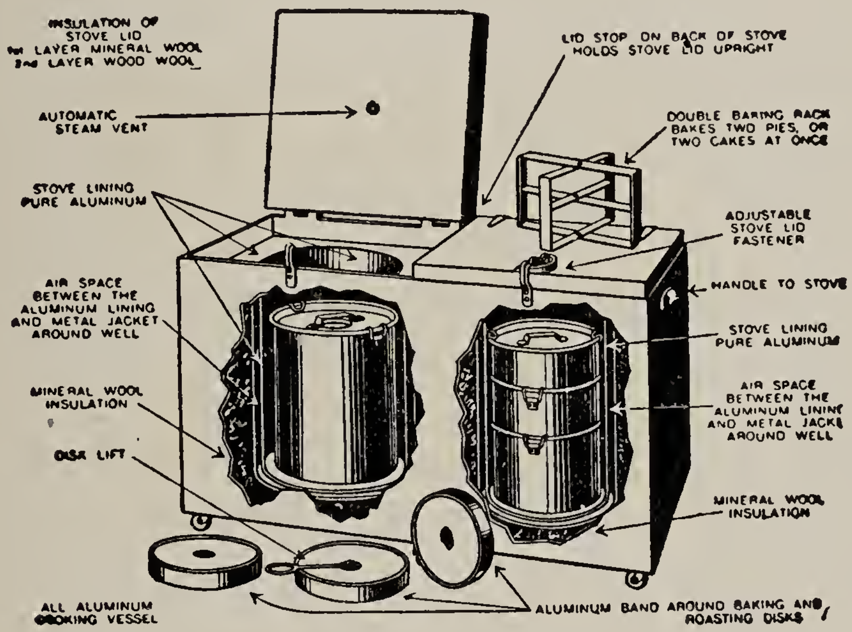

FIG. 100.—A fireless cooker.

are good conductors of heat; air, asbestos, and paper are poor conductors.

145. Fireless Cookers.—FIRELESS COOKERS are constructed of materials which are poor conductors. They are usually vessels of box-like construction with thick walls constructed of poor conductors and provided with closely fitting covers of similar construction (Fig. 100). The food to be cooked is usually brought to the desired temperature and then quickly placed in the fireless cooker. The cooker largely prevents the loss of heat; therefore the food may be maintained for many hours at an approximately constant temperature. A fireless cooker intended for baking is usually provided with one or more blocks of soapstone. These are cut to fit the cooker. Soapstone is used because of its great capacity of holding heat, *i.e.,* its high sensible heat (Art. 106). When baking is to be done, the soapstone is heated to a high temperature and placed in the cooker with the article to be baked. The temperature of the interior of the cooker is soon raised to the temperature necessary to bake the food.

The chief purpose of fireless cookers is to save fuel. They are very successful, and, when properly handled, they effect a considerable saving of fuel and at the same time lighten the labors of cooking, since they require little or no attention while the cooking is in progress.

CHAPTER III

THE WEATHER

146. Why Study the Weather?—Weather is the condition of the atmosphere. It includes heat, cold, moisture, rain, snow, sunshine, cloudiness. The weather in the past has crumbled the rocks, formed the soil, watered the fields. In that way it has largely determined where food crops and food animals could be grown; and thus it has largely controlled the growth of nations and the progress of the human race. The weather also affects the health and comfort and enjoyment and the outdoor occupations of all people every day. An understanding of the weather enables one to safeguard his health, protect his property and manage his outdoor business or recreation more successfully.

147. Beginnings and Growth of Weather Knowledge.—We do not know when man commenced to watch the weather; but some of the sayings and proverbs about the weather date back more than 6,000 years. The ancient Hindus measured the rainfall; the Chaldeans named the wind directions; the Greeks kept records of the wind, and one of their philosophers, 500 B. C., made an instrument that showed changes in temperature. The modern thermometer and barometer were not invented until the 17th century; then explorers soon began carrying thermometers on their journeys to measure the temperatures they found in different lands. About 150 years ago men began to understand a little of the laws governing the weather. Today, in all the leading countries, there are men whose business it is to watch the weather and to see what is coming in the next day or two. And many people and many lines of business plan their work or their affairs according to the expected weather.

(In the recent great war, scores of men on each side took regular observations of the weather. Each important army had trained forecasters who received those weather observations and told the commanders, as fully as possible, when clouds or fog, rain, snow, haze and changes in humidity were coming, and how the winds would blow both on the ground and high in the air. This was done to help the armies in bombing raids, air fighting, the photographing of enemy lines from airplanes and balloons, for gas warfare, for making surprise attacks, for the moving of troops and supplies, for the aiming of long-range cannon, and other operations of the armies. As airplanes come to be used more, the weather will need careful and constant watching in order to make flying safest and easiest and least expensive.)

Almost anyone can learn something of the weather, and will find the knowledge interesting and useful. To study the weather best, we begin with our own.

I. METHODS OF STUDYING THE WEATHER

148. Observing Weather Without Instruments.—Can you describe yesterday's weather in your locality? Do so. Was the day clear or cloudy? Was it warm or cold for the season? What was the direction of the wind? Was it strong or light? Did it change direction during the day? Did you notice the clouds? What direction were they moving? If there was rain or snow, when did it fall? Was the fall heavy or light? Describe today's weather fully, giving all changes that have occurred since morning.

Such features as the amount of rain, the exact temperature, or the speed of the wind, can best be measured and recorded by instruments; and some of those instruments will be studied soon. But an interesting and useful record of many weather conditions can be made without instruments. Such records are kept at all weather stations.[1]

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[1] To the Teacher: The class should keep a record of, and study their local weather for at least two or three weeks in September or early October, two weeks in midwinter, and two or three weeks in late April or May, in order to become better acquainted with the weather of the different seasons.

After the study of general storms, the daily weather maps should be studied each day in connection with your local weather.

Exercise 42.—Daily Observations without Instruments

Keep a record like the following. Observe the weather about 9 A. M. and 4 P. M. if practicable.

Date	Hour	Clouds	Temperature	Thermometer degrees	Wind	Remarks	Indications
Sept. 1	9 a.m.	⅓ dark-low	Warm	80	Brisk↗	Thunderstorm	Showers
Sept. 1	4 p.m.	Cloudy, heavy	Cooler	70	High→	Rain ended in night	Rain
Sept. 2	9 a.m.	⅔ high	Cool	62	Mod.↘		Clearing

For clouds, express the portion of sky covered, by the appropriate word from group *"a"* below; for color or appearance, use words in group *"b"*; for elevation, use *"c"* words. Record the temperature as it seems to you, whether warm or cool, etc., for the time of year. Record the exact temperature if you have a thermometer.

Record the wind direction by arrows flying with the wind. Call the top of the page north, the right side (your right as you face it) east, etc. Record as follows:

Light, when just moving the leaves of trees.
Moderate, when just moving small branches.
Brisk, when swaying large branches.
High, when swaying entire trees and picking papers and dust up from the ground.
Gale, when breaking small branches and damaging light buildings.

Under "Remarks" note any special features.

The following groups of words may be used in the proper columns of the record, to express the conditions:

Clouds		Temperature	Wind	Remarks
(*a*)	(*b*)	Very warm	Calm	Raining
Clear	Light clouds	Warm	Light	Snowing
Few clouds	Dark clouds	Moderate	Moderate	Sleeting
⅓ cloudy	(*c*)	Cool	Brisk	Threatening
⅔ cloudy	Low clouds	Cold	High	Storm clouds
Cloudy	High clouds	Very cold	Gale	Thunderstorm
	Heavy clouds			

The class should continue this record while they are learning to use weather instruments. Study your record carefully once each week and write answers to as many of the following questions as you can:

1. Does the sky appear to be more or less cloudy for the few hours preceding a storm? How is it for the few hours after the storm?
2. Is there any direction from which the wind blows frequently before a storm? If so, what direction? Is there any direction from which it blows most frequently after a storm?
3. Does the wind increase, or decrease, in the few hours before a storm? Does it blow harder before, or after, a storm?
4. Does the temperature seem warmer, or colder, before a storm? How does it change after a storm, if at all?

II. THE USE OF WEATHER INSTRUMENTS

Most persons know something of the thermometer and how to use it. Some have seen or used a raingage. The barometer, which measures the pressure, or weight, of the air, is the most important of weather instruments. We shall study it first.

149. The Measurement of Air Pressure; Air Has Weight. —When compared with any common liquid or solid, air is so light that it seems to have no weight. Yet smoke rises through the air, and balloons ascend out of sight. This is possible only because air is heavier, or denser, than the smoke or the gas in the balloon and crowds them upward, just as a cork rises to the surface of water because water is heavier, or denser, than cork and crowds it upward. But we can not see the air; we scarcely feel it; we seldom think of it. That such a substance constantly surrounds us, filling every nook and corner of our houses, even penetrating deep into the ground itself; that it is constantly pressing with great force upon our bodies—these things many of us have not realized.

It was not until 250 or 300 years ago that even men of science began to understand that air is a real substance and has weight as truly as has water or stone or iron. About

1630, Galileo made the first attempt to find the weight of air. He weighed a flask filled with air, then removed part of the air by heating the flask just as we did in Ex. 36, Art. 111. He sealed the flask while hot and then weighed it again. Since this method removed but part of the air, he placed the mouth of the inverted flask in water, unsealed it, and lowered it as it filled with water. He then closed the mouth and lifted the flask from the water. The volume of water remaining in the flask equaled the volume of air removed by the heating.

About 25 years later, Guericke constructed the first air pump. After that, the air could be removed by the pump. But no air pump will remove all of the air, and today when this experiment is performed, we must find some means of discovering how much air has been removed from the flask.

Exercise 43.—Weighing Air

Fit a 2-qt. or 4-qt. bottle with a new one-hole rubber stopper through which passes a short glass tube. To the glass tube attach about 2 ft. of rubber tubing.[1] Fit the rubber tubing with a screw clamp. Now weigh the bottle full of air with all attachments, using trip scales. Attach the rubber tube to the air pump, making sure that all joints are tight. Vaseline the joints if necessary. Pump as much air as possible out of the bottle; close the rubber tube tightly with the screw clamp; detach the tube from the pump and quickly weigh the bottle and fittings. Place the tube and mouth of the bottle under water and open the screw clamp. The bottle quickly fills nearly full of water. Why? Hold the bottle so that the water inside and outside is on a level. Close the tube and lift the bottle from the water. Pour the water from the bottle into a measuring graduate and record the volume. This volume is the same as that of the air removed from the bottle. Compute the weight of 1 liter, 1000 c.c., of air.

A student performing this experiment obtained the following results (metric system):

Weight of bottle full of air............	786.2 grams
Weight of bottle after removal of air...	784.8 grams

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[1] Note: Thick-walled or pressure tubing should be used.

Therefore, weight of air removed.......	1.4 grams
Volume of water in the bottle...........	1150 c.c.
From these facts he computed the weight of 1 liter of air to be nearly.........	1.22 grams

Prove the correctness of his computation.

Air varies much in weight at different times and places. Cold air is heavier, or denser, than warm air, and moist air is lighter, or less dense, than dry air. At sea level, dry air weighs about 1.29 grams per liter, or about 1¼ oz. per cu. ft. About 13 cu. ft. of air weigh 1 lb.

150. Air Pressure.—Though a cubic foot of air weighs but little, the atmosphere is many miles deep and presses with great force upon all the earth's surface. This fact was discovered soon after it was found that air has weight.

Exercise 44.—To Study the Pressure of Air

(*a*) Place a palm glass upon the stand of the air pump. Place rubber dam over the mouth of the palm glass and tie its edges down tight with a cord. Connect the stand with the pump. With the first stroke of the pump notice the effect on the rubber dam. If the rubber is fresh and strong, continued pumping may stretch it till it very nearly lines the inside of the receiver.

(*b*) Tie the rubber dam over the mouth of a thistletube. Attach a rubber tube to the stem of the thistletube. Suck some of the air from the tube and note how the dam is pressed into the tube's mouth. Pinch the tube so that air cannot enter; then hold the thistletube with its mouth upward, downward, sidewise. May we conclude that air pressure is equal in every direction?

The total air pressure upon our bodies is many hundreds of pounds. We do not feel it, because the air enters our lungs and thus exerts the same pressure on both the inside and outside of our bodies. These pressures balance each other.

151. Torricelli's Experiment.—Galileo, who proved that air has weight, also noticed that a pump in a deep well raised the water only about 32 ft. All scientists before him had taught that "Nature abhors a vacuum." Galileo remarked, when observing the pump, that nature's abhorrence seemed to stop at 32 ft. His experiments in search of the explanation were ended by his death in 1642. Torricelli, his pupil, at Galileo's request, continued the investigation. Torricelli concluded that air pressure had something to do with the action of the pump. He remembered that mercury is 13.5 times as heavy as water; he reasoned that if the air pressure raised water 32 ft. in the pump, it would raise or support mercury $1/_{13.5}$ as high, or about 29 in. He experimented and proved his theory. One of his experiments, first performed in 1643, is often repeated today.

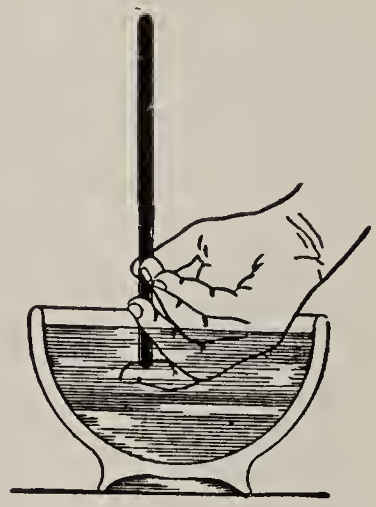

FIG. 101.— Torricelli's experiment. The tube is shortened very much in the illustration.

Exercise 45.—Torricelli's Experiment

Secure a glass tube about 36 in. long, closed at one end. Fill it with mercury, working over a pan to catch spilled mercury. Pour the remaining mercury into a glass or iron cup (Fig. 101). Place your finger firmly over the top of the glass tube and invert the tube carefully, putting the open end into the mercury in the cup. Remove the finger. What happens? There is likely to be considerable air in the mercury column, which quickly rises as bubbles to the surface in the tube. To remove this air, slip your finger over the open end of the tube. Lift the tube from the cup and stand it upright. Add mercury till the tube is full. Invert it again in the cup of mercury. Measure the height of the mercury in the tube above the surface of the mercury in the cup. This should be about 76 cm., or about 29.9 in. at sea level, becoming less at higher altitude.

152. Measuring the Atmospheric Pressure.—The pressure of the air on the surface of the mercury in the cup supports the mercury in the tube. The height of the mercury column thus shows the weight, or pressure, of the air; and we have come to speak of the pressure as being *so many centimeters or inches,* meaning that the pressure of the air holds a column

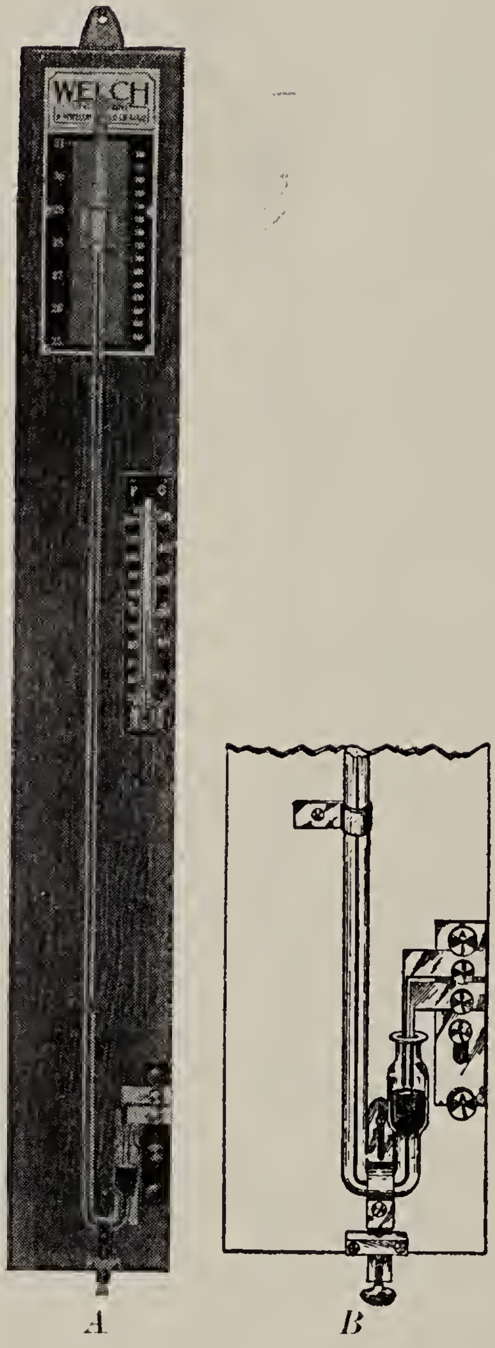

Fig. 102.

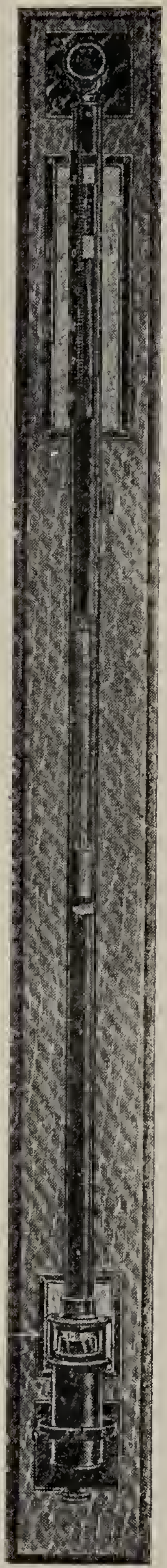

Fig. 103.

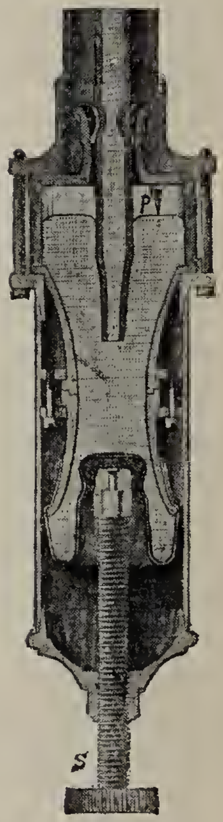

Fig. 104.

Fig. 102.—*A*. Siphon barometer. *B*. Device for adjusting the barometer tube so as to bring the surface of mercury in the cistern to the proper height.

Fig. 103.—Fortin's pattern barometer.

Fig. 104.—Sectional view of the cistern of a Fortin's pattern barometer.

of mercury that high. (Another way of expressing the pressure is in pounds per square inch, or in grams per square centimeter.)

153. The Barometer.—The common mercury barometer is a mounted Torricellian tube having a scale for measuring the height of the mercury column. The cheaper "siphon" type (Fig. 102) has the lower end of the tube bent upward forming a cistern to hold the mercury. The Fortin pattern (Fig. 103) is more accurate. In it the tube is straight; the sides of the cistern are metal and glass; the bottom is stout buckskin (Fig. 104) and is supported by a metal plate which can be raised or lowered by a screw. Extending down from the top of this cistern is an ivory point, P. The scale near the top of the barometer is so placed that the line "26 in.," for instance, is exactly 26 in. above the tip of this ivory point.

To read the barometer, first turn the screw *s*, at the bottom so that the top of the mercury in the cistern just touches the ivory point. Then read the height of the top of the mercury in the column above. To do that, turn the thumbscrew at the side to move the slide so that the bottom of the slide is just even with the middle of the curved top of the mercury. Then notice carefully where the bottom of the slide comes on the fixed scale at the side. Practice by moving the scale so that its bottom is exactly at 29.0 inches, then at 29.1, 29.2, and each other tenth to 30.0 inches. Next, place the bottom of the slide midway between the tenths, at 29.05, 29.15, 29.25, etc., until that is easy to do correctly. (Pay no attention yet to the marks on the slide itself.) Then go back to 29.15 and carefully see where you would move the scale for 29.17, 29.18, 29.19, etc. Practice until you can read the scale accurately and quickly to two decimal places, at any portion of the scale.

154. Correcting the Barometer Reading for Temperature.—Mercury expands when heated (as in thermometers, Art. 15). If, on a cold winter day two barometers be hung, one just outside of a window and one just inside of the window in a warm room, the one within the room will read considerably higher than the one outside. The air pressure supports the column of mercury. When the mercury is warm, and therefore lighter, it requires a higher column to balance the air pressure than when the mercury is cold.

In order to compare the air pressures as indicated by barometers on warm days and cold days, or at different places where the temperature differs, it is necessary to correct the readings for temperature. This is done by subtracting the proper amount from the reading for temperatures above 28½°F. Since barometers are nearly always kept indoors, and therefore warm, it will not be necessary to consider temperatures lower than 50°F. nor above 100° F. Table V (see p. 145) gives the necessary temperature corrections.

Directions for Using Table V.—Notice that the table has a column for each half inch of the barometer from 24 to 31 in. At the left side is a temperature column. If the barometer reads 29.42 in. and its attached thermometer reads 68°, find the barometer column with heading nearest to 29.42 (in this case the 29.5 column); then follow that column down to the horizontal line running across from "68°." Where that line crosses the barometer column you find "0.10." This means that 0.10 in. must be subtracted from the barometer reading as a correction for temperature. The corrected reading is therefore 29.32 in.

155. Correcting the Barometer for Altitude.—Since the barometer shows the weight or pressure of the atmosphere, it is evident that it will read highest when at the bottom of the atmosphere. The higher up into the atmosphere we carry a barometer, the less air there is above to press upon the mercury, and the lower the barometer will read. This fact was discovered soon after Galileo found that air had weight. Pascal, a Frenchman, heard of Torricelli's experiment in 1644. After several years of experimenting, Pascal concluded that the mercury in the tube would stand lower on a mountain top than at its base. He carried a tube to the top of a high tower and noticed a slight drop in the mercury column. He then asked his brother-in-law, who lived near the Puy de

Dôme, a mountain in southern France, to carry a barometer to the summit of the mountain. This Perier did on September 19, 1648, and Pascal's theory was confirmed (Fig. 105).

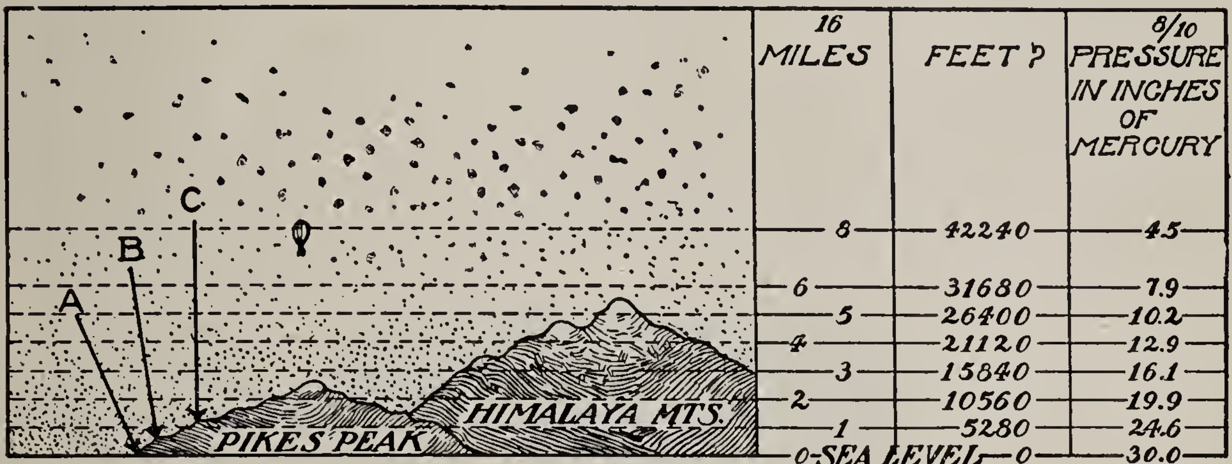

FIG. 105.—Atmospheric pressure varies with altitude. *A* shows elevation of New Orleans, (8 ft.); *B*, of Oklahoma, 1150 ft.; *C*, of Denver, 5600 ft. Barometer readings must be corrected for altitude before they can be compared.

The barometer is used in studying the weather. Barometer readings at sea level are ordinarily about 30 in.; at the altitude of Chicago, about 29.4 in.; at Denver, about 23 in.; and at the top of Pike's Peak, about 15 in. Scarcely any two weather stations have the same elevation. Therefore, in order to compare barometer readings with those of other weather observers, all readings must be corrected for altitude as well as for temperature. In doing this it is customary to change all readings to what they would have been if the barometer had been at sea level. These corrections are easily obtained from Table VI. (See p. 146).

DIRECTIONS FOR USING TABLE VI.—The proper correction is found from Table VI in a manner similar to that followed in using Table V. This correction, however, is *added* to the barometer reading.

NOTE.—Extensive tables for the correction of barometers for any altitude from the sea level up to several thousand feet have been prepared. It is intended that the teacher or student wishing to use this book at an altitude not given in this table shall ascertain the corrections necessary at the required altitude and the various temperatures by applying to some nearby weather station, and record them on the line marked X.

The corrected barometer readings everywhere in the United States will be exactly alike unless the actual pressure of the atmosphere differs in different places. We cannot see or feel differences in pressure as we do the differences in cloudiness or temperature or wind. But these differences in pressure cause most of the weather changes that occur. And if we write all the corrected barometer readings in their proper places on a map of the United States, we can see from the map where storms are developing and where the weather will remain fair. This enables the Weather Bureau to make forecasts of coming weather. Barometers, used in that way, are the most important of weather instruments.[1]

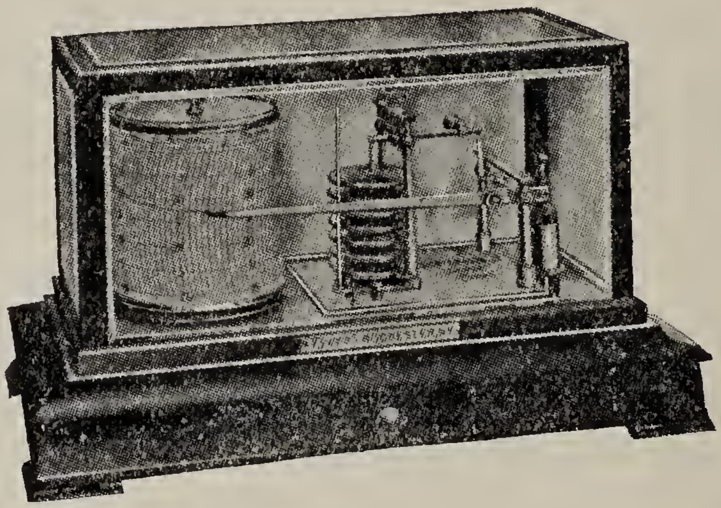

FIG. 106.—The barograph.

156. The Barograph.—The barograph writes a continuous record of the barometer readings. The record paper is wrapped around a brass cylinder that is turned by an eight-day clock. The barometer portion consists of a series of six or eight hollow elastic shells shaped like a canteen or two saucers turned top to top (Fig. 106). These shells are made of corrugated metal, soldered together one above the other, and the air has been exhausted from them. The atmospheric

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[1] In addition to the pressure of the air, fully equipped weather stations record the temperature, the rainfall and snowfall, the direction and force of the wind, the duration of sunshine and cloudiness, the amount of moisture in the air, and a number of other conditions. Several of these are recorded automatically by special apparatus.

TABLE V.—REDUCTION OF BAROMETER READINGS TO 32°F. CORRECTIONS ARE TO BE SUBTRACTED FROM THE READING OF THE BAROMETER

Temperature F. of barometer	Barometer reading in inches														
	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0
50	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.06	.06	.06	.06	.06
51	.05	.05	.05	.05	.05	.05	.05	.06	.06	.06	.06	.06	.06	.06	.06
52	.05	.05	.05	.06	.05	.06	.06	.06	.06	.06	.06	.06	.06	.06	.07
53	.05	.05	.05	.06	.06	.06	.06	.06	.06	.06	.06	.06	.07	.07	.07
54	.05	.06	.06	.06	.06	.06	.06	.06	.06	.06	.07	.07	.07	.07	.07
55	.06	.06	.06	.06	.06	.06	.06	.06	.07	.07	.07	.07	07	.07	.07
56	.06	.06	.06	.06	.06	.06	.07	.07	.07	.07	.07	.07	.07	.07	.08
57	.06	.06	.06	.06	.07	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08
58	.06	.06	.07	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08
59	.07	.07	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08	.08
60	.07	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08	.08	.08	.09	.09
61	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08	.08	.09	.09	.09	.09
62	.07	.07	.08	.08	.08	.08	.08	.08	.08	.09	.09	.09	.09	.09	.09
63	.07	.08	.08	.08	.08	.08	.08	.08	.09	.09	.09	.09	.09	.09	.09
64	.08	.08	.08	.08	.08	.08	.09	.09	.09	.09	.09	.09	.10	.10	.10
65	.08	.08	.08	.08	.09	.09	.09	.09	.09	.09	.09	.10	.10	.10	.10
66	.08	.08	.08	.09	.09	.09	.09	.09	.09	.10	.10	.10	.10	.10	.10
67	.08	.08	.09	.09	.09	.09	.09	.09	.10	.10	.10	.10	.10	.11	.11
68	.08	.09	.09	.09	.09	.09	.10	.10	.10	.10	.10	.10	.11	.11	.11
69	.09	.09	.09	.09	.09	.10	.10	.10	.10	.10	.11	.11	.11	.11	.11
70	.09	.09	.09	.10	.10	.10	.10	.10	.10	.11	.11	.11	.11	.11	.12
71	.09	.09	.10	.10	.10	.10	.10	.10	.11	.11	.11	.11	.11	.12	.12
72	.09	.10	.10	.10	.10	.10	.11	.11	.11	.11	.11	.12	.12	.12	.12
73	.10	.10	.10	.10	.10	.11	.11	.11	.11	.11	.12	.12	.12	.12	.12
74	.10	.10	.10	.10	.11	.11	.11	.11	.11	.12	.12	.12	.12	.12	.13
75	.10	.10	.10	.11	.11	.11	.11	.12	.12	.12	.12	.12	.13	.13	.13
76	.10	.10	.11	.11	.11	.11	.12	.12	.12	.12	.12	.13	.13	.13	.13
77	.10	.11	.11	.11	.11	.12	.12	.12	.12	.12	.13	.13	.13	.13	.14
78	.11	.11	.11	.11	.12	.12	.12	.12	.12	.13	.13	.13	.13	.14	.14
79	.11	.11	.11	.12	.12	.12	.12	.12	.13	.13	.13	.13	.14	.14	.14
80	.11	.11	.12	.12	.12	.12	.12	.13	.13	.13	.13	.14	.14	.14	.14
81	.11	.12	.12	.12	.12	.12	.13	.13	.13	.13	.14	.14	.14	.14	.15
82	.12	.12	.12	.12	.12	.13	.13	.13	.13	.14	.14	.14	.14	.15	.15
83	.12	.12	.12	.12	.13	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15
84	.12	.12	.12	.13	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	.15
85	.12	.12	.13	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	.15	.16
86	.12	.13	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	15	.16	.16
87	.13	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16
88	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	.17
89	.13	.13	.14	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	.17	.17
90	.13	.14	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	.17	.17	.17
91	.13	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	.17	.17	.17	.17
92	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	.17	.17	.17	.17	.18
93	.14	.14	.14	.15	.15	.15	.16	.16	.16	.17	.17	.17	.17	.18	.18
94	.14	.14	.15	.15	.15	.16	.16	.16	.16	.17	.17	.17	18	.18	.18
95	.14	.15	.15	.15	.16	.16	.16	.16	.17	.17	.17	.18	.18	.18	.19
96	.15	.15	.15	.15	.16	.16	.16	.17	.17	.17	.18	.18	.18	.18	.19
97	.15	.15	.15	.16	.16	.16	.17	.17	.17	.18	.18	.18	.18	.19	.19
98	.15	.15	.16	.16	.16	.17	.17	.17	.17	.18	.18	.18	.19	.19	.19
99	.15	.15	.16	.16	.16	.17	.17	.17	.18	.18	.18	.19	.19	.19	.20
100	.15	.16	.16	.16	.17	.17	.17	.18	.18	.18	.19	.19	.19	.20	.20

TABLE VI.—REDUCTION OF BAROMETER READINGS TO SEA LEVEL

Corrections are to be Added to the Reading of the Barometer

Altitude in feet	Temperature of outdoor air in degrees Fahrenheit												
	−20°	−10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
20	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
40	.05	.05	.05	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04
60	.08	.08	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
80	.10	.10	.10	.10	.09	.09	.09	.09	.09	.08	.08	.08	.08
100	.13	.13	.12	.12	.12	.12	.11	.11	.11	.11	.10	.10	.10
120	.16	.15	.15	.14	.14	.14	.13	.13	.13	.13	.12	.12	.12
140	.18	.18	.17	.17	.16	.16	.16	.15	.15	.15	.14	.14	.14
160	.21	.20	.20	.19	.19	.18	.18	.18	.17	.17	.17	.16	.16
180	.23	.23	.22	.22	.21	.21	.20	.20	.19	.19	.18	.18	.18
200	.26	.25	.25	.24	.23	.23	.22	.22	.22	.21	.21	.20	.20
220	.28	.28	.27	.26	.26	.25	.25	.24	.24	.23	.23	.22	.22
240	.31	.30	.30	.29	.28	.27	.27	.26	.26	.25	.25	.24	.24
260	.34	.33	.32	.31	.30	.30	.29	.29	.28	.27	.27	.26	.26
280	.36	.35	.34	.33	.33	.32	.31	.31	.30	.29	.29	.28	.28
300	.39	.38	.37	.36	.35	.34	.34	.33	.32	.32	.31	.30	.30
320	.41	.40	.39	.38	.37	.37	.36	.35	.34	.34	.33	.32	.32
340	.44	.43	.42	.41	.40	.39	.38	.37	.36	.36	.35	.34	.34
360	.46	.45	.44	.43	.42	.41	.40	.39	.39	.38	.37	.36	.35
380	.49	.48	.46	.45	.44	.43	.42	.42	.41	.40	.39	.38	.37
400	.51	.50	.49	.48	.47	.46	.45	.44	.43	.42	.41	.40	.39
420	.54	.53	.51	.50	.49	.48	.47	.46	.45	.44	.43	.42	.41
440	.56	.55	.54	.53	.51	.50	.49	.48	.47	.46	.45	.44	.43
460	.59	.57	.56	.55	.54	.53	.51	.50	.49	.48	.47	.46	.45
480	.62	.60	.59	.57	.56	.55	.54	.52	.51	.50	.49	.48	.47
500	.64	.62	.61	.60	.58	.57	.56	.55	.53	.52	.51	.50	.49
520	.67	.65	.63	.62	.61	.59	.58	.57	.56	.54	.53	.52	.51
540	.69	.67	.66	.64	.63	.61	.60	.59	.58	.56	.55	.54	.53
560	.72	.70	.68	.67	.65	.64	.63	.61	.60	.59	.57	.56	.55
580	.74	.72	.71	.69	.67	.66	.65	.63	.62	.61	.59	.58	.57
600	.77	.75	.73	.71	.70	.68	.67	.65	.64	.63	.61	.60	.59
620	.79	.77	.75	.74	.72	.70	.69	.67	.66	.65	.63	.62	.61
640	.82	.80	.78	.76	.74	.73	.71	.70	.68	.67	.65	.64	.63
660	.84	.82	.80	.78	.77	.75	.73	.72	.70	.69	.68	.66	.65
680	.87	.85	.83	.81	.79	.77	.76	.74	.72	.71	.70	.68	.67
700	.89	.87	.85	.83	.81	.79	.78	.76	.75	.73	.72	.70	.69

Altitude in feet	Temperature of outdoor air in degrees Fahrenheit												
	−20°	−10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
720	.92	.90	.88	.86	.84	.82	.80	.78	.77	.75	.74	.72	.71
740	.94	.92	.90	.88	.86	.84	.82	.80	.79	.77	.76	.74	.73
760	.97	.95	.92	.90	.88	.86	.84	.82	.81	.79	.78	.76	.75
780	.99	.97	.95	.93	.90	.88	.86	.85	.83	.81	.80	.78	.77
800	1.02	.99	.97	.95	.93	.91	.89	.87	.85	.83	.82	.80	.79
820	1.04	1.02	.99	.97	.95	.93	.91	.89	.87	.85	.84	.82	.80
840	1.07	1.04	1.02	.99	.97	.95	.93	.91	.89	.87	.86	.84	.82
860	1.09	1.07	1.04	1.02	.99	.97	.95	.93	.91	.89	.88	.86	.84
880	1.12	1.09	1.06	1.04	1.02	1.00	.97	.95	.93	.91	.90	.88	.86
900	1.14	1.12	1.09	1.06	1.04	1.02	1.00	.97	.95	.94	.92	.90	.88
920	1.17	1.14	1.11	1.09	1.06	1.04	1.02	1.00	.98	.96	.94	.92	.90
940	1.19	1.16	1.14	1.11	1.09	1.06	1.04	1.02	1.00	.98	.96	.94	.92
960	1.22	1.19	1.16	1.13	1.11	1.08	1.06	1.04	1.02	1.00	.98	.96	.94
980	1.24	1.21	1.18	1.16	1.13	1.11	1.08	1.06	1.04	1.02	1.00	.98	.96
1000	1.27	1.24	1.21	1.18	1.15	1.13	1.11	1.08	1.06	1.04	1.02	1.00	.98
1020	1.29	1.26	1.23	1.20	1.18	1.15	1.13	1.10	1.08	1.06	1.04	1.02	1.00
1040	1.32	1.29	1.26	1.23	1.20	1.17	1.15	1.12	1.10	1.08	1.06	1.04	1.02
1060	1.34	1.31	1.28	1.25	1.22	1.19	1.17	1.15	1.12	1.10	1.08	1.06	1.04
1080	1.37	1.33	1.30	1.27	1.24	1.22	1.19	1.17	1.14	1.12	1.10	1.08	1.06
1100	1.39	1.36	1.33	1.30	1.27	1.24	1.21	1.19	1.16	1.14	1.12	1.10	1.07
1120	1.42	1.38	1.35	1.32	1.29	1.26	1.23	1.21	1.18	1.16	1.14	1.12	1.09
1140	1.44	1.41	1.37	1.34	1.31	1.28	1.26	1.23	1.20	1.18	1.16	1.14	1.11
1160	1.46	1.43	1.40	1.37	1.33	1.31	1.28	1.25	1.22	1.20	1.18	1.15	1.13
1180	1.49	1.45	1.42	1.39	1.36	1.33	1.30	1.27	1.24	1.22	1.20	1.17	1.15
1200	1.51	1.48	1.44	1.41	1.38	1.35	1.32	1.29	1.27	1.24	1.22	1.19	1.17
1220	1.54	1.50	1.47	1.43	1.40	1.37	1.34	1.31	1.29	1.26	1.24	1.21	1.19
1240	1.56	1.53	1.49	1.46	1.42	1.39	1.36	1.33	1.31	1.28	1.26	1.23	1.21
1260	1.59	1.55	1.51	1.48	1.45	1.42	1.39	1.36	1.33	1.30	1.28	1.25	1.23
1280	1.61	1.57	1.54	1.50	1.47	1.44	1.41	1.38	1.35	1.32	1.30	1.27	1.25
1300	1.64	1.60	1.56	1.53	1.49	1.46	1.43	1.40	1.37	1.34	1.32	1.29	1.27
1320	1.66	1.62	1.58	1.55	1.51	1.48	1.45	1.42	1.39	1.36	1.34	1.31	1.29
1340	1.69	1.65	1.61	1.57	1.54	1.50	1.47	1.44	1.41	1.38	1.36	1.33	1.30
1360	1.71	1.67	1.63	1.60	1.56	1.52	1.49	1.46	1.43	1.40	1.38	1.35	1.32
1380	1.74	1.69	1.65	1.62	1.58	1.55	1.51	1.48	1.45	1.42	1.40	1.37	1.34
1400	1.76	1.72	1.68	1.64	1.60	1.57	1.54	1.50	1.47	1.44	1.42	1.39	1.36
1420	1.78	1.74	1.70	1.66	1.63	1.59	1.56	1.52	1.49	1.46	1.43	1.41	1.38
1440	1.81	1.77	1.72	1.68	1.65	1.61	1.58	1.55	1.51	1.48	1.45	1.43	1.40
1460	1.83	1.79	1.75	1.71	1.67	1.63	1.60	1.56	1.53	1.50	1.47	1.45	1.42
1480	1.86	1.81	1.77	1.73	1.69	1.66	1.62	1.59	1.55	1.52	1.49	1.46	1.44
1500	1.88	1.84	1.79	1.75	1.71	1.68	1.64	1.61	1.57	1.54	1.51	1.48	1.46
X													

pressure tends to crush them together as it would an empty bellows. But coiled springs within the shells keep them more or less distended. The gradual changes in atmospheric pressure give a slow up or down movement to the top of the set. This makes the pen fall or rise as it writes on the record sheet of the revolving cylinder. In most barographs the cylinder turns once round in a week, and each sheet holds a week's record (Fig. 106).

157. The Measurement of Rain.—The amount of rain helps to determine what crops can be raised, the height of water in the streams for navigation and other purposes, the size of drains needed in city and country, and the kind of weather in which all outdoor work must be carried on. A record of the rainfall is useful in many ways.

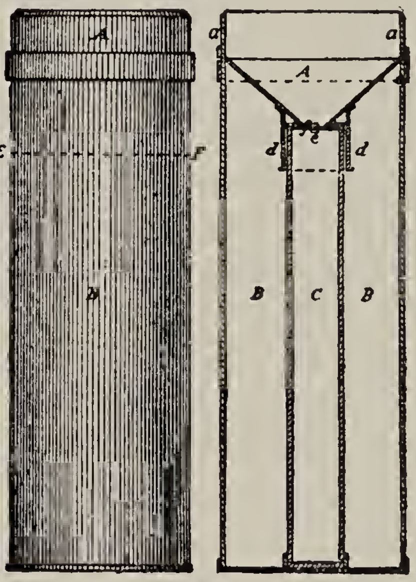

Fig. 107.—Rain-gage.

Rain can be caught and measured in a home-made gage. A rain gage should be circular, with flat bottom and vertical sides. It should stand with its top exactly horizontal. It should be placed in the open away from trees or anything that might prevent rain from falling into the gage or cause wind eddies about the gage and interfere with a proper catch of rain. A common ruler trimmed as thin and narrow as possible may be used to measure the depth after each storm. The gage shown in Fig. 107 is better for accurate measuring of small amounts. The rain caught in it runs through the funnel, *A*, into the smaller can, *C*. It fills this can to ten times the proper depth. Then 1/10 inch on the ruler in "C" is only 1/100 inch of actual depth of rain. In very heavy rains, some of the water overflows into the outer can, *B*, and has to be poured back for measuring.

158. The Measurement of Snow.—Snow is harder to measure than rain. Unless we know how much snow falls, and the amount of water in it, we can not know how much water the soil and rivers of that region receive. The large outer part of the rain gage is used for snow. When there is but little wind the depth of snow can be measured in the gage, and then melted to get the depth of water it contains. When there is even a moderate wind with the storm some snow blows out of the gage. Then we need to measure the *new* snow in several places in the open yard or field, to find its average depth. If the average depth is 4.2 inches, then go where it was just 4.2 inches deep, turn the empty snow gage bottom side up, use its top like a biscuit cutter to cut a "biscuit" of the *new* snow. Do not lift the gage till you slide a shingle or piece of tin across the mouth of the gage under the *new* snow. Then pick up the gage, carefully keeping the snow inside. Melt the snow and record the water as if it were rain. Record the snow as 4.2 inches. The most accurate method is to weigh the snow picked up in that way. Weather Bureau offices have weighing gages that show on the scale the depth of water in the snow picked up.

The density of snow varies much in different storms. It may take anywhere from 7 inches to 30 inches of new snow to yield an inch of water. When the snow cannot be melted, people sometimes call ten inches of snow equal to an inch of water, and record it that way.

Kansas City averages about 34 in. of rain and 25 in. of snow annually; while Marquette, Mich., has about 20 in. of rain and 10½ ft. of snowfall per year. We cannot compare records like these unless the snow is melted and the resulting water measured.

159. Measuring the Temperature; Value of Knowing the Temperature.—Two places may have the same yearly average temperature, but one may have warm summers and cold winters while the other does not. Two regions may have the same average summer temperature, but one may have much warmer days and cooler nights than the other. One place may have few and small changes in temperature, and another place may have many and decided changes. In one region alternating warm and cool periods in spring may destroy fruit buds, while another region with colder but more even temperature may be good for orcharding. All these conditions affect the crops and the industries, and the comfort and health of the population. For example: Corn requires hot days and warm nights. Grass and small grains thrive better in moderately cool weather. People engaged in either physical or mental labor can do more work in a changeable temperature that becomes rather cool occasionally than they can where it is too warm or where the temperature is too uniform. A record of the temperature in every region is needed.

In measuring air temperatures two classes of instruments are used: (1) Ordinary thermometers; and (2) Self-registering maximum and minimum thermometers. Recording thermometers, or thermographs, write a continuous record of temperature, and show its changes.

160. Ordinary Thermometers.—Thermometers usually contain mercury. The tubes, while open at the top, are filled and the mercury heated till it completely fills the bulb and stem. The tubes are then sealed. This leaves a vacuum above the mercury when it cools. The scale is then placed on the stem as described in Arts. 16 to 21; or the scale may be put on by comparing it with a standard thermometer. For very low temperatures, alcohol thermometers are generally used. Mercury freezes at 38.5° below zero F.; therefore, mercury thermometers do not record a lower temperature.

161. Self-registering Thermometers. The Maximum.—In the maximum thermometer (Fig. 108) the tube is narrowed near the bulb so the mercury does not easily pass. The thermometer is placed nearly horizontal. When the temperature rises the mercury is forced through the narrowed portion (*B*, Fig. 108) and you can see it slipping past in small drops. When the temperature falls, the mercury in the tube remains there. Then if the bulb end be held a little lower than the top, so that the mercury is all joined together against the bulb end without crowding any back into the bulb, the top of the column shows the highest temperature reached since the instrument was last "set." To set the maximum, lower its bulb end to a vertical position. The mercury will then run past the narrowed point until the bulb is full. Sometimes the maximum must be jarred slightly, or whirled on its pivot, to make the mercury run down. After setting, the maximum should read practically the same as an accurate common thermometer placed beside it. The "fever" thermometer used by physicians is a small maximum.

FIG. 108.—Maximum and minimum thermometers. *A* marks the index in the minimum and *B* the break in the mercury column of the maximum.

The Minimum.—The minimum thermometer contains alcohol and rests in a horizontal position. Within the alcohol in the tube is a small, double-headed, pin-like index (*A*, Fig. 108). Like other liquids, alcohol has a film over its surface. When the temperature falls and the alcohol contracts, this surface film draws the index back toward the bulb. When the temperature rises, the index remains still and the expanding alcohol runs past it. The upper end of the index, farthest from the bulb, marks the lowest temperature reached since the instrument was last set. To set the minimum thermometer, the bulb end is raised till the tube is nearly vertical. Then the index slides down to the "top" end of the alcohol column. Sometimes a slight jarring is needed to start the index. A minimum after setting should read practically the same as an accurate common thermometer beside it.

162. Recording Thermometers. The Thermograph.—The thermograph (see Fig. 109) writes a continuous record of temperature. The thermometer bulb is a flattened brass tube bent into a curve and filled with alcohol. One end of this bulb is fastened rigidly to the frame, the other connects with a set of levers ending at the pen. Rising temperature expands the alcohol and gradually straightens the curved tube; this raises the pen higher. Falling temperature contracts the alcohol and curves the bulb more; this moves the pen downward. In that way the pen writes a complete record of the temperature, showing all changes and the time when they occurred. Thermographs are used at all Weather Bureau stations, and are in many high school laboratories.

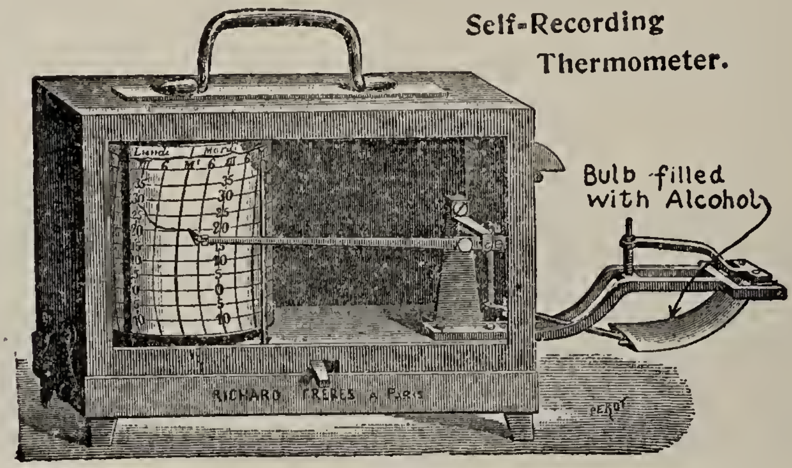

FIG. 109.—Thermograph. The clock turns the cylinder round once each week. The days and hours are marked by vertical lines; the degrees by horizontal lines. The pen rises and falls with all changes in temperature.

163. Obtaining Accurate Temperature Records.—Thermometers should be (1) accurate and (2) sheltered and (3) read at proper hours.

1. Many thermometers have errors of one or more degrees. They should read exactly 32° in melting ice or snow, and the scale should be properly spaced. It is best to compare your thermometer with one known to be accurate.

2. A thermometer hanging in sunshine, or near a building, or over pavements or bare ground, may often give wrong

readings. Sunshine directly on the dark colored mercury warms it too much. A house wall may be too warm; or moisture from the house may gather on the thermometer, and later be evaporated and cool the thermometer too much (see Ex. 10, Art. 12). Walls, pavements and bare ground reflect heat. To avoid all such errors, the weather observers of all countries use screens or shelters for their thermometers (Fig. 110). The American shelter has double roof, slatted sides, and is placed 5 to 10 feet above sodded ground amid open surroundings. Its door opens to the north. In cities the shelter sometimes has to be above a flat roof; for schools it is sometimes just outside a north window; though usually neither of these places is as good as a shelter in the open lot.

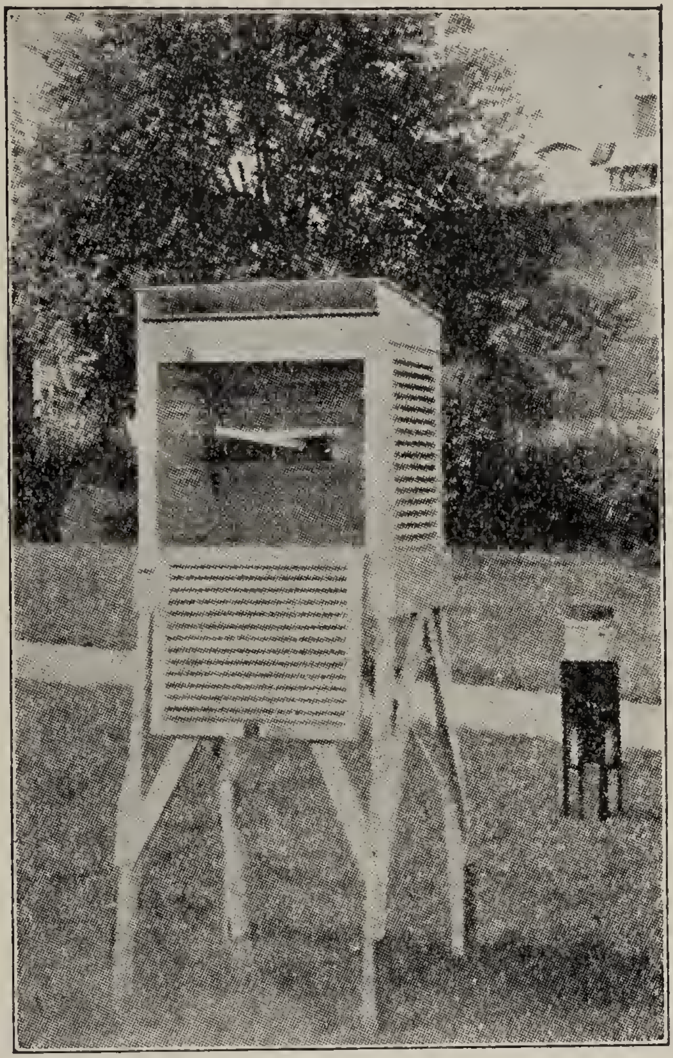

FIG. 110.—Thermometer shelter; U. S. Weather Bureau Pattern. Maximum and minimum thermometers are shown in position. The ordinary rain-gage is seen at the right.

3. If a thermometer is read once a day, in the early morning, the temperature record would be too low. If read only in early afternoon the record would be too high. Reading the thermometer at 7 A. M. and 7 P. M., and dividing the sum by 2, gives a fairly correct average for the day. The Weather Bureau uses self-recording maximum and minimum thermometers to get the highest and lowest extremes in the 24 hours, then adds these extremes and divides by 2, for the average of the day.[1]

164. Keeping the Weather Record with Instruments.—The class should now use the thermometer, barometer and rain gage in keeping the weather record for one month. A home-made rain gage will do. Inexpensive thermometers may be compared with a reliable thermometer and used if their readings are corrected. Keep the record as shown in the condensed and convenient form below. A part of the government weather records are kept in similar manner.

WEATHER RECORD

Barometer								Temp. outdoors			Wind		Clouds			Precipitation		
Date	Hour—a = a.m.; p = p.m.	Barom. reading	Temp. on barom.	Subtract for temp.	Corrected pressure	Add for Altitude*	Reduced to sea level	Temp. at inst. shelter	Maximum thermom.	Minimum thermom.	Direction	Velocity	Kinds	Direction	Amount	Time	Kind	Amount
Jan. 20	9 a	29.14	68°	.10	29.04	.94	29.98	25°	38°	22°	↘	Mod	Lig't high	→	1/10	3 5 p.m.	S	T

* Altitude 830 ft.

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[1] If your school has a thermograph, test both those methods for a few days. From the thermograph sheet get the temperature at the end of each hour; add these 24 temperatures and divide by 24. This gives an accurate average for the day. The average obtained by the other methods will often differ a little from this for a single day, but for a month they will run about the same.

Having learned something of the methods and the instruments by which men study the weather, let us now turn to some of the facts that have been learned. We begin with the temperature.

III. THE ATMOSPHERE AND ITS TEMPERATURE

A Few Facts About the Atmosphere

165. How the Atmosphere Is Heated and Cooled.—The sun's rays pass through the atmosphere to the earth without warming the air much. They warm the earth's surface in the daytime, and the air is warmed by coming in contact with the warm earth, from heat reflected back by earth into the air and by the mixing of air as the warm air rises from the ground. The air is cooled chiefly by expansion as it ascends, by mixing with colder air, or by coming in contact with objects colder than itself (as with earth's surface at night), and in several other ways. For these reasons the air is usually warmest near the ground and grows colder as we ascend. (This is true up to 8 or 10 miles.) Recording thermometers sent up by kites, balloons or airplanes, have found the temperature at the height of 1 mile 10° or 12° colder; at 5 miles 70° to 80° colder; at 10 miles 120° colder; and at 20 miles about 90° colder that at the ground. These figures differ in different seasons and in different parts of the earth. There are many changes from day to day in the lower 2 or 3 miles of air.

166. Unequal Heating and the Winds.—The earth's surface is heated most near the equator; also wherever there is most sunshine, and where the land slopes toward the sun, and where there is bare ground, or certain kinds of soil. This unequal heating is the chief cause of the winds. Warm air is expanded and is lighter than cold air. The warm lighter air is then pushed away or crowded upward by the colder heavier air from other places or from above. Those movements of the air are the winds. The greater heating at the equator is the principal cause of the whole system of earth's winds (See Arts 216 and 221). Many other influences help.

167. The Wind and Our Personal Temperature; Why a Windy Day Seems Cool.—The air is usually cooler than our bodies, and takes away heat from the body. The wind forces air through the clothing and brings fresh supplies of cold air into contact with the body to carry away our heat. The harder the wind blows the faster the body loses its heat and the colder seems the day.

Fig. 111.—A lath screen. These are usually arranged to roll or slide aside to admit sunshine. Night temperature under this screen averaged 4 degrees higher than in an unprotected orchard nearby. To left of center, in foreground, is seen one type of firepot used in warming the ground air.

(Illustration by F. A. Carpenter, in *Monthly Weather Review.*)

168. The Lag of Temperature; Afternoon and Night.—While the earth is being warmed by the sun, it is also cooling all the time by radiating heat out into space. During the forenoon of a clear day the ground receives heat faster than it radiates heat, and our temperature rises. This continues usually till about 2 or 3 P. M. But the warmer the ground becomes, the faster it radiates heat. By 2 or 3 P. M. radiation (cooling) usually becomes faster than the warming. At that moment the temperature begins to fall. Ordinarily radiation (cooling) continues greater through the remainder of afternoon and all night; so the temperature continues to fall from 2 or 3 P. M. until nearly morning. Then the rising sun begins the warming of another forenoon.

Clouds interfere with both sunshine and radiation, and often make the temperature changes different. Winds that blow from warmer or colder regions may bring the highest or lowest temperature of the day at any hour of day or night, especially in winter.

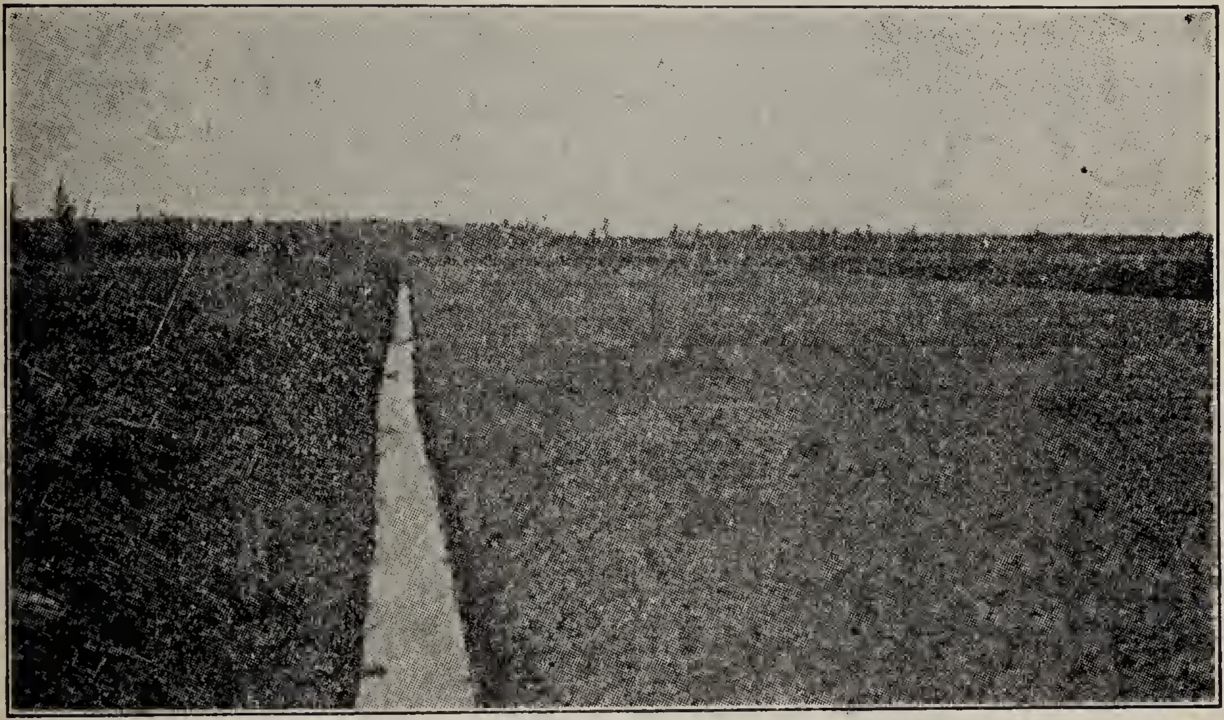

FIG. 112.—Newly planted cranberry bog. Two or three inches of sand were spread over the bog before the plants were set. The ditch at the side of the bog drains the water off quickly when danger of frost is passed.

169. Lag of the Season.—Just as the warmest hour of day comes later than noon, so the warmest part of our summer usually comes later than June 21st, when the sun is farthest north; and the coldest of our winter usually comes later than December 22nd, when the sun is farthest south.

170. Night Cooling and Frost.—The cooling at night, by radiation, is greater on mountains and plateaus, because there the air is thinner owing to elevation, and so permits freer radiation. When the cooling at night goes low enough, dew or frost is formed. Radiation is most rapid when the sky is clear, hence clear nights are coolest and most likely to have dew or frost.

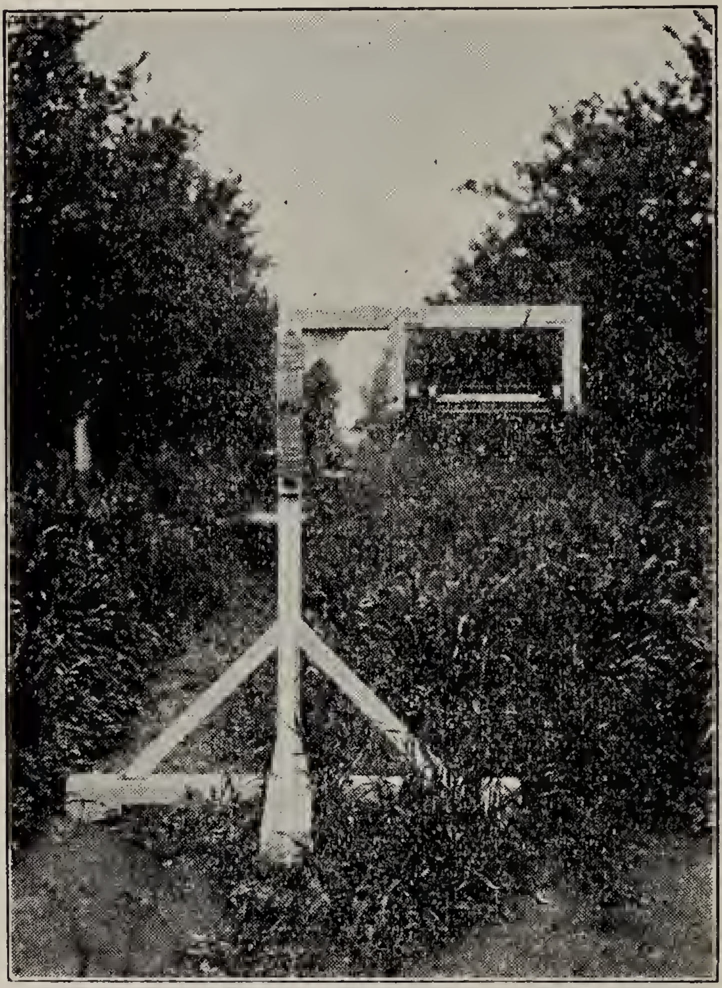

Fig. 113.—Frost fighting in a lemon grove. (Firepots along path near middle. In foreground an alarm thermometer, arranged to ring a bell in the watchman's headquarters when temperature falls to danger point. (F. A. Carpenter, in *Monthly Weather Review.*)

171. Frost Protection by Checking Radiation.—Orchards, gardens and other crops are often protected from frost by using overhead screens (Fig. 111), or fires of some fuel that makes dense smoke. The smoke or the overhead screens check radiation and sometimes keep the temperature 4° to 6° warmer than it would have been.

172. Frost Protection by Warming the Ground Air.—The radiation that chills the night air takes place chiefly from the ground and vegetation. Therefore, the air cools in a thin layer next to the ground. Cooling makes it denser and heavier so that, on still nights, it remains on the ground and continues to cool, while the air a few feet or a few yards above remains warmer throughout the night. Orchardists often prevent frost by warming this shallow bottom layer of cold air with fires of oil, coal, wood, etc., placed on the ground, 15 to 100 per acre.

Cranberry marshes, in Wisconsin and elsewhere, are often flooded with water (often completely covering the vines) to protect them from frost. Water holds its heat better than soil, and keeps the air above the water too warm for frost. Covering the marsh soil with an inch or two of sand also keeps the ground warmer and prevents some frosts (Fig. 112).

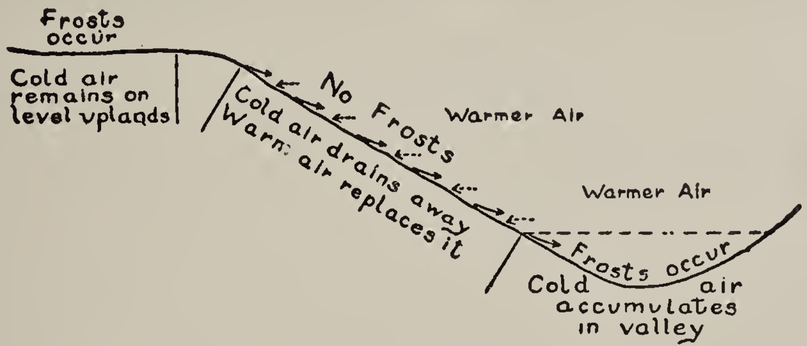

Fig. 114.—How frosts sometimes occur both on the uplands and in the valley bottom, while the slopes escape. Solid arrows, cold air; broken arrows, warm air.

Large orchards are often equipped with alarm thermometers (Fig. 113) arranged to ring a bell in the watchman's quarters when the temperature drops to the danger point. He can then leave the lighting of the fires until they are needed, and can tell where the fires are needed first. This saves expense.

The Weather Bureau issues frost warnings 12 to 20 hours or more ahead of the cold, so that people may protect their orchards, gardens and crops. These warnings have saved as much as $100,000 in one frost in a single state.

173. Air Drainage and Frost.—Valleys usually have frost later in spring and earlier in autumn than the surrounding slopes and low hills. On a hillside the cooled heavier air, close to the ground, settles downhill, leaving warmer air on the

FIG. 115.—One type of landscape where orchards are successful on the slopes, while frosts prevent them both above and below. Lemon groves flourish beyond the rounded oak-forested hills across the lake near center of photograph.

(F. A. Carpenter, in *Monthly Weather Review.*)

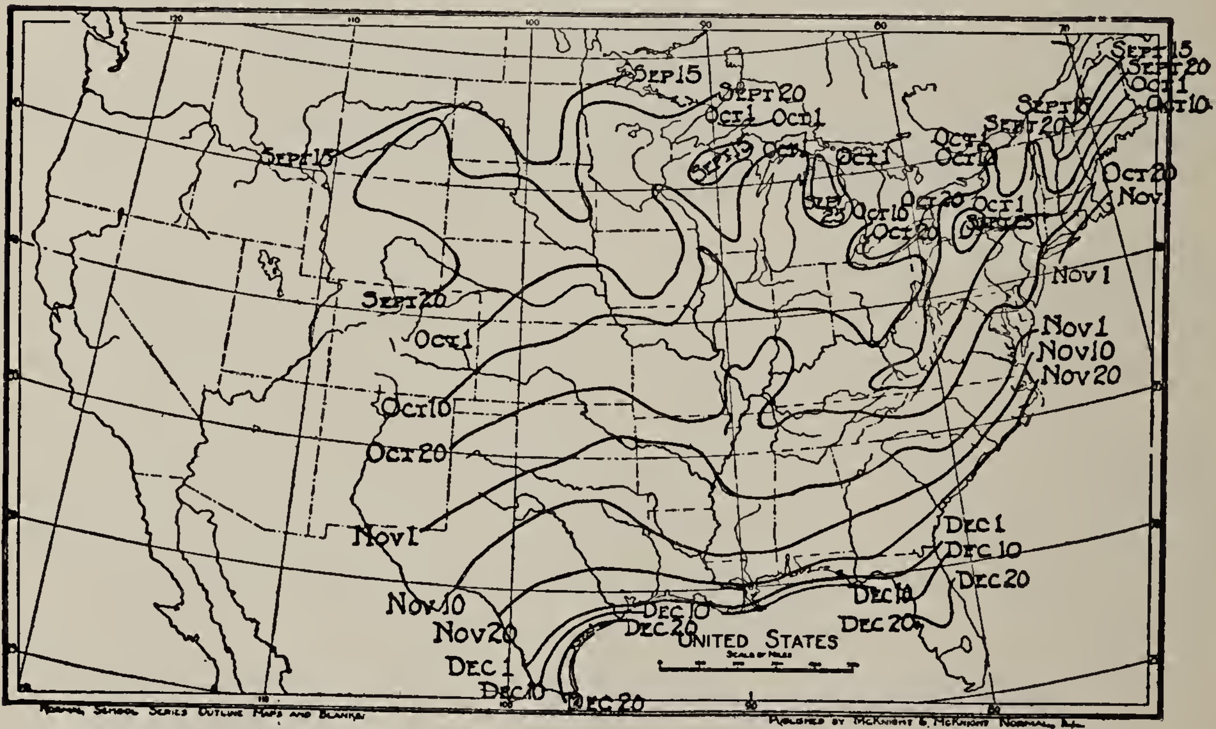

FIG. 116.—Average date of first killing frost in autumn.

slopes (Fig. 114). In the valley the cold air cannot drain away, but keeps getting colder until frost sometimes forms. On the upland, radiation is faster, and the chilled air does not drain away much where the ground is nearly level. So both the uplands and the valley bottom often become colder than the slopes, and both have frost sometimes when the slopes do not. Because of this many orchards in fruit growing regions are placed on hillsides (Fig. 115).

174. **Wind and Frost.**—The wind sometimes prevents frost by stirring and mixing the air. That mingles the warmer air above with the cold air on the ground, and sometimes keeps the bottom air too warm for frost.

Notice that the frost date retreats northward in spring and returns southward in autumn. The time between these frost dates is called the "growing season" for vegetation. About how many days is the average growing season in your locality?

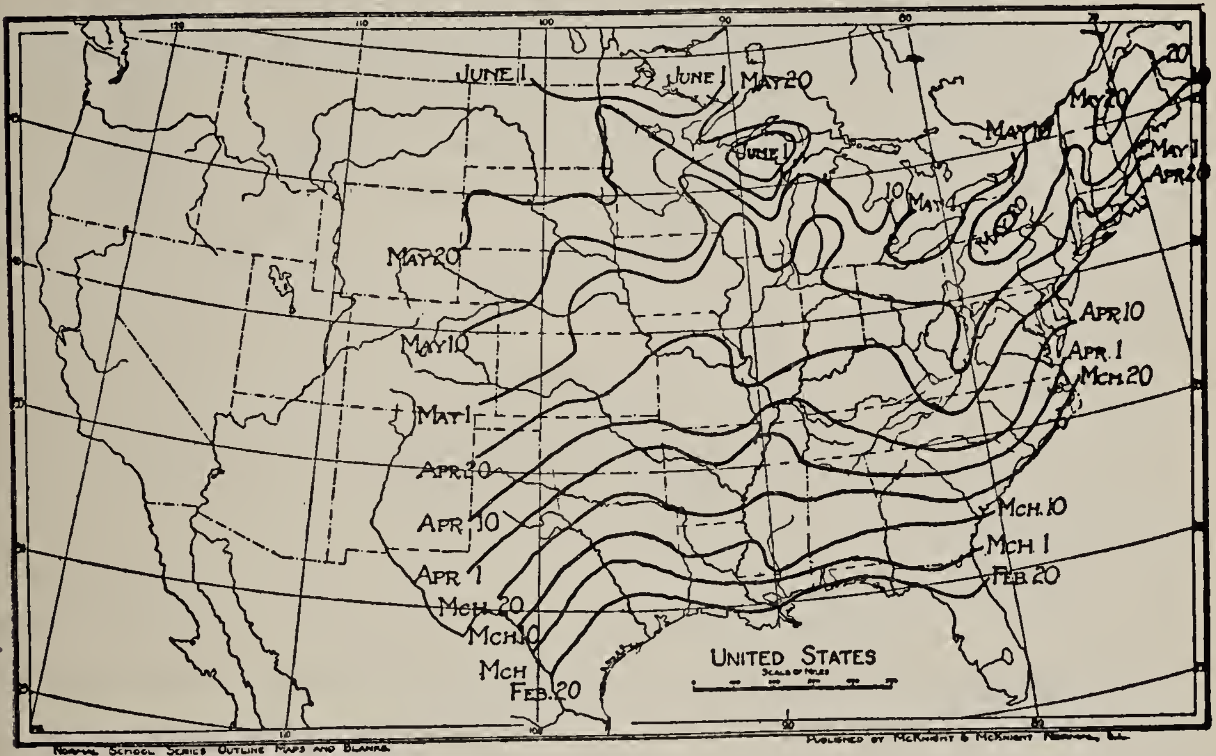

FIG. 117.—Average date of latest killing frost in spring.

In the mountainous regions of the west, frost lines are too irregular to chart easily (Figs. 116, 117).

IV. THE WATER VAPOR OF THE AIR

175. The Moisture of the Air.—Clouds, fog, rain, snow, dew and frost are formed from invisible water vapor in the air. This vapor is very important. From it comes the rain that supplies all the water in the soil and lakes and rivers of the earth. The water vapor in the air also affects our comfort, our health and our business nearly as much as the temperature does. Water vapor extends above the highest clouds but most of it is in the lower 2 or 3 miles of air.

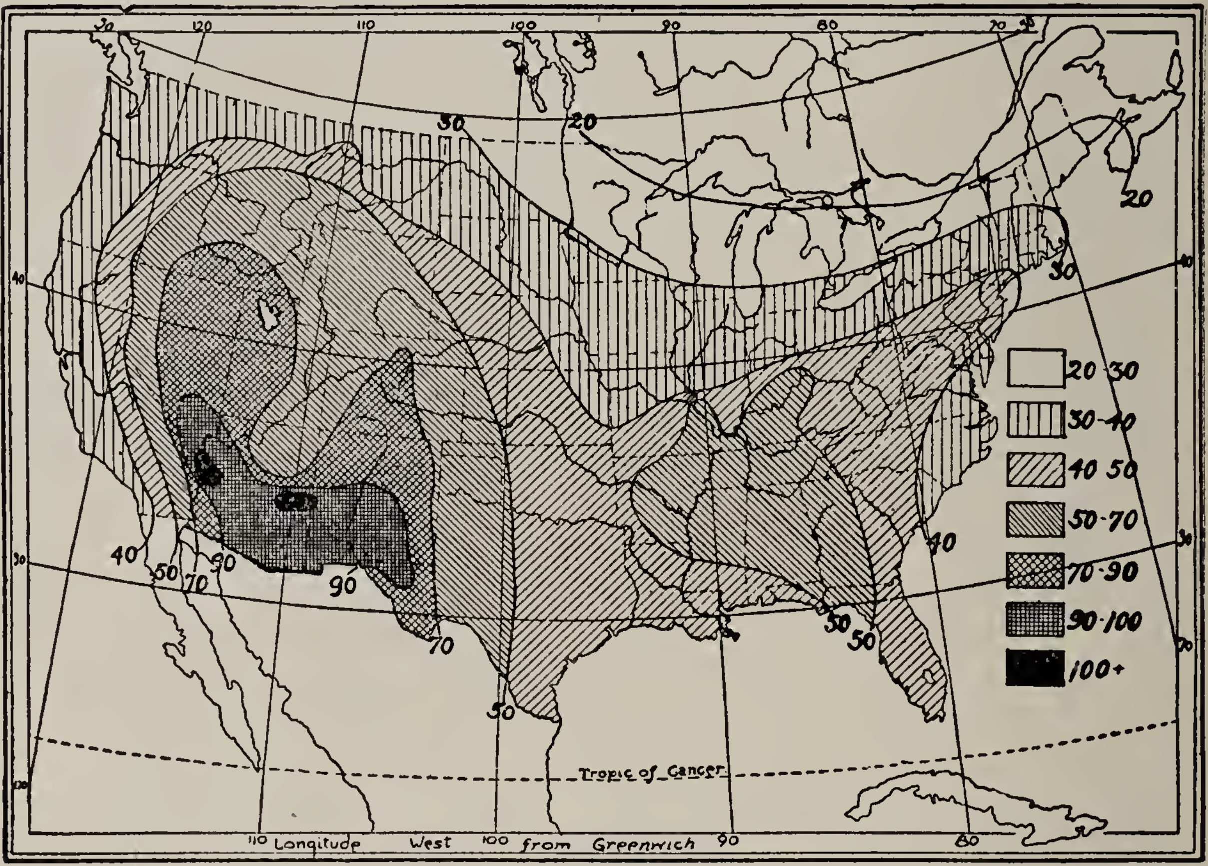

FIG. 118.—Average annual evaporation from the surface of a body of water. Depth in inches; found by measurement in pans on the surface of lakes, ponds or reservoirs.

176. Moisture of the Air; Its Source.—This vapor of water comes through evaporation, chiefly from water surfaces, vegetation and the soil. (1) Evaporation from water surfaces ranges from a very small amount per day in polar regions, in winter, to ¼ inch, or more, on some days, over tropical oceans and over lakes in hot dry regions (Fig. 118). (2) All plants give off water vapor through their leaves. (3) Evaporation from the soil varies with the kind of soil, the dampness of the soil, the way its surface has been cultivated, the dryness of the air, and the force of the wind. Wet soil, dry air, high temperature and strong winds all increase evaporation. Evaporation is greater from porous soils than from packed soils. Rolling a field checks evaporation. Cultivating a field or garden or flower bed so as to form a "dust mulch" an inch or so thick over the surface, keeps more moisture in the soil and makes the plants and flowers grow better in dry weather. ("See Art. 473, How Soil Moisture may be conserved.")

Fig. 119.—The sling psychrometer. The lower bulb is covered with muslin and is moistened before an observation. The thermometers are then whirled about the hand, and read every half minute or so till the wet thermometer ceases to fall lower.

177. Measuring Evaporation.—You may find about how fast water evaporates in your locality in summer, by placing a shallow tray filled with water out of doors and measuring the remaining depth every few days. Of course you must measure the rainfall of every storm and remember that the storm added that much to the depth in the pan. Figure 118 shows the estimated depth that would be evaporated in a year from a lake or pond in different portions of the United States. Can you tell why evaporation would be so much greater in the Southwest?

PROBLEMS

1. If an acre of clover loses 500 tons of water per season through the plants, and if water weighs 62.5 lbs. per cubic foot, how many cubic feet of water is used by the crop? An acre contains 160 sq. rods; how many inches deep would it be covered by that much water? Ans. 4.4 inches.

2. If corn rows are 3½ feet apart, how many rows on a strip 10 rods wide? If the hills are 3½ feet apart in the row, and the rows 16 rods long, how many hills on an acre (10 by 16 rods)? If there are 3 stalks in a hill, how many corn stalks on an acre? If each stalk gives off 250 lbs. of water in the season, how deep would the rainfall need to be to furnish that much water for the crop? Ans. 14.1 inches.

178. Evaporation Effects; Cooling.—To evaporate a quart of water (*i.e.*, to change it from liquid to vapor, without warming the vapor any) takes about 1075 times as much heat as would be needed to warm the quart of water 1° Fahrenheit. This heat used in evaporation becomes insensible heat, which we cannot feel (See Art. 127, Ex. 39). All that heat is taken away from the surrounding air or ground or pavements or whatever the water was on when it evaporated. That is why the drying of our damp clothing makes us chilly, and why the sprinkling of walks or pavements on a hot day cools them and the air near them.

179. Evaporation Effects; Personal Comfort.—A damp day is usually more uncomfortable, in either summer or winter, than a dry day at the same temperature. (1) In winter out of doors, the body needs to be kept warm. Damp air takes away heat from the body faster than dry air, and so makes us feel more chilly. (2) In hot summer weather the body often needs to be cooled. Usually it is cooled enough by the evaporation of perspiration from the skin. Damp air evaporates less perspiration than dry air. That leaves us feeling warmer and more uncomfortable than when the warm air is dry. This is why high humidity (much moisture) in summer causes more suffering and heat-stroke than low humidity (little moisture). (3) In winter, if the air indoors is very dry it evaporates moisture rapidly from the skin and often causes a slightly chilly feeling even though the air is warm. If the air of our homes, schools, offices, has moisture enough, perspiration does not evaporate so rapidly from the skin, and we feel more comfortable even at a lower temperature. It is also more healthful for lungs and throat. In many modern school and office buildings the heating plant is arranged so that humidifiers automatically throw moisture into the air pipes of the ventilating system whenever the humidity falls too low (see Chap. V).

Fig. 120.—Hair hygrometer.

180. Moisture and the Industries.—An even or uniform humidity aids such work as cotton spinning; a high humidity interferes with the manufacture and storage of wooden articles, food, or other products that might swell or spoil if they absorb moisure.

181. Measuring the Water Vapor.—Hygrometer and Relative Humidity.—The amount of moisture in the air may be measured. One method is by using two thermometers, one wet and the other dry, arranged for whirling (Fig. 119). After wetting and whirling, the wet thermometer reads lower than the dry. In dry summer weather it may read 15° or more below the dry temperature, in damp weather only a little lower; in foggy weather both may read alike. The dry temperature, the difference between the two, and a special table of figures, are then used to work out the per cent. of humidity in the air. The process is a little difficult and is not taken up further here.

One form of Hygrometer, for measuring the humidity, consists of a strand of human hair with the oil removed. This hair lengthens with dampness and shortens with dryness. One end is fastened to a rigid frame, the other to the circumference of a small cylinder. A spring holds the hair tight. A pointer is fastened on the end of the cylinder. As the hair changes in length with varying humidity it turns the cylinder and moves the pointer (Fig. 120).

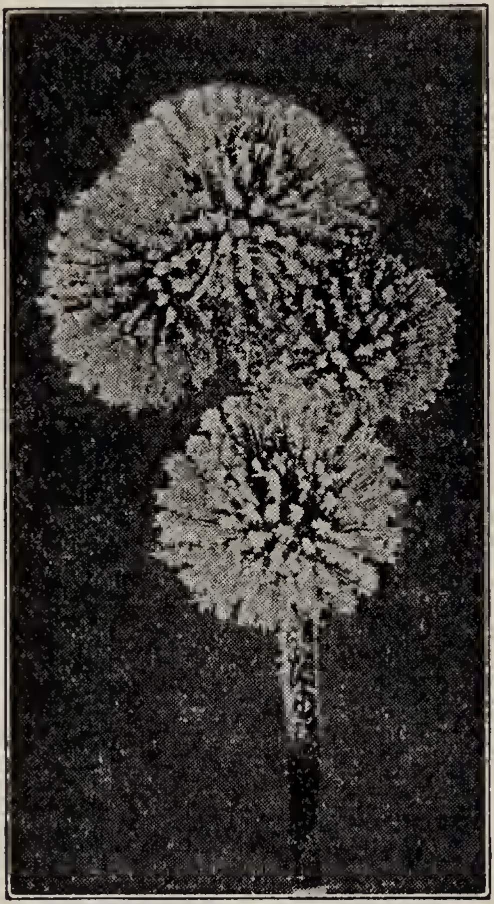

Fig. 121.—Frost on vegetation. Frost on windows often shows beautiful designs.

Fig. 122.—A photograph of dew and unevaporated water exuded from the leaf.

182. Humidity; Dew Point.—The amount of invisible water vapor that can exist in the air depends chiefly on the temperature. Air at 74° can "hold"[1] a certain amount of water vapor; if cooled to 54° it could hold only half as much; at 36°, only one-fourth as much; at 20°, only one-eighth as much water vapor as at 74°. This fact, or law, often causes

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[1] "Hold" is the most convenient word to use here, but is not strictly correct. Water vapor would spread through space if no air were present.

interesting results when the temperature falls. For example, if air, at a temperature of 54°, is ¾ "full" of water vapor (humidity 75 per cent.), and its temperature should fall to 36°, it could not hold all of the moisture it had, and a considerable part of its vapor would be condensed into dew, fog, cloud or rain. The temperature degree at which this condensing of vapor would begin in the cooling air, is called the DEW POINT because it is the temperature at which dew, or cloud, fog, rain, or snow would begin to form. Just where, at what degree, the dew point of air is at any time, depends on the temperature of the air and the amount of moisture in it. All dew, frost, fog, cloud, rain, snow, etc., are formed by the cooling of the air below its dew point.

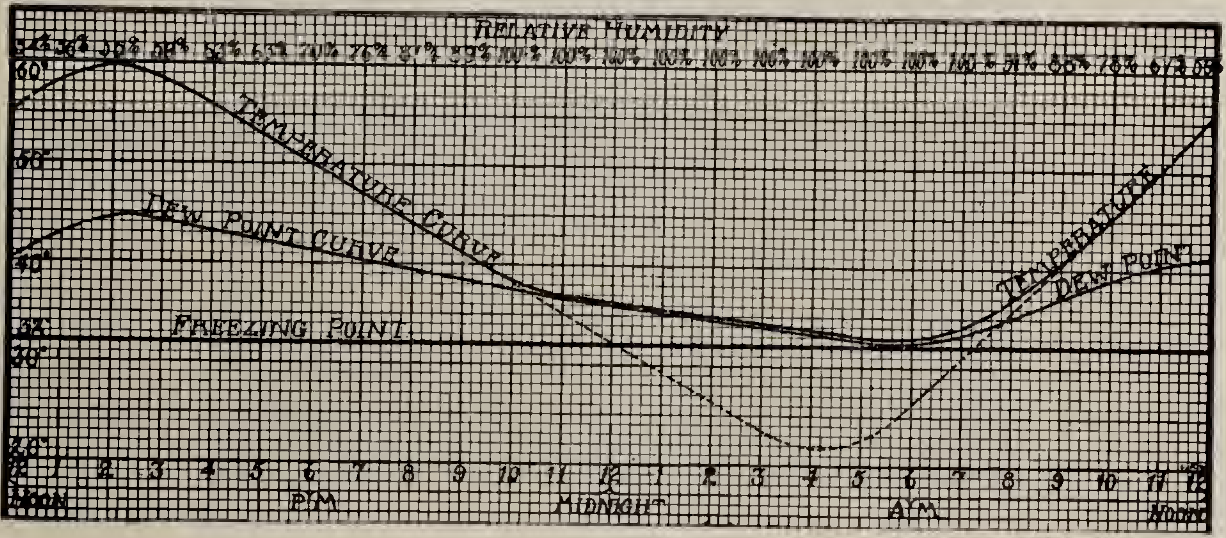

FIG. 123.—This figure shows the general or usual relation of temperature and the dew-point throughout the day. The dotted line shows about how the temperature would fall were it not for the heat of condensation set free when dew forms. Note the rather sharp bend in the temperature curve when dew begins to form.

183. The Forming of Dew or Frost.—As the ground and vegetation cool at night, by radiation, they often become colder than the dew point of the surrounding air. That chills the air resting against them and makes it colder than its dew point. And that in turn condenses some of the moisture in the chilled air into dew or frost upon the ground or vegetation. If the temperature is above 32°, dew is formed; if 32° or lower, frost results. Hoar frost is made of fine crystals of ice which often arrange themselves in beautiful designs (Fig. 121). Dew is usually in small droplets. The large drops frequently seen on the edges of grass or leaves often come partly from the leaf pores of the plant. Figure 122 shows both the small droplets of dew, and other large drops which may have come partly from the leaves.

Fig. 124.—Photograph of two cloud sheets. Taken from an airplane flying between the two cloud sheets. The cloud sheet below the airplane is stratus clouds; the cloud sheet above the airplane is alto-stratus. The stratus sheet below receives the lights and the shadows of the upper sheet just as the surface of a body of water would. (Airplane photo, *Monthly Weather Reveiw.*)

184. The Forming of Ground Fog.—While dew or frost is forming, the air often remains clear. But the cooling may go far enough to chill the whole mass of air near the ground to below its dew point. Then part of the vapor within the chilled air is condensed into very small particles of water that remain suspended in the air as *Fog.* Sometimes this fog may be seen first in the few inches of air next the ground, gradually deepening as the air chills higher.

Deep, widespread fogs are often formed by the mixing of

FIG. 125.—Upper third cirrus clouds; lower half cirro-stratus. Cirrus are light feathery clouds, more or less scattered. When they have the form of plumes with frayed or torn edges, and are moving rapidly, they usually indicate increasing cloudiness and rain or snow. Cirrus moving very slowly seldom indicate an approaching storm. In temperate zones cirrus and cirro-stratus nearly always move from a westerly direction. The thickening of cirrus into cirro-stratus, as shown here, often indicates rain or snow. The clouds seem to thicken gradually until the sky is hidden. This thickening is sometimes partly due to the growth of the clouds themselves; usually it is caused mainly by the coming of denser masses as the earlier clouds pass on.

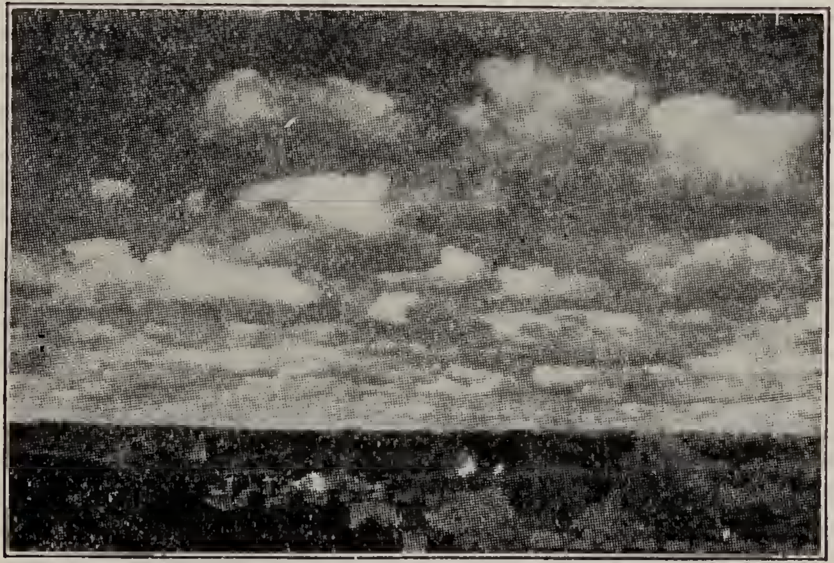

FIG. 126.—Fair-weather cumulus clouds. This type of cumulus is often seen. Note the level bases and rounded tops. (The bases are all at the same height, though the distant bases appear lower because farther away.) These clouds do not indicate rain.

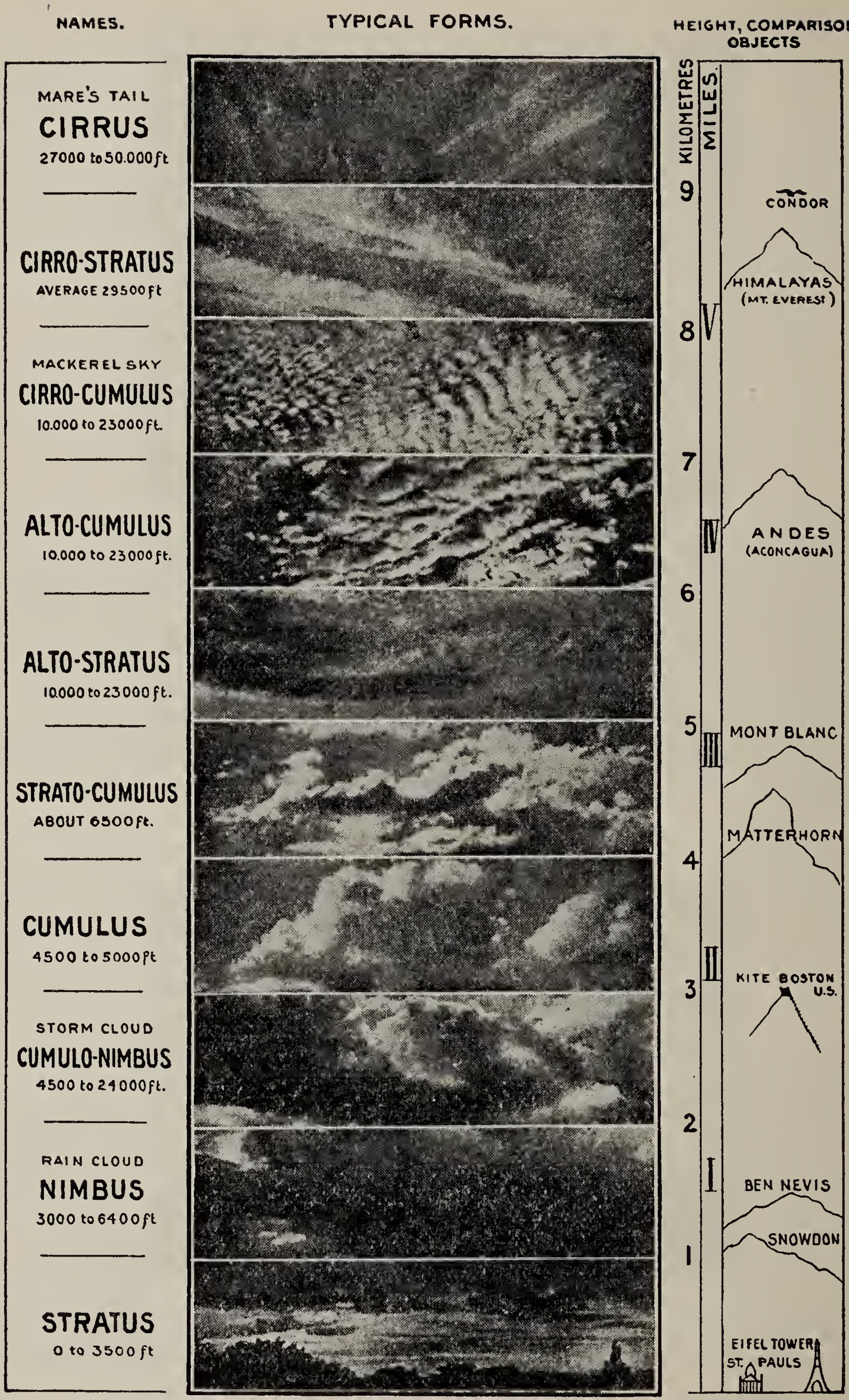

FIG. 127.—Cloud forms, in order of their elevation. (*Note.* These classes and heights should be learned.)

Classes of Clouds.—Description

PRINCIPAL TYPES

1. **Cirrus.**—Whitish color. Makes no shadow. Is made up of threads or fibers that are sometimes arranged like a feather and sometimes woven like cloth. Sometimes these fibers are straight; sometimes curved. Cirrus clouds often move very fast, but do not seem to do so because they are so high. They average about 5 to 7 miles above sea level.

2. **Cumulus.**—The rounded heap cloud. Seen oftenest in summer. Is dark on shaded side and bright on sunny side. Casts a shadow on the ground. Cumulus range from very small to as large as a mountain. Their bottoms are usually flat, and may be ¼ mile to 1 mile high, while the tops are sometimes 3 or 4 miles higher.

3. **Stratus.**—A flat, sheet-like cloud; color dark gray. It may cover all the sky like a blanket, or it may be broken into patches. It may have either clear sky or higher clouds above it. It is seen in all seasons, but oftenest in cool or cold weather. It is usually ¼ to ¾ mile high.

COMBINATION TYPES

4. **Cirro-Stratus.**—Is like cirrus, only the threads are woven into a sheet or layer. This thin whitish sheet sometimes covers all of the sky, at other times only in patches or bars. Such bars are made up of shorter fibers than those in cirrus clouds. When cirro-stratus gets thicker and darker in color it sometimes becomes alto-stratus. Cirro-stratus clouds are about 2 to 6 miles high.

5. **Alto-Stratus** (alto means high).—This is a gray sheet of high cloud. One type is like cirro-stratus, only thicker and dark gray in color; the other type is made up of small lumpy clouds joined together into a sheet or layer. Alto-stratus may cover all the sky or may be only in patches. It is 3 to 5 miles high.

6. **Cirro-Cumulus.**—Balls or heaps or "fleeces" of whitish cloud. They are made of fibers like cirrus, and are heaped or rounded like very small cumulus. They cast no shadow. They are much higher than small cumulus, being 3 to 6 miles high.

7. **Alto-Cumulus.**—A high cumulus. It is usually smaller than the low cumulus clouds, and looks to be rather dense or solid; 2 to 4 miles high.

8. **Strato-Cumulus.**—Has a bottom like stratus, and tops like cumulus joined together. Dark colored underneath. Sometimes covers whole sky; sometimes in long rolls with gaps between. Sometimes the rolls are rather flat, other times they are heaped up rather high. About ½ to 3 miles high.

9. **Cumulo-Nimbus.**—The thunder shower cloud. It has the cumulus top; is often very large. Black underneath; the tops are often a bright golden color on the sunny side. Tops may be 3 to 8 miles high. Rain falls from Cumulo-Nimbus clouds.

10. **Nimbus.**—Any cloud from which rain or snow is falling. It may be any of the following forms: Nos. 2, 3, 5, 7, 8, or 9.

(For illustrations of clouds, see Figs. 124 to 133.)

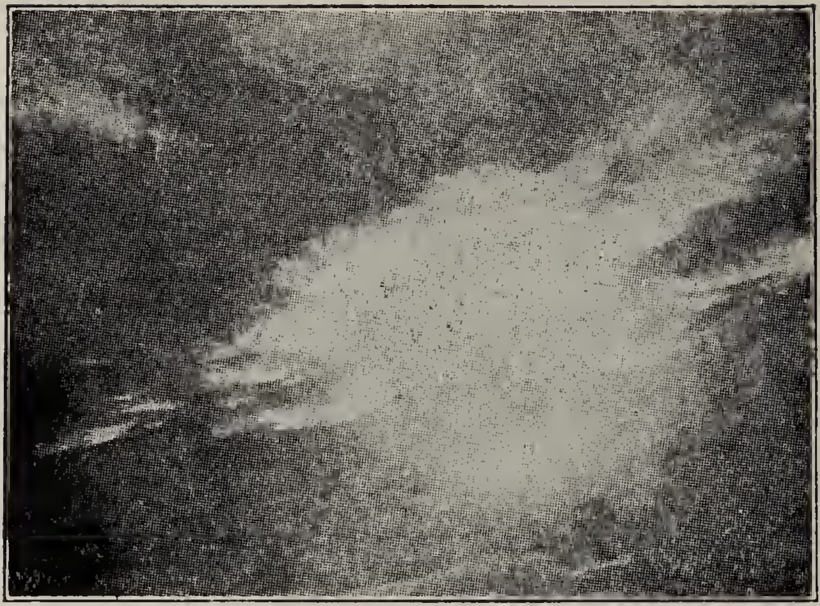

Fig. 128.—Cirrus clouds. Light feathery clouds that float at an elevation of 4 or 5 miles above the earth's surface. When in the form of plumes with frayed and torn edges increasing cloudiness and rain or snow are usually indicated, especially if the clouds are moving rapidly. Cirrus moving very slowly seldom indicate an approaching storm. In temperate latitudes cirrus nearly always move from a westerly direction.

Fig. 129.—A cumulo-nimbus, or thunder head. This cloud has begun to rain, but not long ago. The longer cirrus fringe at *A* shows that portion probably began raining before the other visible portions.

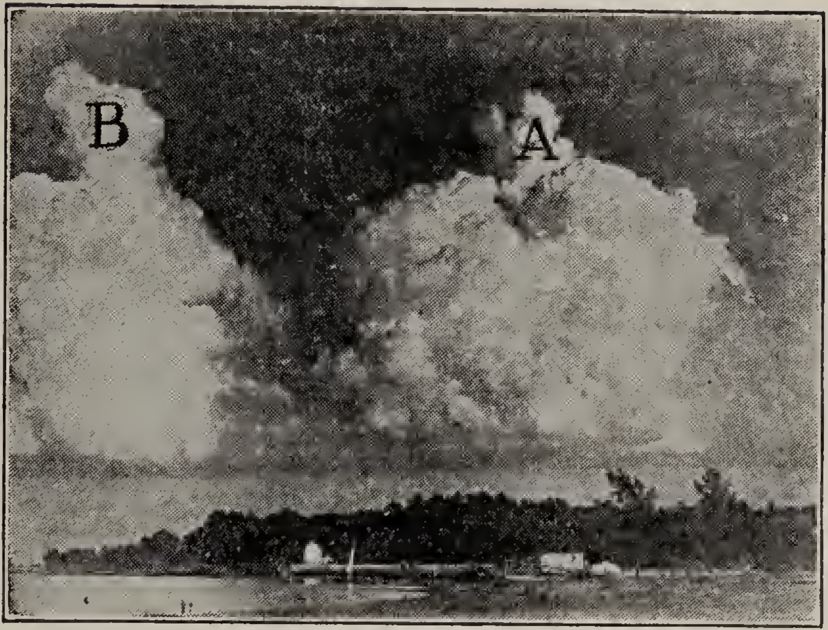

Fig. 130.—A large cumulus. Note the level base and high tops. The turret above each dome shows a much stronger upward current of air at those points. The sharp clean-cut upper edge over most of both domes shows that rain has not yet begun in those portions of the cloud. Turret "A" is slightly fringed (not very clear in cut), showing that rain is beginning in that part of the cloud.

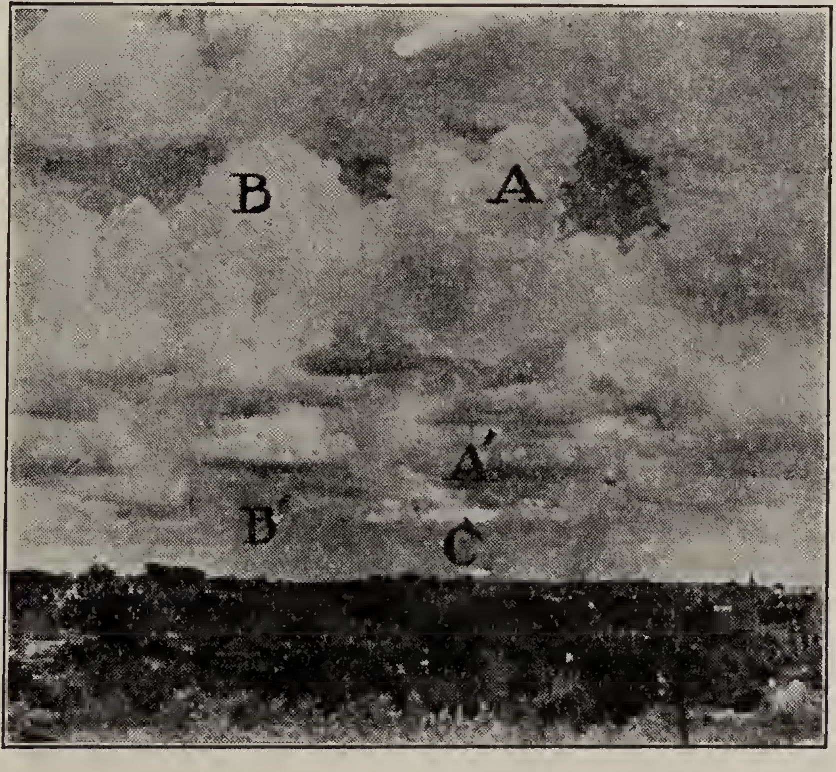

Fig. 131.—Cumulus clouds. Types frequently seen in summer. Tops like "*A*" are likely to develop showers, sometimes before long. The dark spot *A′* is the base of "*A*" or of a similar top behind "*A*." The top "*B*" is slightly fringed, showing that rain has begun. The rain at *B′* is probably falling from cloud "*B*." The rain at "*C*" apparently falls from another cloud behind "*A*."

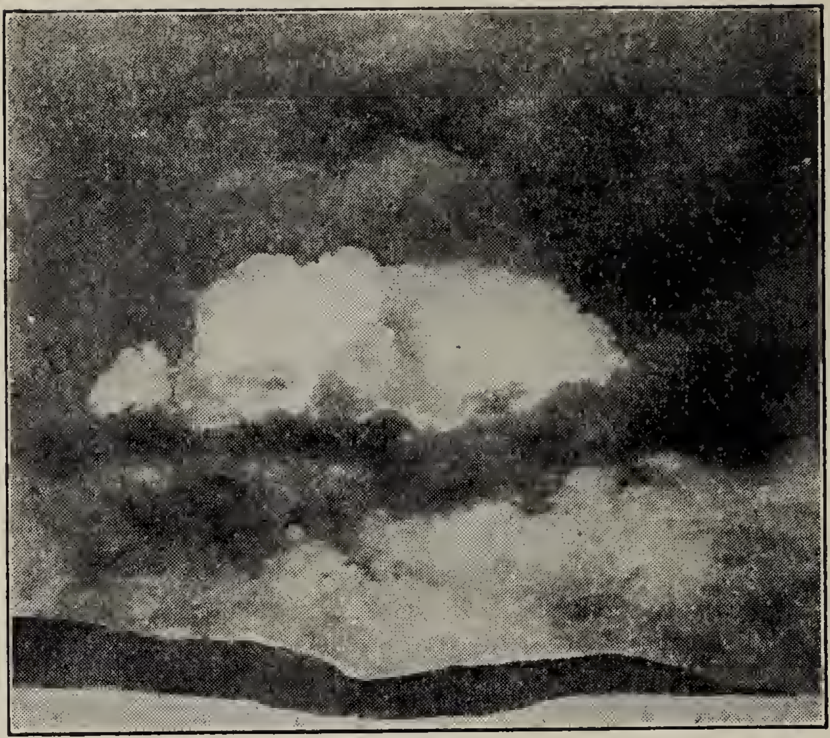

Fig. 132.—Large cumulus, partly hidden. The dark clouds across its front are rather low clouds much nearer the camera. Note the brilliantly lighted top. The sharp, clean-cut outline above shows that no rain has developed in the portions visible.

Fig. 133.—Strato-cumulus, lower surface. Note the uneven shading. The dark spots are sometimes caused by the greater thickness of the cloud at those spots; sometimes by the shadows of higher clouds falling upon the strato-cumulus layer.

masses of warm air with masses of cold air; sometimes in winter, by warm damp winds blowing over a colder region.

185. The Forming of Clouds.—The lowest clouds and all the denser clouds are like fog. Clouds are formed by the condensing of water vapor in the air. They are interesting and often beautiful. Clouds are the messengers of the air. Sometimes they tell us of sunny days to come; often they warn us of approaching storms. What they tell depends on how much one knows of them.

The foregoing six pages introduce clouds and show how to study them for yourself.

Figure 127 shows the principal classes of clouds, arranged according to their height. The accompanying table gives the chief divisions and a number of their combinations. Some cloud forms are further illustrated in Figures 124 to 133.

In recording cloudiness in weather records, a day with 3/10 or less of cloudiness is called clear; 4/10 to 7/10 is called partly cloudy; and 8/10 or more is cloudy. See Weather Record, page 154, and study the government's Weather Reports.

186. Cumulus Clouds; How They Are Formed.—Clouds may be formed in several ways. The most important is that

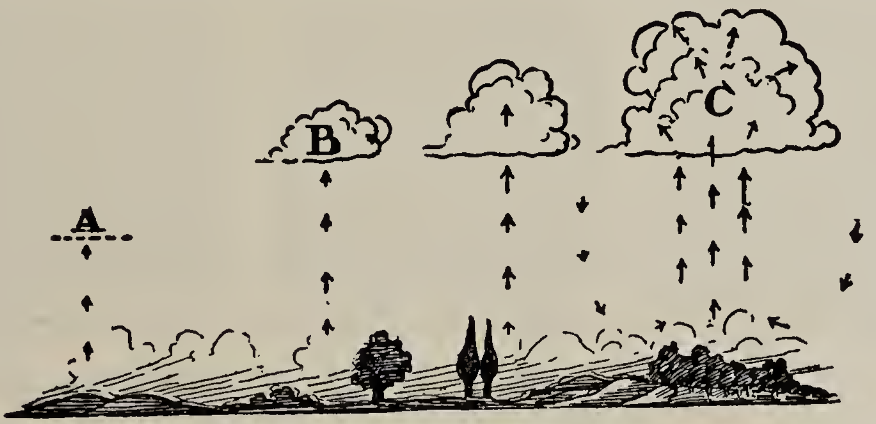

FIG. 134.—Rising air currents, due to warming of earth's surface.
At "*A*" no cloud is formed.
At "*B*" a small cloud results.
At "*C*" a stronger current builds a much higher cloud.

which builds the cumulus. Cumuli are formed by the cooling that takes place in ascending currents of rather warm and moist air. Air is warmed most next to the earth's surface

(Art. 165). Often, especially in summer, this lower air becomes considerably warmer, and therefore considerably lighter, than the air above. Then, for a brief time, there is cool heavier air above, and warm lighter air below it next to the earth (Fig. 134). Soon this warming air below breaks upward through the overlying colder heavier air, and ascends in broad streams or masses here and there, while the colder heavier air settles downward between. The ascending streams of warm air continue to rise as long as they are warmer than the air around them at the same height. As they rise the pressure on them becomes less. That lets them expand. The expanding cools them. Whenever the rising air cools below its dew point, cumulus cloud begins to form.

187. Cumulus; Large and Small.—The beginning of a cumulus is at the bottom of the cloud. If the rising air current at that height is still considerably warmer than the surrounding air, it will keep on rising considerably higher, forming cloud all the way up, and so build a tall cumulus. But if the rising air at the cloud base is only a little warmer than the surrounding air, it will rise only a little higher and so will build only a low-topped cumulus. The size or volume of the ascending air current, and the amount of water vapor in it, also makes a difference in the size of the cloud (Fig. 134).

Cumuli are often fair weather clouds; at other times they develop into showers. By watching their growth one who is acquainted with clouds can usually see whether or not they will rain, and what paths the showers will follow.

188. How Rain is Produced.—The fine water droplets of a cumulus cloud float in the air like fog. The ascending air currents help to keep the droplets from falling. When enough vapor has been condensed these droplets usually join together and settle downward faster than the rising air currents carry them upward. They then begin to fall as rain. Rain drops that reach the ground range from very small up to ¼ inch or more in diameter. You can measure their sizes by catching some rain in an inch or so of flour. The rain drops will form pellets in the flour. You can then put other water drops from a medicine dropper into the flour. Hold the dropper close to a ruler and carefully measure the size of the water drops before they fall. Then measure the flour pellets formed by these drops. That will show whether the pellets are larger or smaller than the drops that made them, and how much.

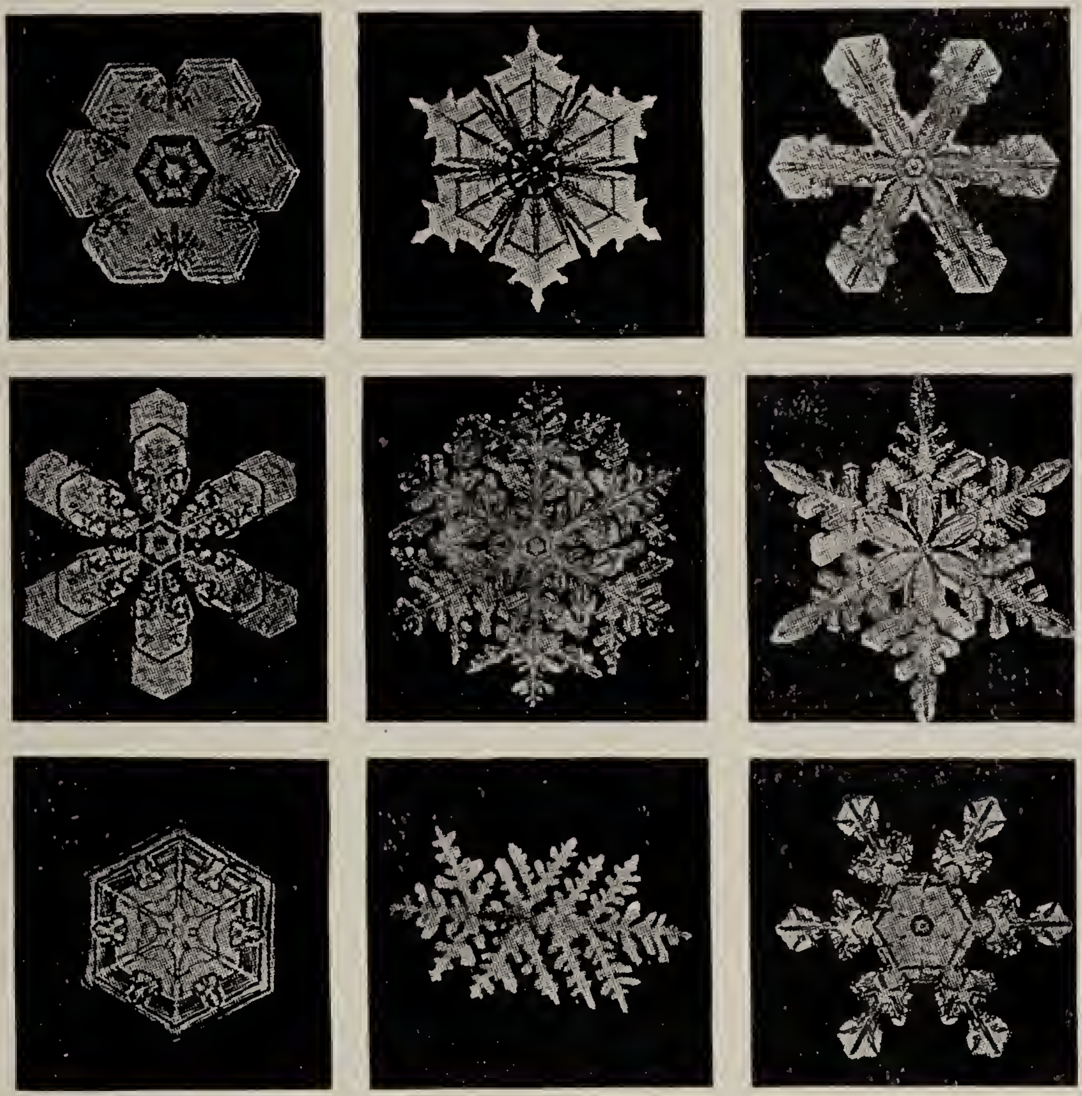

Fig. 135.—Types of snow crystals.
(Photographed by Mr. W. A. Bentley.)

Then you can measure the pellets formed by the rain, and find very nearly the size of the rain drops.

189. Snow.—When the temperature in a cloud is below freezing, snow forms instead of rain. Snow flakes, when not too much broken by the wind, show many beautiful forms. Those in Fig. 135 were caught on a board covered with dark cloth. The board was placed just outside a window so the flakes could be photographed through the glass. Many hundred different forms of snow flakes have been photographed by Mr. W. A. Bentley, of Jericho, Vt.

Sleet. Either raindrops or partly melted snow flakes may fall through freezing air below the cloud and form pellets. If these pellets rattle when they strike the ground or other objects, they are called sleet.

Hail.—(See Thunderstorm, Art. 194).

Soft Hail.—Soft hail is composed entirely of snow. The pellets are usually small, but are sometimes a half inch or more in diameter.

Glaze, or Ice Storm.—This is a name given to rain that falls unfrozen, or mostly unfrozen, but freezes as soon as it strikes the ground or other objects, and forms a coating of ice upon them. The weight of this ice sometimes causes much damage to trees and wires.

V. LOCAL STORMS

190. Showers.—The showers of summer nearly always develop from cumulus clouds. These showers sometimes form in an hour or two. They usually move eastward, but they may come from any direction. They sometimes seem to turn backward or sidewise, instead of going forward. But you may learn to see beforehand when most showers are likely to develop, and what paths they will follow.

191. Showers From the Larger Cumuli.—A cumulus cloud that is likely to rain nearly always builds up higher than others. Its bottom usually becomes blacker. Its top is brilliant white or golden-white on the sunny side and dark on the shaded side. The top is rounded and often billowy, with a clean sharp edge at first that becomes fringed with wispy fibers as soon as rain begins to fall (Figs. 129, 131). As the shower develops, this fringe at the top spreads out usually on all sides of the cloud but much the farthest in front, because the air current carrying the cloud moves faster above and brushes the fringe ahead (Fig. 137).

192. Showers; to Find the Paths They Will Follow.— All the large cumuli in the sky at a given time are moving in the same direction. Therefore, if you live at "z," in Fig. 136, and the large cumuli are moving from the southwest, clouds or showers, from "A" in the southwest are the only ones that will pass over you. Showers at "B" or "D" would pass by on either side (see also Art. 193).

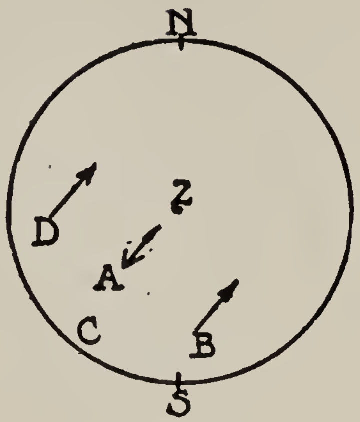

Fig. 136.—The path of a cloud.

To find the direction that clouds are moving, stand so you can "sight" directly past the corner of a chimney or roof or the top of a telephone pole, etc., to a distinct point on the cloud. Notice carefully the direction the cloud moves away from the chimney. To avoid mistakes you should stand so the cloud seems to move straight away from the chimney toward the zenith (point over your head). Then the chimney is in the direction that cloud is coming from. All this must be done carefully or you may make mistakes.

193. To Foresee Showers; the Clouds That May Rain.— After learning to recognize the shower clouds and to find the direction they are moving, the next step is to watch for the approach of clouds that may rain in your vicinity. Generally those will be either:

(a). Clouds already raining. With practice these are usually easy to see for some time before they arrive.

(b). Other, growing clouds, not yet raining, that may begin to rain before they reach you. Usually these will be large cumuli with rather dark bottoms, and will be in one of the following classes:

1. One or more separate or scattered clouds, not near another storm or shower.
2. Clouds that develop near another shower. Most of these are in one of three classes. (See Fig. 137 and note.)

Sometimes low stratus or strato-cumulus move in a direction different from that of the main storm cloud. Do not be confused by them. Sometimes low clouds hide the upper

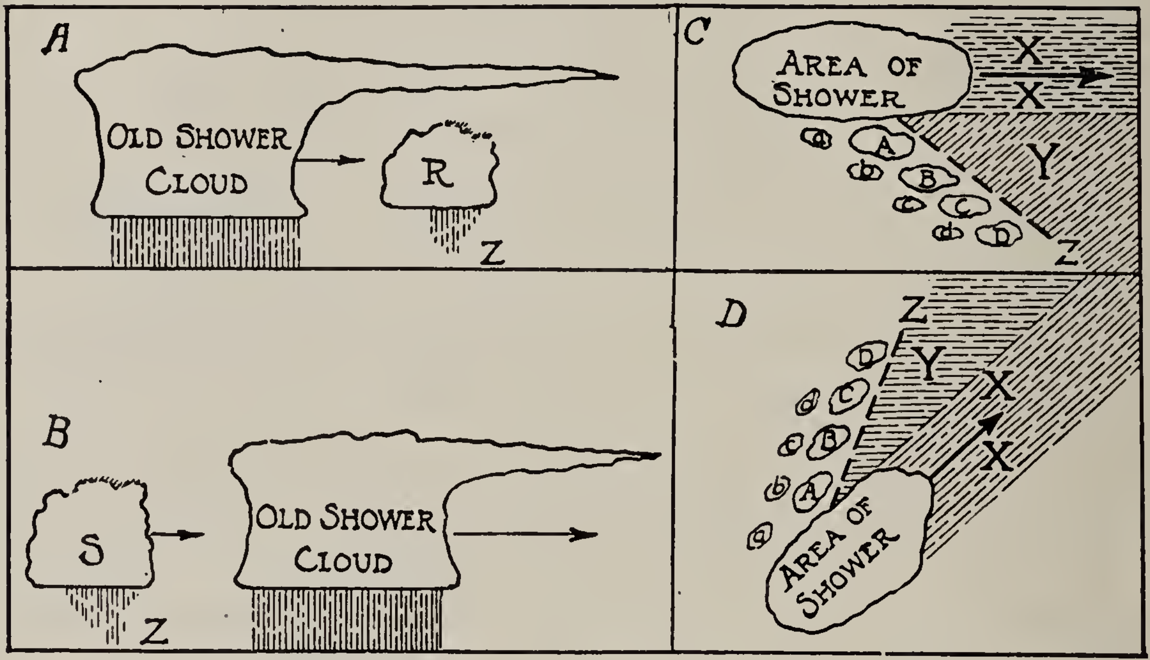

Fig. 137.—Growing Shower Clouds.

In Fig. A, the growing cloud, R, is a considerable distance ahead of the main shower. R begins to rain on reaching you, or just before reaching you. That often makes it appear as though the main shower had suddenly jumped forward. This is a side view.

In B, the growing cloud, S, is some distance behind the storm. S begins to rain on reaching you, or just before reaching you. That often makes it look as though the main storm had returned. Side view.

In C, the small clouds, a, b, c, d, and the shower itself are all moving due eastward. The small clouds, a, b, c, d, grow rapidly into large clouds, A, B, C, D, and each begins to rain as it reaches the broken line. The shower thus spreads over all the territory east of the broken line, and the edge of the rain reaches you at Z. This is a top view.

In D, all the clouds are moving from the southwest, and the same sort of spreading is shown on the north side of the storm. The rain spreads over all the territory east of the broken line. This is a top view of the storm.

In C and D, "X" shading shows where the old shower will rain. "Y" shading is the added rain area from the new clouds.

and important clouds from view. Then it is difficult to know what the upper clouds are doing. It is not always easy for a beginner to distinguish the different kinds of clouds accurately. But it is always interesting to watch showers, and it is useful to know beforehand, as far as possible, what they will do.

194. The Thunderstorm; Its Approach and Passing.—After a shower has become well developed, the cirro-stratus fringe at its top may reach many miles ahead, and is often the first we see of the coming storm. It is frequently more or less hidden by lower clouds. This high cloud, and the storm behind it, may advance broadside toward us, as in (*a*) (Fig. 138). They may pass by to one side, as in (*b*) or (*c*). They may travel endwise over a narrow strip of sky, as in (*d*). They may come obliquely (on a slant), as in (*e*). The high advance cloud may be thin at first, so the sun can be seen through it. Before long it becomes thicker and heavier. Later, back toward the horizon that it is coming from, you can see the dense black, or greenish-black, base of the storm

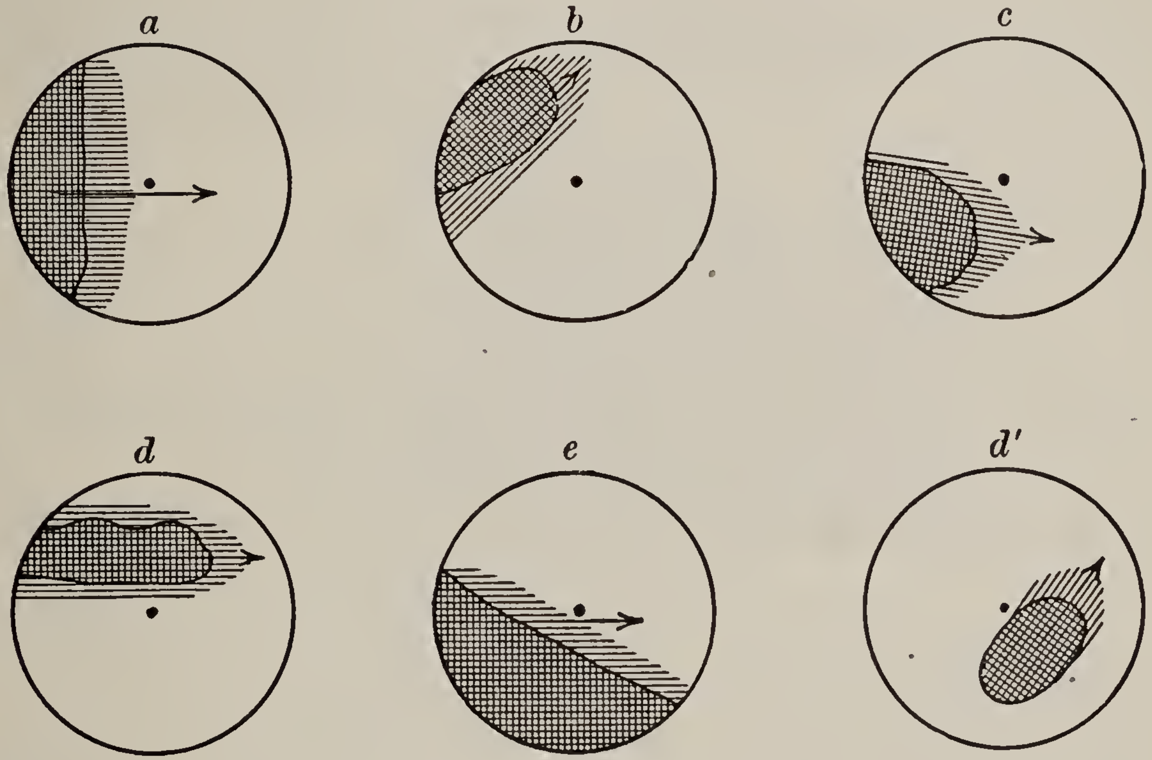

Fig. 138.—The dot is your position. The circle is your horizon. The double shading is the area now covered by the thunderstorm. Single shading is outspreading upper clouds. The arrow shows the direction in which the storm cloud is moving. In *a* and *e* the storm will reach you; *b* and *c* show how some thunderstorms pass by to one side of you; *d* and *d′* show the narrow strips of country covered by some thunderstorms. These are top views.

cloud; then the gray, or dark blue, curtain of rain falling from it. Often just in front of the rain is a roll or bank of ragged grayish cloud that is tumbled and tossed by the wind. This is called the "squall cloud," and immediately after it usually comes the first dash of heavy rain. The rain may last from a few minutes to an hour or two, and may be steady or broken. Toward the last it usually slackens gradually until it stops. Not long after the rain ends, and sometimes before it ends, the clouds begin to break. About one to three hours later, especially if it is toward evening, you can sometimes see in the east the brilliantly lighted tops of the departing storm cloud. The tops of cumulo-nimbus reflect the light of the setting sun.[1]

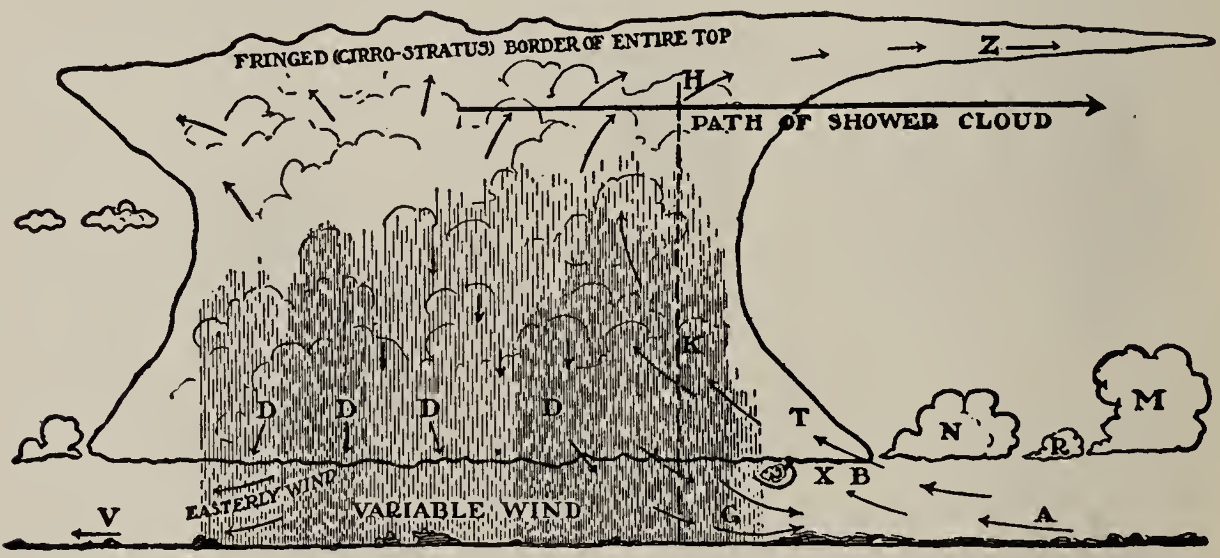

Fig. 139.—Diagram of a thunderstorm.

A, *B*. Warm air flowing into and up through the cloud, largely from in front but often also from sides.

D. Downward movement of air within a portion of the storm.

Z. Cirro-stratus advance extending often far in front.

M, *N*, *R*. Lower clouds in front of storm; almost any size and amount may be present.

G. Outflowing wind of storm front.

X. Squall cloud, a ragged roll mixing and tumbling; not always present.

T. Front of main cloud.

H, *K*. Points mentioned in discussing hail.

V. Backward flow of air in rear of storm; not always present.

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[1] Sometimes the sun may set clear while a sheet of storm cloud covers most of the sky. The sun then shines under the west edge of

195. The Winds of a Thunderstorm.—The winds, at the ground, near a thunderstorm often blow outward on all sides, away from the storm (Fig. 140). When a storm comes from the west, the wind close in front with the squall cloud, is from the west. When the rain is about ended the wind sometimes has changed to the east and is blowing back as a light or brisk breeze from the departing storm. When a thunderstorm passes near by to the north of you, you will often have a north wind that blows out several miles from the storm. And when a storm passes near on the south of you, a similar wind often blows out from the south. If the storm stood still perhaps all these winds would have about the same force. But most thunderstorms are moving, and so the winds in front are usually the strongest. (Why?) The

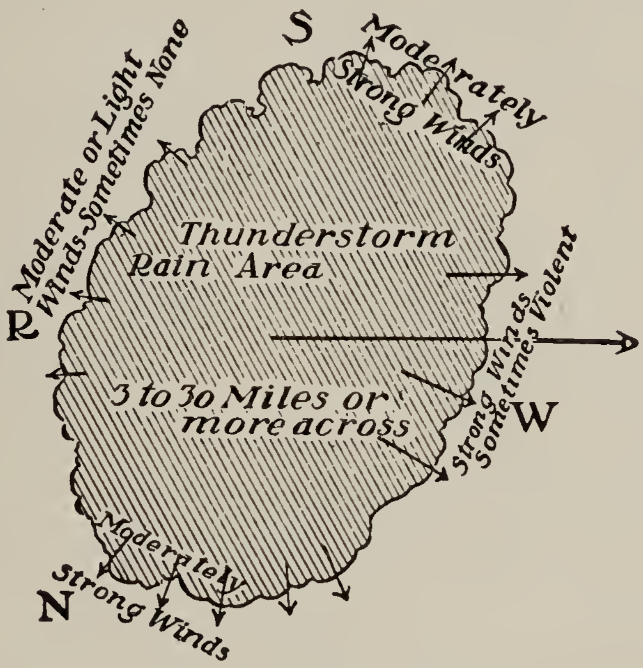


Fig. 140.—Outflowing winds at the ground often occurring on all sides of a summer thunderstorm. Not all these winds are present with every storm. This is a top view of a thunderstorm area. The length and width of a storm may be either greater or less than shown in the figure.

the storm cloud and its light is reflected from the under side of the cloud, giving the whole sky a brilliant pink or golden glow. A fainter coloring is sometimes caused in fair weather by a sheet of cirrus or cirro-stratus over the east or southeast sky while the sun sets clear. Lower clouds sometimes hide such sunsets and are lighted up by the reflected glow from the higher clouds.

warm air that builds the thunder cloud and keeps it raining is slanting upward into the storm cloud above these outflowing ground winds, especially on the south and east sides of the storm. This is shown for the front side of the storm, in Fig. 139.

196. The Thunderstorm; Its Lightning and Thunder.—Lightning is an electric flash or discharge. It is thought that the electricity in the cloud exists on the surface of the water droplets. When many small droplets join together into fewer and larger drops the few large drops have much less surface than the many small drops had. We might perhaps say that this "crowds" the electricity and increases its intensity. When that process goes far enough an electric discharge takes place. This discharge is the lightning flash. Tall objects like trees, chimneys, spires, etc., are most likely to be struck, and any object much taller than its surroundings should be avoided during a thunderstorm. Kite flying in or near a thunder storm is dangerous.

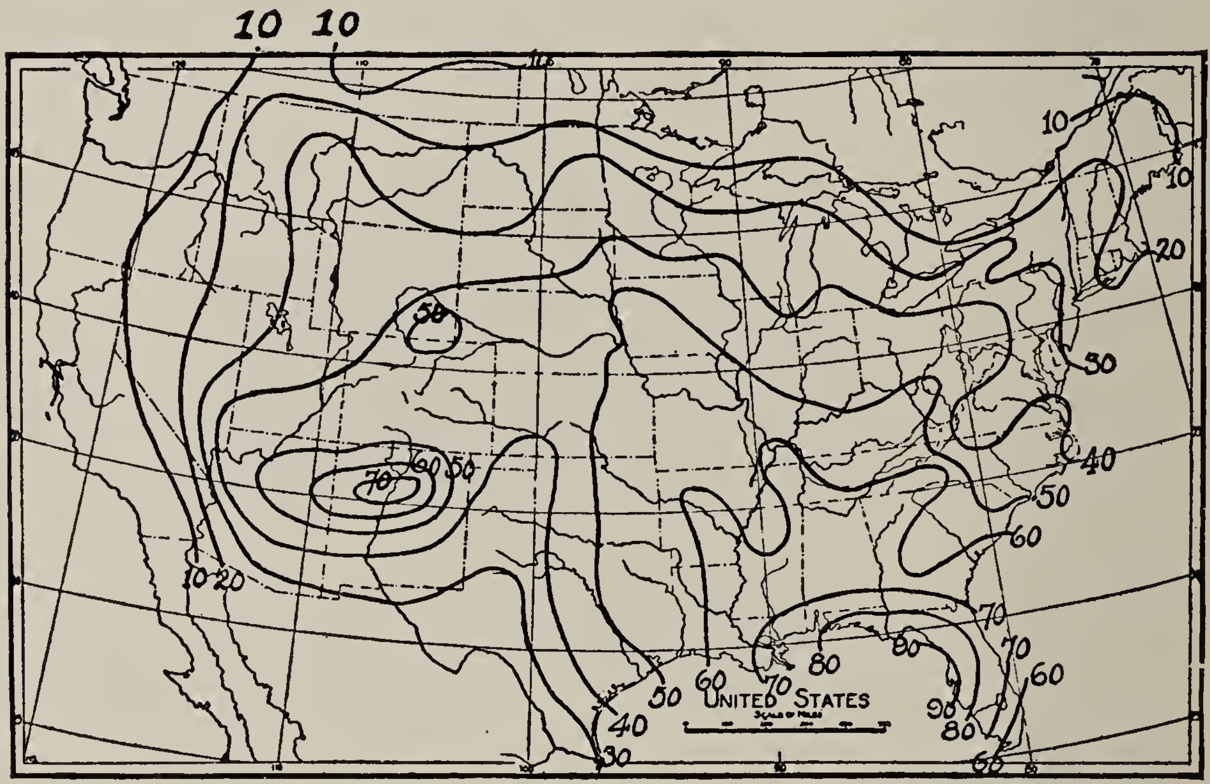


Fig. 141.—Average annual number of thunderstorms in the 10 years 1904–1913.
(W. H. Alexander, in *Monthly Weather Review.*)

The lightning of a distant thunderstorm at night often makes a beautiful display if not hidden by other clouds. What is called HEAT LIGHTNING, is usually the reflected lightning of a distant storm.

THUNDER is caused by lightning. A flash of lightning heats the air along its path suddenly with an intense heat. This causes a sudden expansion of the air. Almost instantly the air cools and contracts again. This sudden expanding and contracting of the air along the path of the flash produces the sound waves which we call thunder.

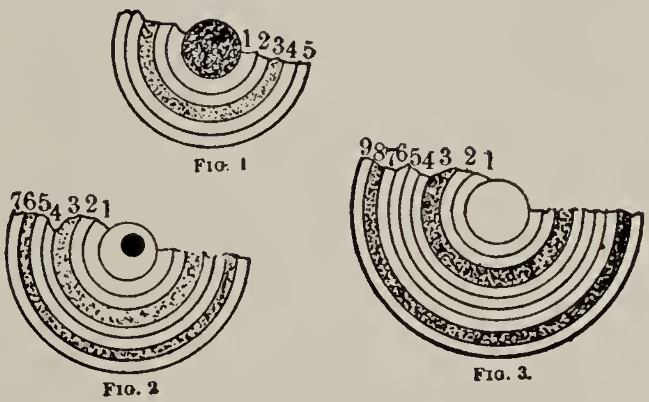


FIG. 1 FIG. 2 FIG. 3.

FIG. 142.—The layers of hail stones. Figs. 1, 2, and 3 show the formations of hailstones having five, seven and nine layers, respectively, outside the central nucleus. The stippled dark portions represent snow.

197. The Thunderstorm; Hail.—Hail is usually made up of alternate layers of clear ice and of cloudy ice or snow. How hail forms is not fully understood. One of the principal theories may be explained from Fig. 139. Suppose that the uprush of air in a portion of such a storm carries a drop of rain up into the colder part of the cloud near *H*, where the raindrop mixes with snow, freezes, then falls back toward *K*, receives a layer of water which immediately freezes to its icy surface; is then carried aloft for another coating of snow; and so on until the stone becomes too heavy and falls to the ground. Hailstones may be split with a sharp knife, showing the layers (Fig. 142). As many as 20 to 25 layers have sometimes been found. Damaging hail is rare in most places. Falls of hail 8 inches or a foot deep have been known. Hailstones 13 inches in circumference have been measured.

198. The Tornado.—The tornado is the most violent storm that occurs on earth. It is something like the dust whirlwinds seen on street corners or in the fields, except that the

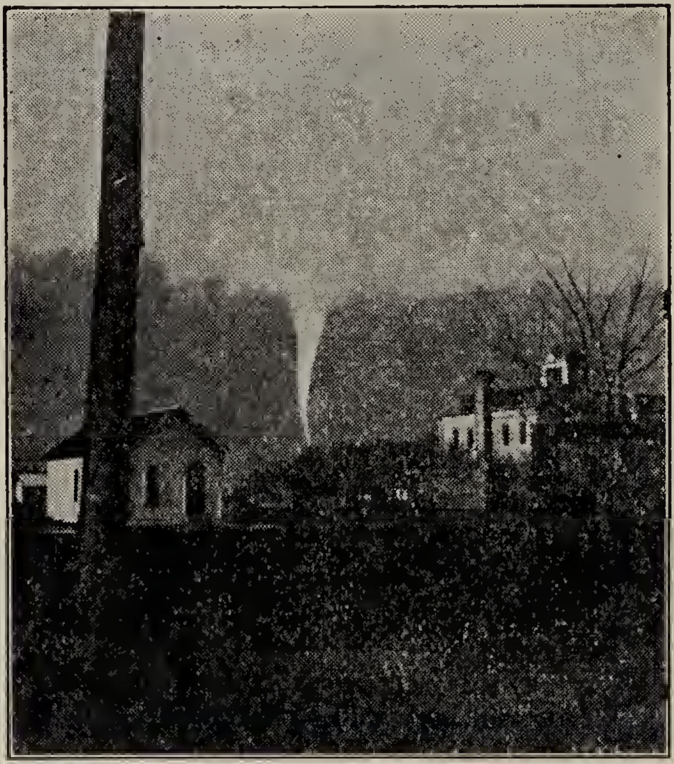


FIG. 143.—Tornado. Rather small funnel cloud extending to ground.

FIG. 144.—Same tornado, closer view.

tornado is very much larger and stronger. The tornado is usually not more than 50 to 500 yards wide. Some have been only a few yards, others a mile or more in diameter (Figs. 143, 144 and 145).

The rising air currents in a cumulus cloud sometimes meet at the proper angle to throw themselves into a whirl as they go up through the cloud (much as the water in a wash bowl throws itself into a whirl as it runs down through the opening in the bottom). Occasionally this whirl in the cloud becomes strong enough to extend itself clear down to the ground, and then it is usually marked by a funnel-shaped or tail-like cloud. When the air whirl becomes strong enough this funnel cloud reaches to the ground. The stronger the tornado is, the wider the funnel cloud becomes.

Fig. 145.—Shows the base of the funnel of the same tornado when about one mile west-northwest of the camera. This view is from the side and somewhat in front, as the storm passed by.

199. Damage Done by Tornadoes.—The damage done by a tornado is caused: (1) By the violent winds in the whirl, which blow perhaps 200 miles or more per hour; and (2) By the low pressure in the core of the tornado. The air in a tornado whirls so fast that it pulls itself away from the center, just as a stone pulls on the string when you whirl it around your head. That makes the air pressure less in the funnel than it is outside the funnel. The pressure of air is about 15 lbs. per square inch. Suppose the pressure in the tornado center is only 10 lbs. per sq. inch, the difference between the funnel center and outside would therefore be 5 lbs. per sq. inch. Then when the funnel comes suddenly over a closed house, the air inside the house will instantly push outward with a force of 5 lbs. per square inch. (How much would that be on one side wall of your school room?) That pressure is often enough to break out a wall or "explode" the house. We do not know just what the pressure

Fig. 146.—Effects of a tornado.

Note.—The name "cyclone" belongs to a wholly different class of storms (see Arts. 200 and 215) and should never be used for a tornado. (1) The tornado always has the local twisting winds and a hanging core of revolving cloud; the cyclone never has either. (2) The diameter of the tornado is always a few hundred yards, or less; the diameter of the cyclone is always a few hundred miles or more.

is inside a tornado, but the above is thought to be the correct explanation of some of the effects of a tornado. Tornadoes have been known to carry heavy stones high in the air; to carry children a mile or more and lodge them unhurt in tree tops; to pluck the feathers from chickens, and to drive straws into boards and plank through sheets of steel. The tornado is confined principally to the United States east of the Rocky Mountains, and rarely occurs in other portions of the earth. Most tornadoes develop in the southeast half of a low-pressure area (Figs.147 to 150).

VI. THE GENERAL STORM; A LOW PRESSURE AREA

200. The General Storm; How It is Studied.—Thus far the weather may be studied by one person working alone. But to study the widespread storms, and to predict their coming, many countries have weather bureaus with a large number of stations that take simultaneous observations and telegraph them immediately to a central office. There the weather conditions at each station are written in the proper places on a large map. For example, the weather at Denver is written near Denver on the map; Chicago's weather is written at Chicago, etc. When the map is finished it gives a bird's-eye view of the weather over the entire country. Such a map is made twice each day, at 7 o'clock, morning and at 7 o'clock, evening. The forecaster can look at yesterday morning's map and see where the storms and the fair weather, and the warmer and the colder were at that time. Then he can look at this morning's map and see just how the weather conditions have traveled since yesterday. From that he can see about what kind of weather is coming to each state in the next day or two. He then writes out the weather forecasts for each section, and sends them by wire and by mail to every locality.

You can learn to understand the weather maps, and by watching them from day to day you too can see the storms

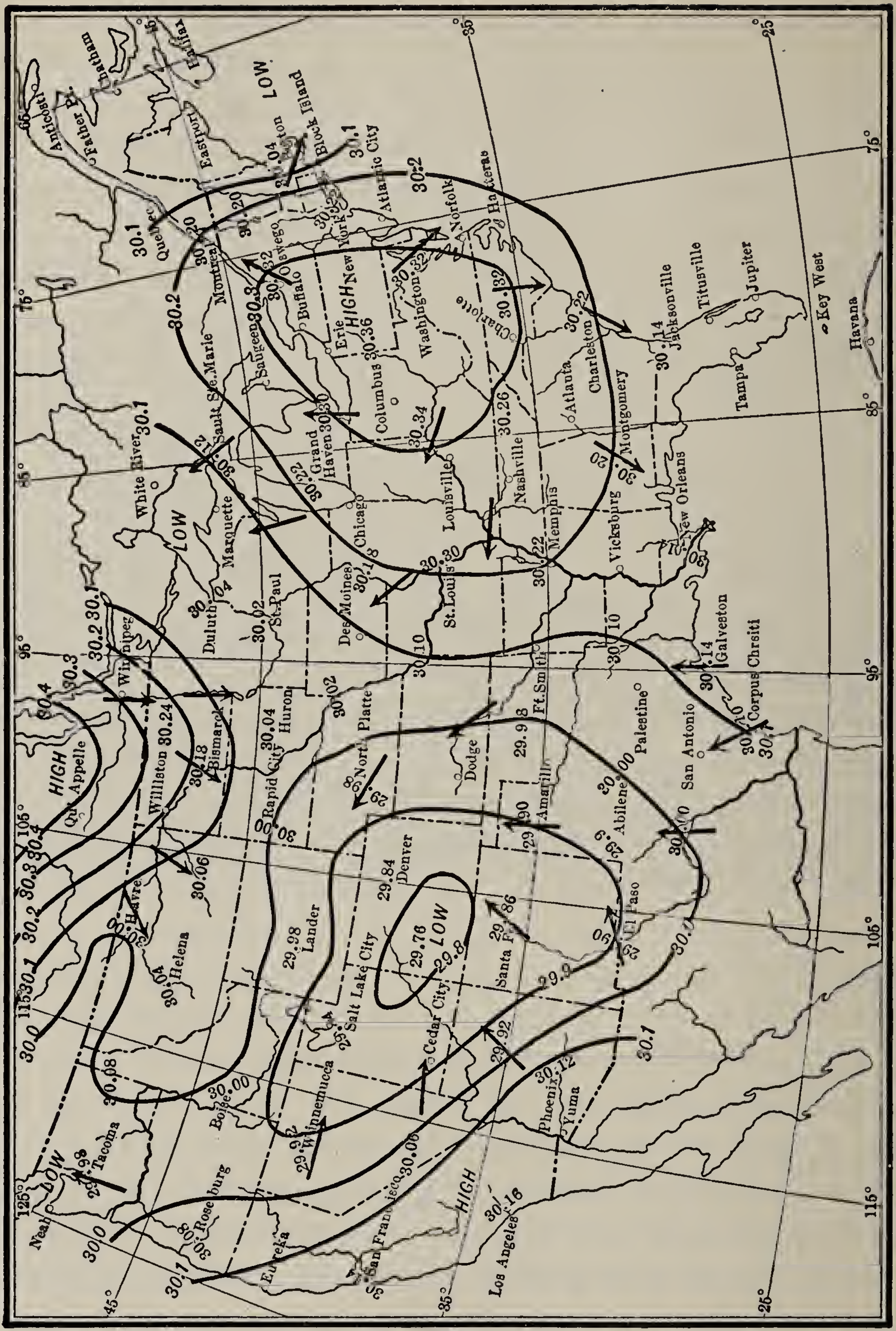


FIG. 147.—Weather map of 7 A. M. (Central Time) December 4, 1906. Numbers at cities give barometer reading, as 30.14 at New Orleans. The lines are then drawn through places having the same pressure; see figures at end of line. Arrows point or fly the way the wind is blowing. The crests of high pressure are over Pennslyvania, Ohio, West Virginia, and northern Manitoba and Saskatchewan. The principal center of low pressure is over western Colorado.

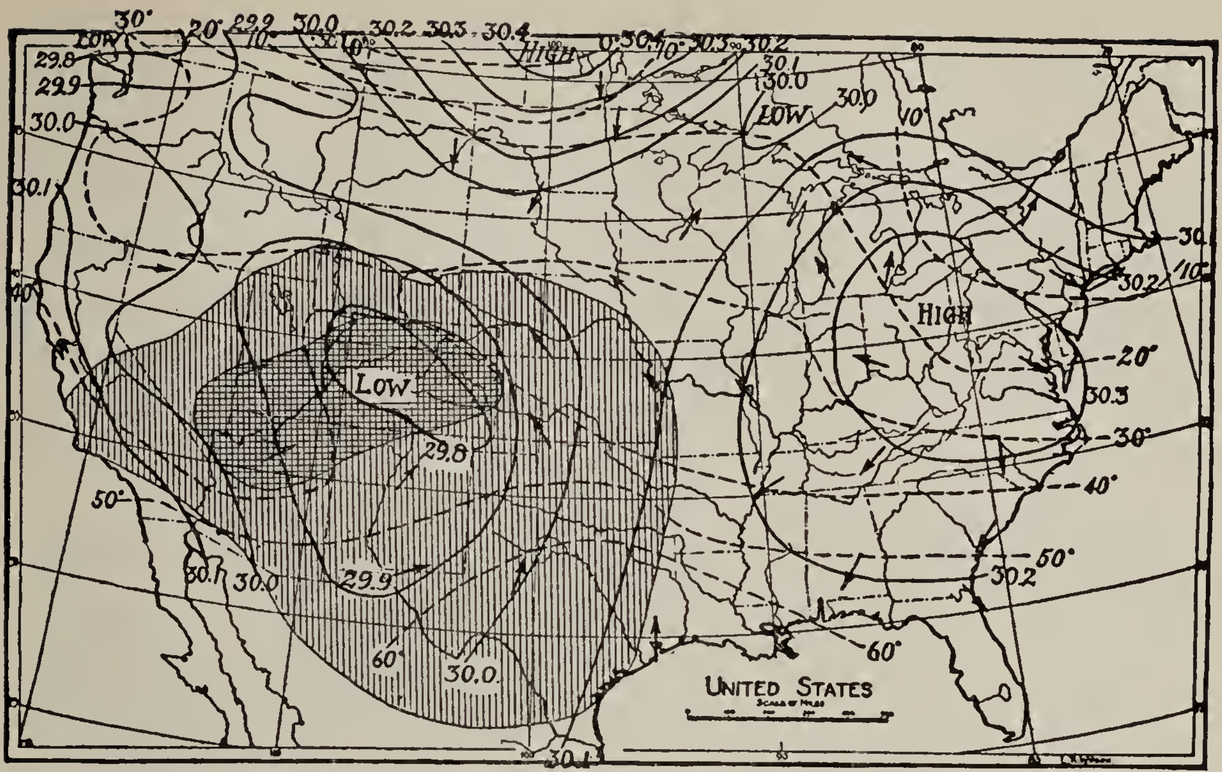


FIG. 148.—Completed weather map of 7 A. M. (Central Time) December 4, 1906. The pressure lines (isobars) and the arrows showing wind direction, are the same as in the preceding chart. The broken lines are isotherms, showing temperature; see degrees at end of line. The single shading shows the cloud sheet around this Low; double shading shows where rain or snow has fallen in last 24 hours. Scattered cirrus clouds usually extend eastward in advance of the cloudy area.

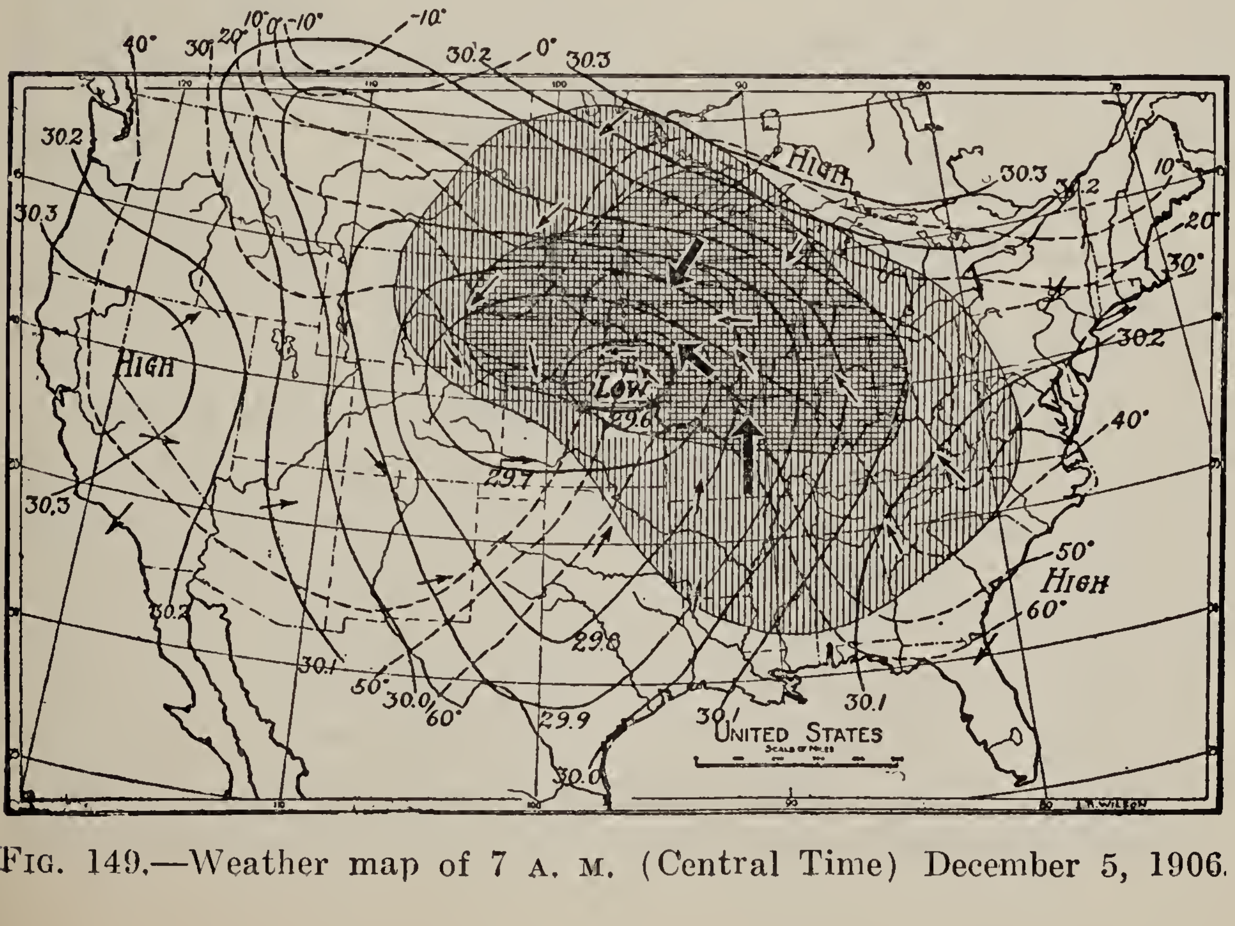


FIG. 149.—Weather map of 7 A. M. (Central Time) December 5, 1906.

cross the country. A study of the following charts will show how.

201. The Weather Map; Pressure and Winds.—Figure 147 shows the barometer readings and the wind directions at a large number of Weather Bureau stations over the United States, at 7 A. M. Central Time, Dec. 4, 1906. The figures at each place give the barometer readings. Each solid line runs through places having the same pressure. That pressure is marked at end of the line. The barometer is lowest over Colorado, and highest over Ohio, Pennsylvania and Virginia and northern Manitoba. In paragraph 152 we learned that the barometer measures the weight, or pressure, of the air. The chart shows that on the morning of December 4th, 1906, the pressure was greater over Ohio than it was over the surrounding region. That greater pressure, or weight, crowded the winds outward away from Ohio, on all sides (the arrows

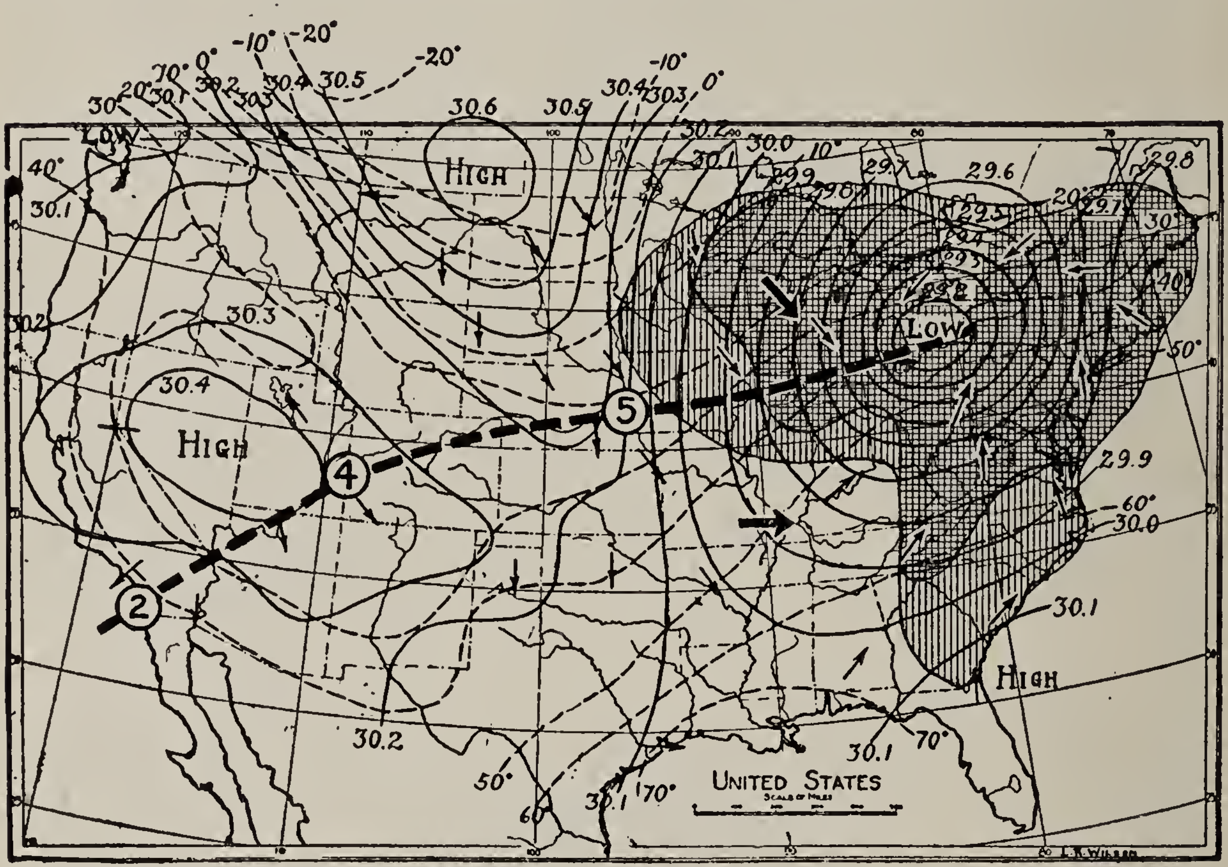


FIG. 150.—Weather map of December 6, 1906. The heavy broken line shows path of the Low; the small circles, its position on successive days.

point or fly with the winds). The same was true over northern Manitoba. (1) *The winds, at the ground, always blow* AWAY *from high pressure.*

Over Colorado the pressure was low. It was higher on all sides of Colorado. That higher pressure surrounding Colorado crowded the winds *towards* Colorado from all sides. (2) *The winds, at the ground, always blow* (*obliquely*) *towards low pressure.* This law is shown more clearly in Figs. 149 and 150, for December 5th and 6th, where the LOW is away from the highlands and the mountains do not interfere so much with the winds.

202. The Weather Map; Clouds and Rain.—Because the winds are crowded toward Colorado from all sides, they cannot escape elsewhere and so are forced upward to higher elevations. As they rise they are cooled. The cooling condenses some of their moisture (see par. 185) into clouds, and later into rain or snow. The single shading (Fig. 147) shows the cloud sheet already developed around this LOW. The double shading shows where rain or snow has begun. (The pupil should carefully review this paragraph and tell why rains develop around a LOW.)

203. The Weather Map; Temperature.—The broken lines on the charts (Figs. 148, 149, 150) are called isotherms. Each line passes through places having the same temperature. The degrees are marked at the ends of the lines. The south winds over Texas are carrying warm air northward. That bends the isotherms to the north a little in that section.

204. The Weather Map; Second Day.—In Figure 149, for 7 A. M., December 5, 1906, the LOW has traveled to near Omaha. The winds blow toward the LOW, to the right of its center but curving to the left around it. The cloud and rain areas are larger than yesterday. The isotherms bend far to the north over Missouri, and far to the southward over the Rocky Mountains.

205. The Weather Map; The Third Day.—In Figure 150, the LOW has reached Lake Ontario. The rain-and-snow area has widened still more. The winds curve towards and around the LOW. The southerly winds carry warm air far northward over the Alleghany Mountains. The northwest winds in the rear carry cold air far southward over the plains and Mississippi Valley. High pressure in the northwest is moving southeastward towards the central states.

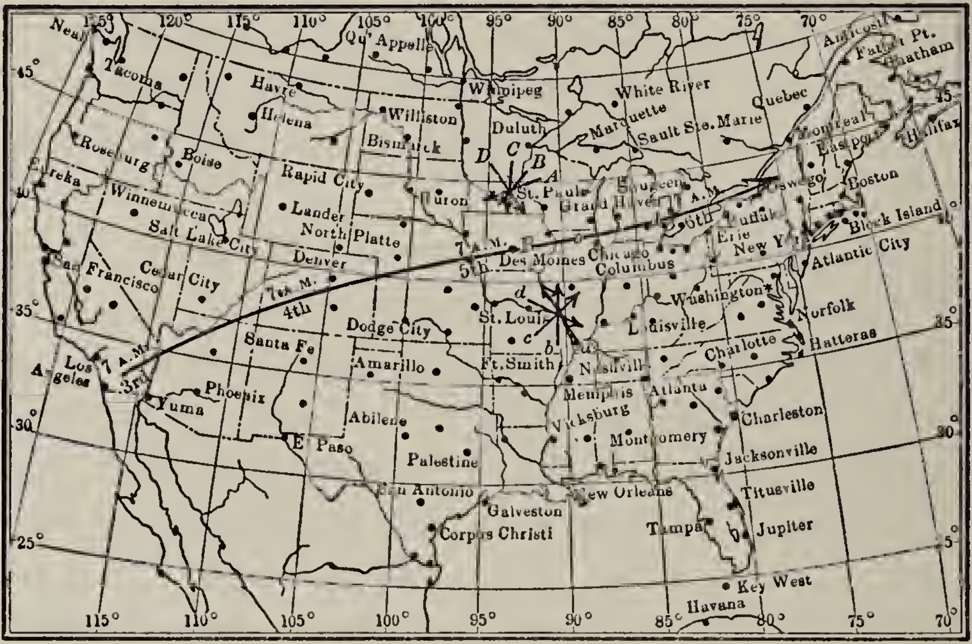


FIG. 151.—Note that the storm center was near Omaha at 7 A. M. of the 5th; and in Southern Ontario at 7 A. M. (Central Time) of the 6th.

At Des Moines, in the path of the storm center, the wind remained steadily in the southeast until the storm center arrived, about 10 A. M. of the 5th, and then changed completely around to the northwest in perhaps an hour or so.

At St. Paul and St. Louis, 250 miles or so on either side of the storm path, the winds changed as follows: When the storm center was at Omaha, St. Louis wind was at arrow "*a*," and St. Paul wind at "*A*" or "*B*." When the storm center reached *B* (at Des Moines), St. Louis wind had shifted to "*b*," and St. Paul to about "*B*." When storm center had reached *c*, St. Louis, wind direction was "*c*," and St. Paul's direction was "*C*." When storm center had reached *d*, the wind had become "*d*" at St. Louis and "*D*" at St. Paul. Thus, while the storm center passed by to north of St Louis, the wind at St. Louis shifted slowly from "*a*" to "*b*," "*c*," "*d*," in about 24 hours. And at St. Paul, while the storm center passed by on the south, St. Paul's wind shifted slowly from "*A*" to "*B*," "*C*," "*D*," in 24 hours. The winds always shift in a similar manner on each side of the path of such a general storm.

206. Watching a Storm Go By; Review.—By looking over the group of charts you will see that this storm caused certain changes in weather at the places over which it passed. Those changes were not alike at all places. They are worth noticing, for all well developed storms cause somewhat similar changes in the regions over which they travel. If we study these we will find many of our storms more interesting to watch.

207. A Passing Storm; How the Winds Changed.—The center of the storm of December 4–6, 1906, passed directly over Des Moines. To see how the winds changed during those two days, both along the path of the storm center and in the regions on either side of the path, see Fig. 151.

Fig. 152.—Cross-section of a storm on December 5th along a line from Omaha to northern New York. The illustration shows a common arrangement of clouds and air movements in the lower few miles of air in such a storm.

208. A Passing Storm; How the Temperature Changed.—The temperature at all three places rose for a day or more after the morning of the 4th, reaching its highest point just before, or about the time, the storm center arrived (midday of 5th); then began to fall again shortly after the center passed, reaching its lowest a day or so later.

209. A Passing Storm; the Pressure Changes.—The barometer fell slowly at all three places while the storm was approaching; reached its lowest reading when the center was nearest; and started to rise again after the center had passed.

The barometer fell lower and faster at points along the storm track than it did at places on either side of the storm path.

210. A Passing Storm; How the Clouds Were Arranged.—Cirrus clouds, from a westerly point, appeared a day or so ahead of this storm. Lower clouds followed; and at length the rain or snow. Fig. 152 shows about how the clouds of that storm would look if we could see a cross section of the storm as we can the sliced end of a layer cake that has been cut. The high clouds in front of a storm cannot always be seen, as lower clouds often hide them from view.

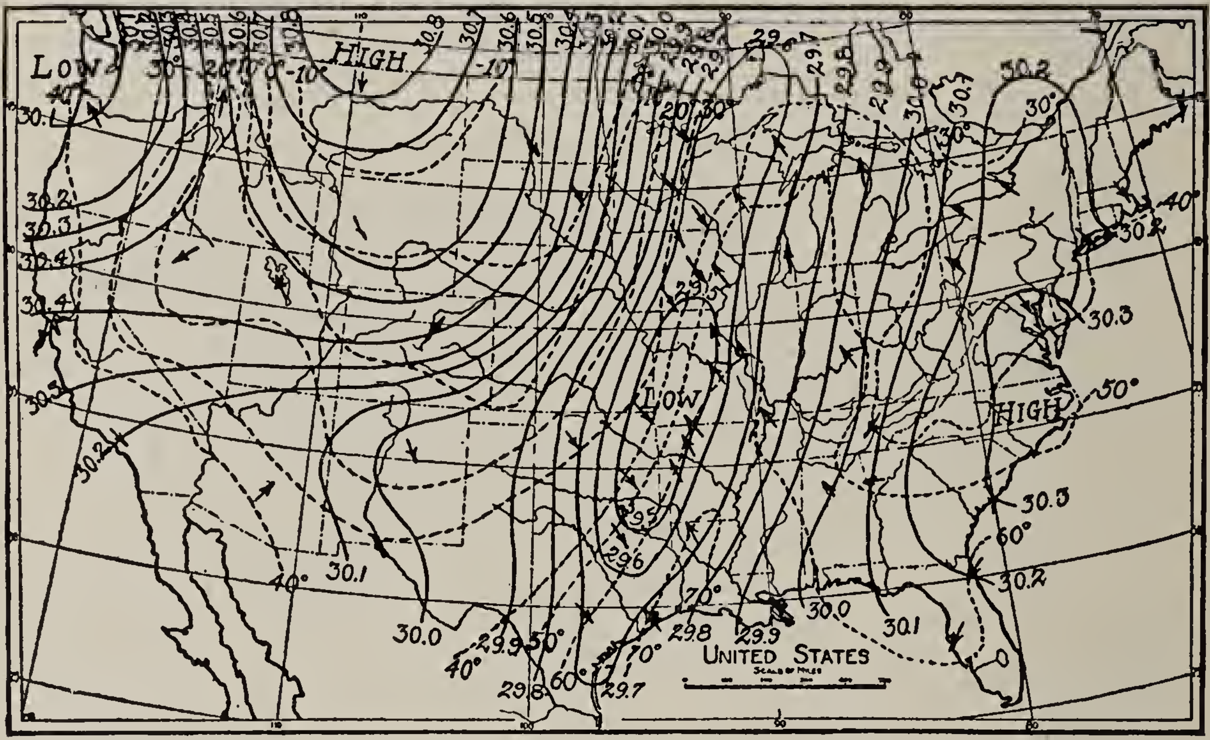


Fig. 153.—The winds of an elliptical Low. Additional arrows have been entered to show winds more clearly. Solid lines are barometer, broken lines are temperature. The center of the Low is a long line or trough; that makes the winds hold nearly the same direction till the center of the Low arrives, and then change rather quickly to nearly the opposite direction.

Pressure Areas in General

The weather changes that occur with storms may be summed up in the following rules, which cover most of the general storms of autumn, winter and spring. Storms in summer are largely of the thunderstorm type. (See Local Storms, p. 178.)

211. Summary of Changes With a Passing Storm (Circular Law).—(1) The barometer falls as the storm center approaches, and rises after the center has passed. (2) The winds blow from easterly or southerly points as the storm center approaches, and change to westerly and northwesterly after the center passes. (a) Along the path of the center, the winds remain steady till the center arrives, and then change quickly as the center passes. (b) South of the storm track the winds shift gradually from southeasterly through southwest to northwesterly. (c) North of the storm track the winds shift gradually from easterly through north to northwest. The winds blow spirally towards the center, curving around it toward the left (in N. Hemisphere).

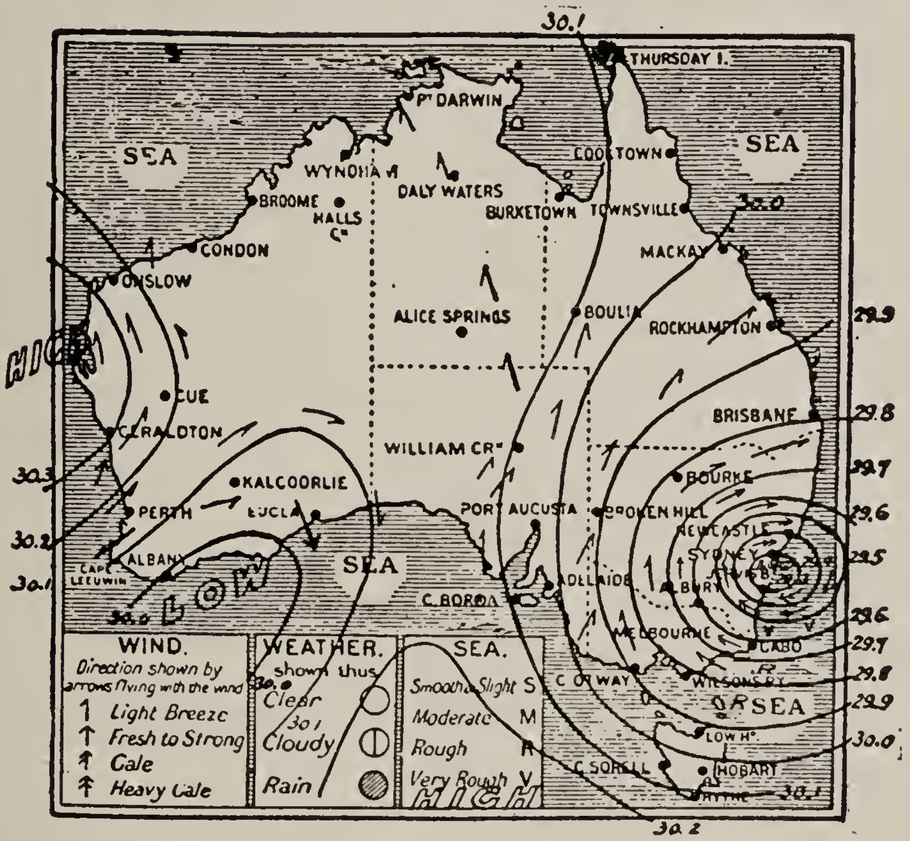


FIG. 154.—A Low in the southern hemisphere has a clockwise whirl. (David J. Mares in *Monthly Weather Review.*)

(3) The air about the middle of a LOW is being crowded upward. That usually causes the development of clouds, and of rain or snow.

(4) The temperature rises as the LOW approaches, and falls after the center has passed. (Remember that a rise in temperature does not always mean that a storm is coming; but

when such a storm is approaching the temperature will rise in its front half.)

(5) If the LOW is not circular in form these changes will be somewhat different.

212. Weather Changes Attending the Passing of a High Pressure Area.—In the same manner, the study of the HIGHS in Figs. 147 and 154 shows the following rules regarding weather changes during the approach and passing of a high pressure area.

(1) The barometer rises as a HIGH approaches, and falls after the center of the HIGH has passed.

(2) (a) The winds in the front half of a HIGH blow from points between north and west. (b) In the center of the HIGH the wind is light and changeable. (c) In the rear portion of a HIGH the winds blow from points between east and south. The winds blow spirally outward and *away* from the center of a HIGH, curving somewhat to the right. The air in and near the center of a HIGH is settling downward. That tends to evaporate clouds and clear the sky.

(3) The temperature falls in the front portion of a HIGH, and rises after the center has passed.

Exercise 46.—Study of Passing Storms

After learning these rules, the class should watch the daily weather maps, and your own local weather, daily for at least a month, to see how these rules apply. No two storms or high pressure areas are exactly alike in all respects. You must watch the weather and the maps a while to know how to use the rules.

213. Lows and Highs of the Southern Hemisphere; Winds Curve the Other Way.—The southern hemisphere has LOWS and HIGHS much like those of the northern hemisphere. But in the southern hemisphere the winds curve in the opposite direction (Fig. 154). At the west side of the same chart is an Australian HIGH pressure area. Compare its winds with those of a HIGH in the United States.

214. Average Paths and Speed of Lows and Highs in the United States.—The LOWS and HIGHS of the temperate zones move eastward. Those of the United States pursue a great variety of paths. (See Figs. 156 and 157; the wider the paths, the more they are followed.) In Fig. 155 the broken lines running nearly north and south show the average speed per day of American LOWS and HIGHS. The actual speed of a single LOW or HIGH varies from about 1200 miles per day, down to nothing when an occasional storm stands still for a day or more.

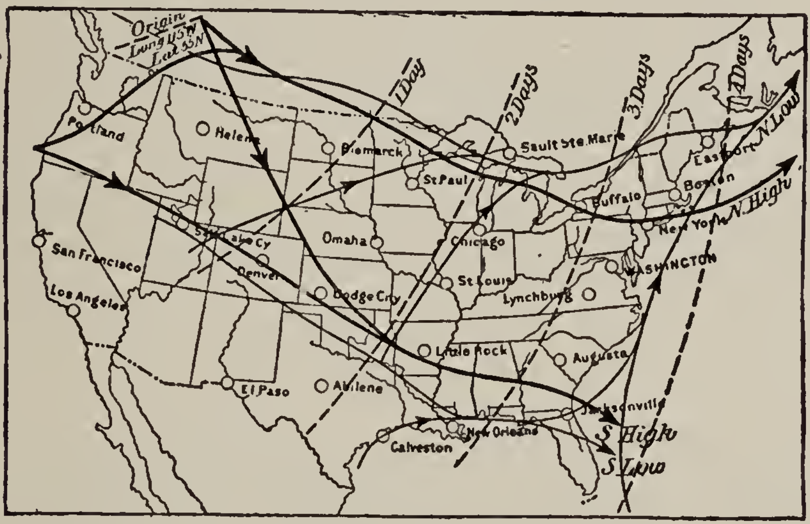


FIG. 155.—Average paths and average daily movement of Lows and Highs. Heavy lines, average paths of Highs. Lighter lines, average paths of Lows.

(*U. S. Weather Bureau.*)

Exercise 47.—Plotting the Paths of Highs and Lows

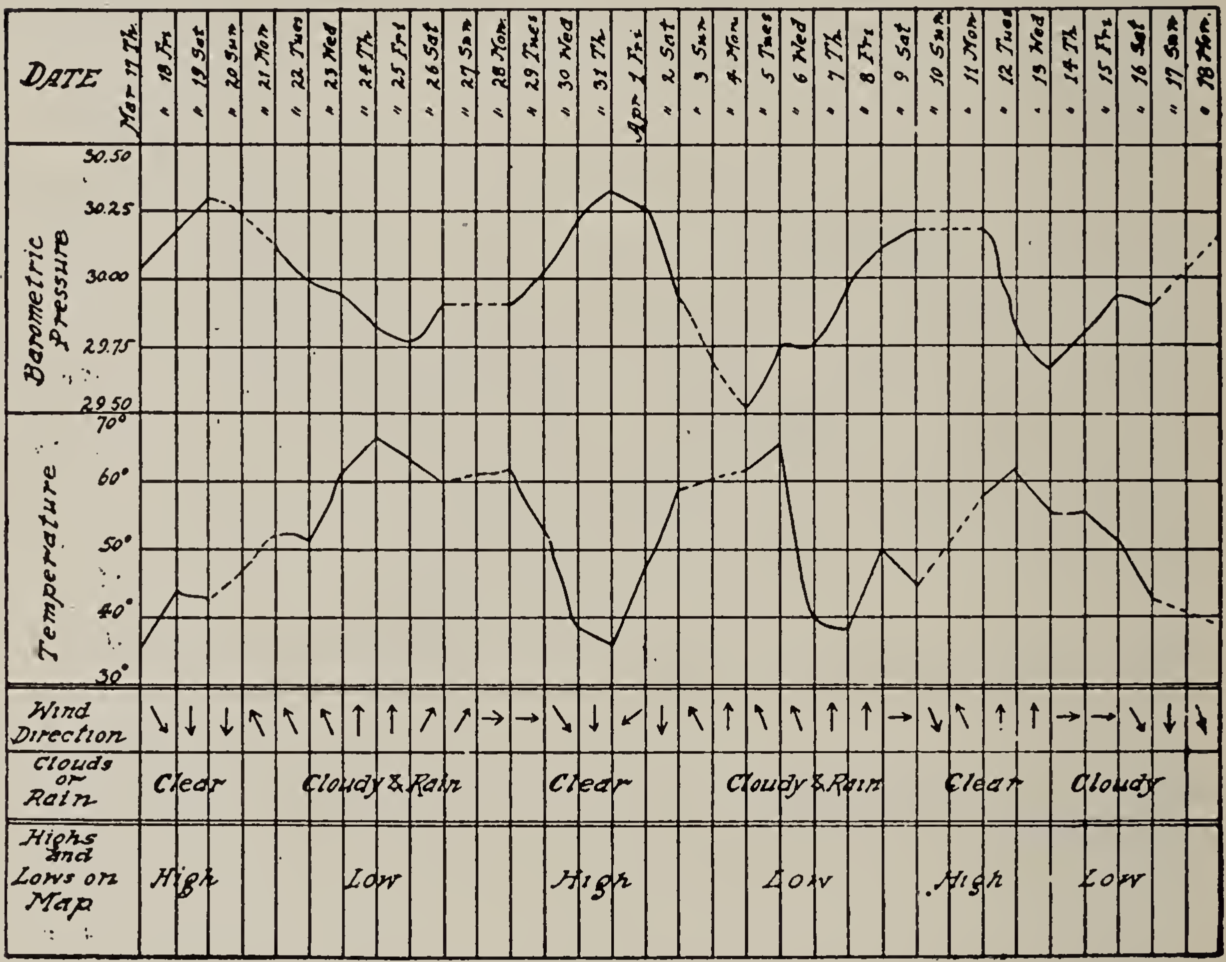
Obtain the weather maps for an entire *winter* month, from a Weather Bureau station. Note the position of the center of the LOW on the first map. Take a blank map of the same kind; make on it a very small circle marking that position of the center of the LOW. Make a circle for the 2nd day, the 3rd, and so on. Connect these small circles by a line. That line shows approximately the path that LOW traveled across the country. Number the path of this first LOW "1." Mark the paths of all other LOWS that appear during the month, numbering them in the order of their coming.

To show the paths of the HIGHS, make a small "x" for the position of the center each day. Number the paths I, II, III, etc., in the order of their occurrence. If convenient, use a different color of pencil for the paths of HIGHS.

Often there is more than one HIGH or LOW on the same day's map. Remember that the paths for that particular month may not be the average paths for that season of the year. Plot the paths for another month if you have time.

The usual or prevailing paths differ with the season of the year.

(Find how many miles per day the LOWS and the HIGHS move; how many miles per hour. Remember that is not the speed of the WIND; it is the rate of progress of the whole system of winds in the LOW or the HIGH.)



Weather chart.

Exercise 48.—Making a Chart of a Month's Weather

Make a chart, like above, showing the weather of your locality for one month, using your class record of the weather. The weather observations should be made as near the same hour each day as possible.

From watching the daily weather maps, and from the preparation of these exercises, it will be clear that most of our daily weather is controlled by the passing LOWS and HIGHS.

215. Lows and Highs; Unusual Paths, the Cause of Unusual Weather.—Whenever a period of unusually dry or hot or wet or cold weather occurs it is generally because the LOWS and HIGHS have kept traveling in unusual paths.

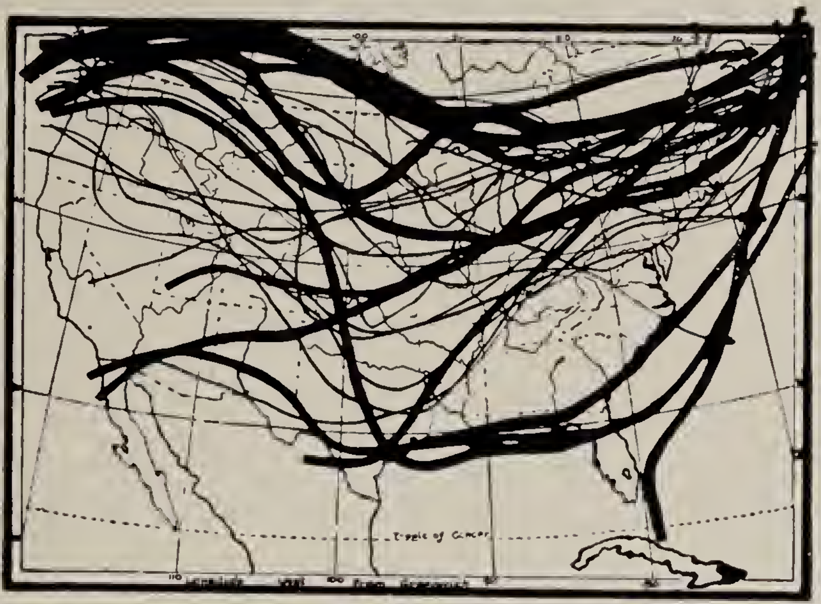


FIG. 156.—1160 Lows classified, showing 27 paths. The wider the path the more it was followed.

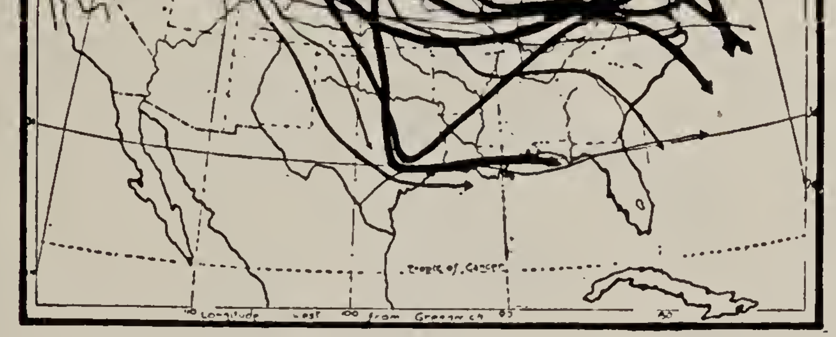


FIG. 157.—928 Highs classified, showing 21 paths. The wider the path the more it was followed.

November, 1909, was very warm and wet over much of the Mississippi Valley. Note in Fig. 158 the average paths of LOWS in autumn. Fig. 159 gives the paths for November, 1909. Notice that most of the LOWS in that month traveled

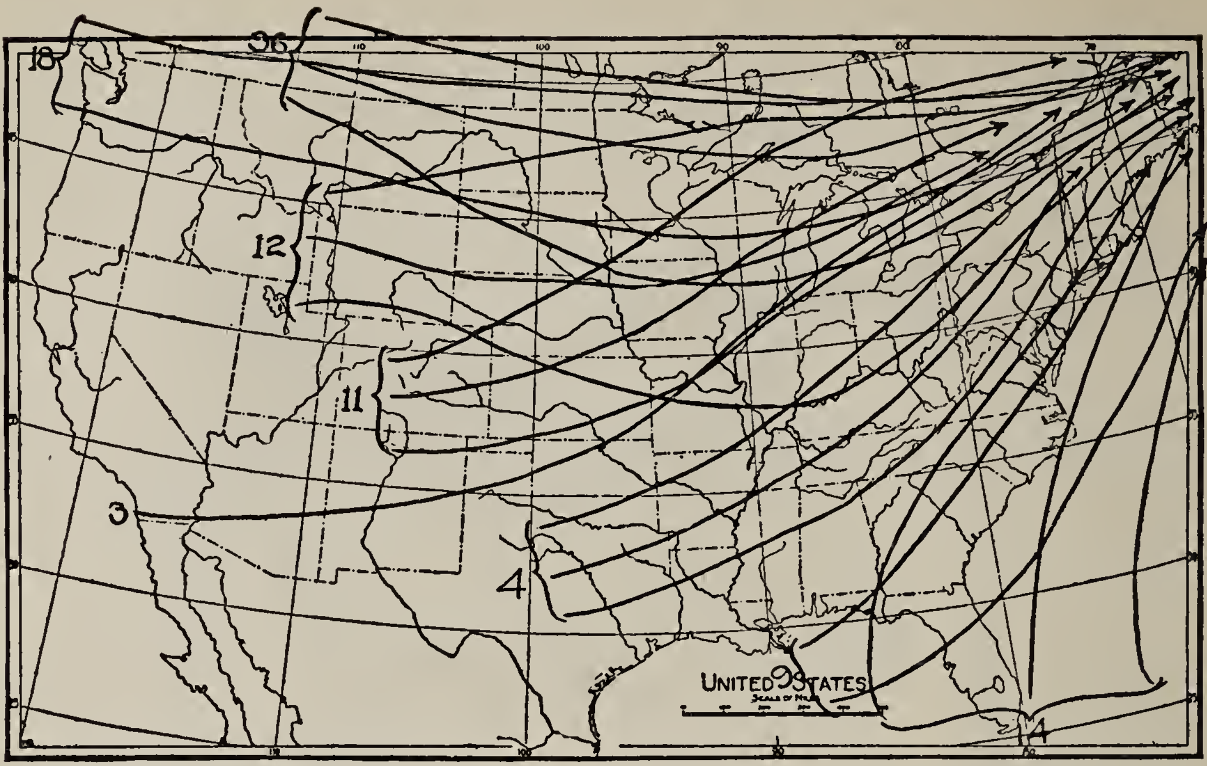


FIG. 158.—Paths of Lows in an autumn month (10 years). Note the scattered distribution. Half the total number are near the northern border. Compare with Fig. 159, paths for November, 1909.

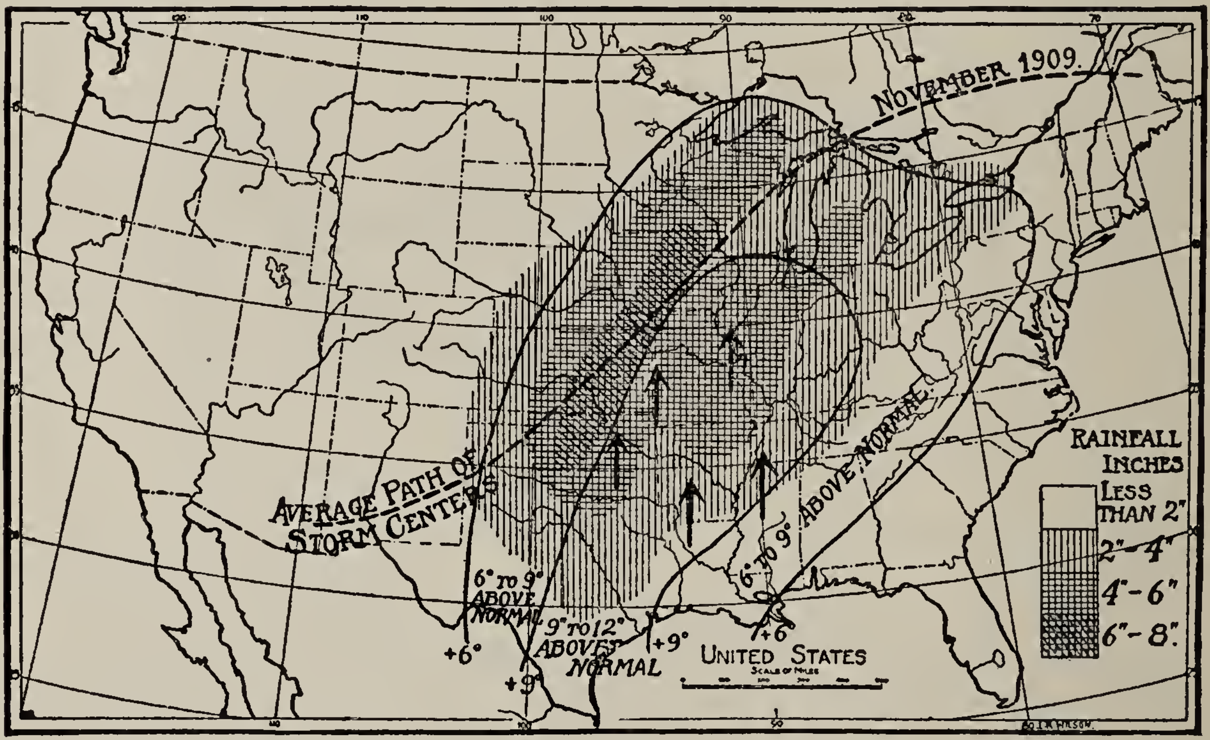


FIG. 159.—One cause of periods of unusual weather; paths of Lows, November, 1909. Most of the Lows traveled from Oklahoma or Kansas across Iowa and Wisconsin. Heavy broken line shows average path. The heavy rainfall, prevailing southerly winds, and warm temperature, thus caused over the Mississippi Valley. Shading shows rainfall, inches. Solid black lines, temperature above normal. Arrows show prevailing winds.

northeastward over Oklahoma, Iowa and Wisconsin. Therefore most of their rain fell where shown by the shading in Fig. 159. Also, while the LOWS were moving along those paths, the southerly winds in the east half of every LOW were carrying warm temperature northward over the Mississippi Valley. That made the month average 6° to 9° warmer than usual in that region, as shown by the isotherms.

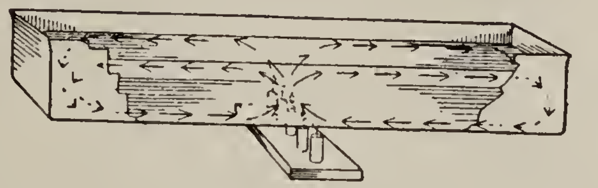


FIG 160.—Illustrates circulation of atmosphere. Middle of pan, equatorial regions; ends are temperate zones.

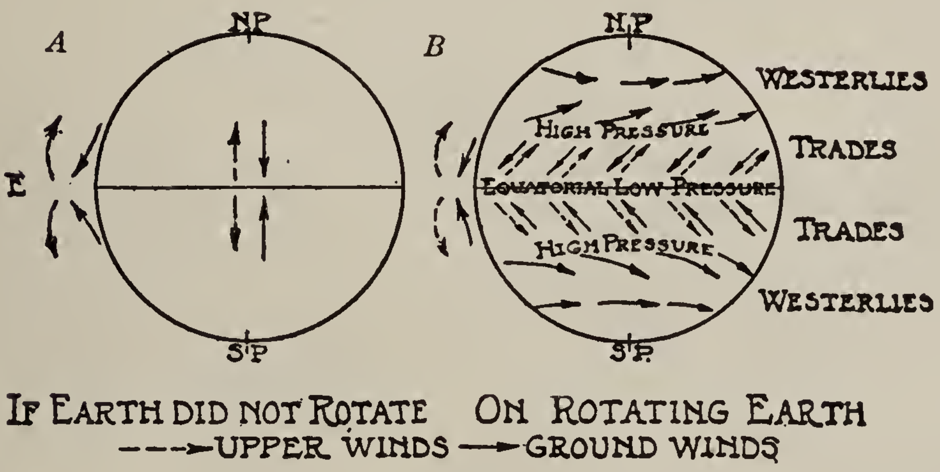


FIG. 161.—Principal features of the general circulation of the atmosphere. *A*. If the earth did not rotate, the winds would blow *straight north* or *south* towards the equator or away from the equator. *B*. As it is on the rotating earth.

VII. GENERAL CIRCULATION OF THE ATMOSPHERE

216. The General Circulation of Atmosphere.—The general circulation of earth's atmosphere is caused by the greater heat received at the equator from the sun. The heat warms the air most near the equator. The warm air is then lighter, and the colder air crowds in under it, toward the equator, on either side. That soon sets up movements in the whole atmosphere something like those shown in the water pan,

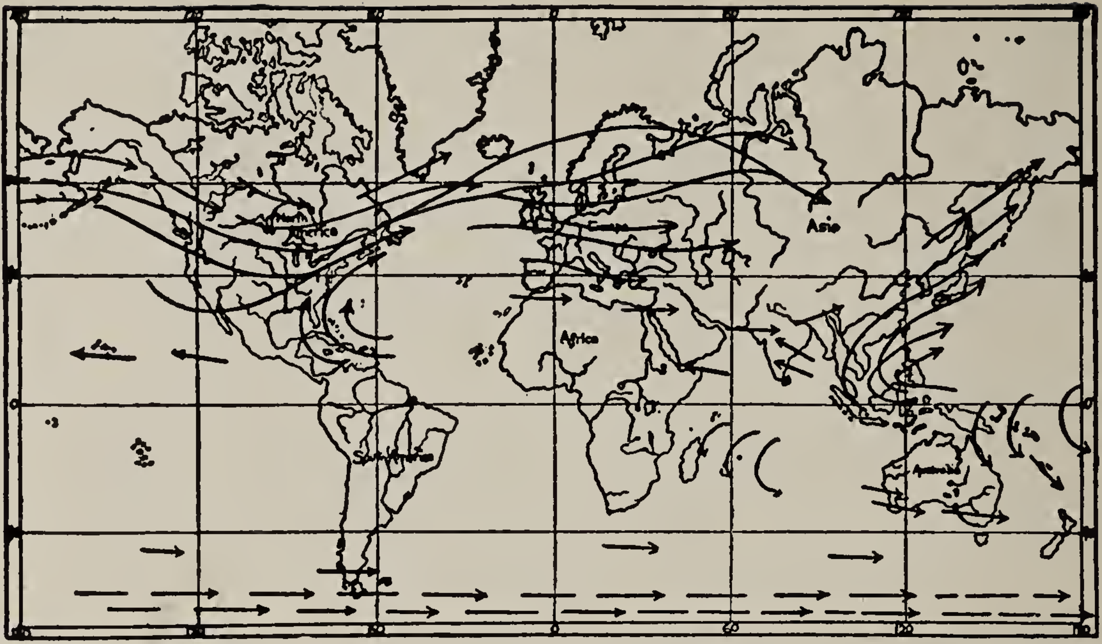


FIG. 162.—Principal paths of Lows of the world (Approximate). Lows of South Temperate zone not charted. Lows in the tropics occur in late summer and autumn; in temperate zones, at all seasons.

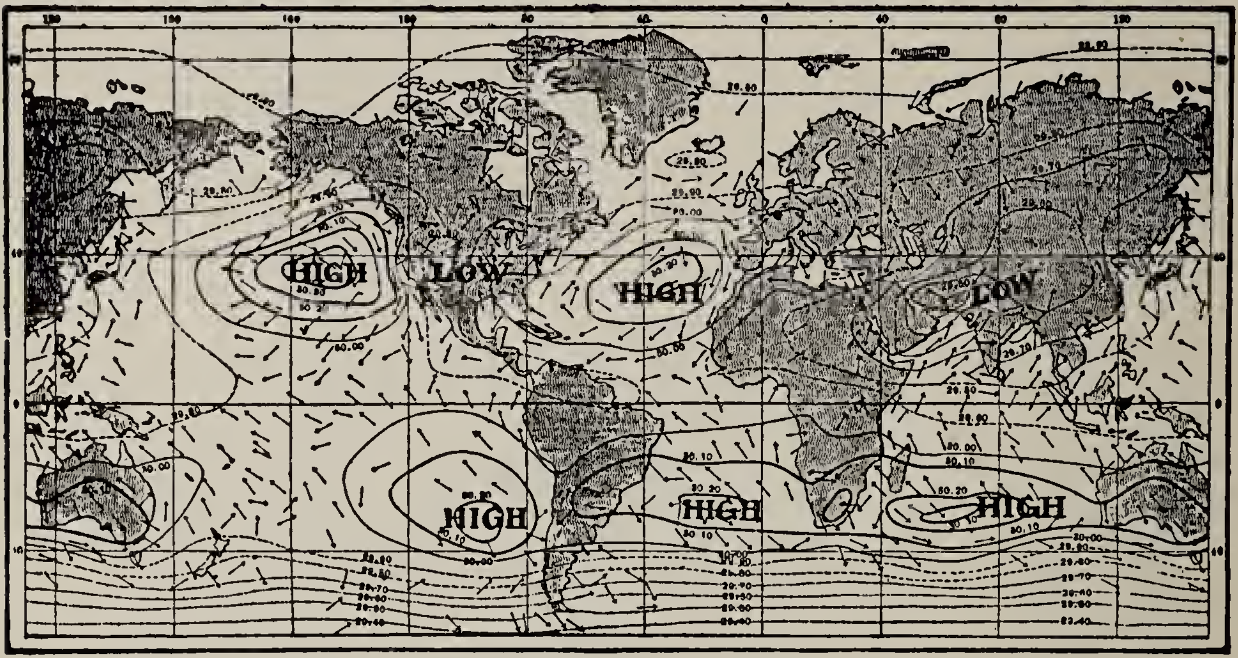


FIG. 163.—Pressure and prevailing winds of the globe for July. High pressure over oceans, low pressure over continents. Winds blowing inland.

Fig. 160. In that pan the middle is the equator, and the ends are the poles. The bottom of the pan is straight, but the same movements would occur on the earth's surface. If the earth did not rotate on its axis, the lower winds on either side would blow straight towards the equator, and the

upper winds would blow straight away from the equator (as in "*A*," Fig. 161). But the rotation of the earth turns all the winds toward the right in the north hemisphere, and toward the left in the southern, as in "*B*," Fig. 161. The rotation of Earth is also what causes the winds of LOWS and HIGHS to slant obliquely as we have seen (Art. 201 and Fig. 148). The warm equator and the rotation of the earth are thus the chief causes of Earth's wind system.

217. The Weather in Different Zones of the General Wind System.—

(1) In the belt of EQUATORIAL CALMS the weather is hot and moist, with light variable winds and frequent heavy showers that are often accompanied by wind squalls. There are no general storms.

(2) In the TRADE WIND ZONE the winds are moderate to fresh, and are remarkably steady, in direction and force. Showers fall about the islands and along windward coasts. General storms occur only in late summer and early autumn. Those general storms are called HURRICANES in the West Indies, CYCLONES in the Indian Ocean, TYPHOONS off southeast Asia, and BAGUIOS in the Philippine Islands. This class of storm is usually 300 to 500 miles or more in diameter, with strong or violent winds that nearly circle about the storm center and blow sometimes 100 miles or more per hour. After traveling westward in the trade winds, the storm usually curves out into the temperate zone and turns eastward, at the same time gradually becoming broader and less violent. West India hurricanes occasionally visit the Atlantic coast of the United States. Sometimes they enter the Gulf of Mexico and pass northward over the Mississippi or Ohio Valleys. Such storms damaged Galveston, Texas, in September, 1900, and August, 1915, and the city of New Orleans in September, 1915.

(3) The WESTERLY AIR CURRENTS of the temperate zones are full of broad waves or surges of unequal pressure. These waves are the HIGHS and LOWS of the weather map, which

control the weather of the temperate zones in the ways we have studied. Fig. 162 shows the usual paths of the LOWS (storms) in various portions of the earth.

218. Effects of the Sun's Annual Migration.—The yearly shift, or migration, of the sun north and south of the equator, from summer to winter, and back, affects the weather of a few portions of the earth in an interesting way. In summer the land warms more than water. That warms and expands the lower air most over the land. This expansion lifts the upper air over the land higher than that over the oceans. That in turn causes some of the upper air to run off the land out over the ocean. This leaves less air, and therefore less pressure, over the land, and adds more air, and therefore more pressure, over the oceans. This greater pressure over the oceans (Fig. 163) crowds the bottom air toward the land, so the prevailing winds at the ground blow inland in summer. The most notable winds of this sort are the monsoons of India, that carry heavy summer rains to the northern interior of that country. In the United States, the prevailing

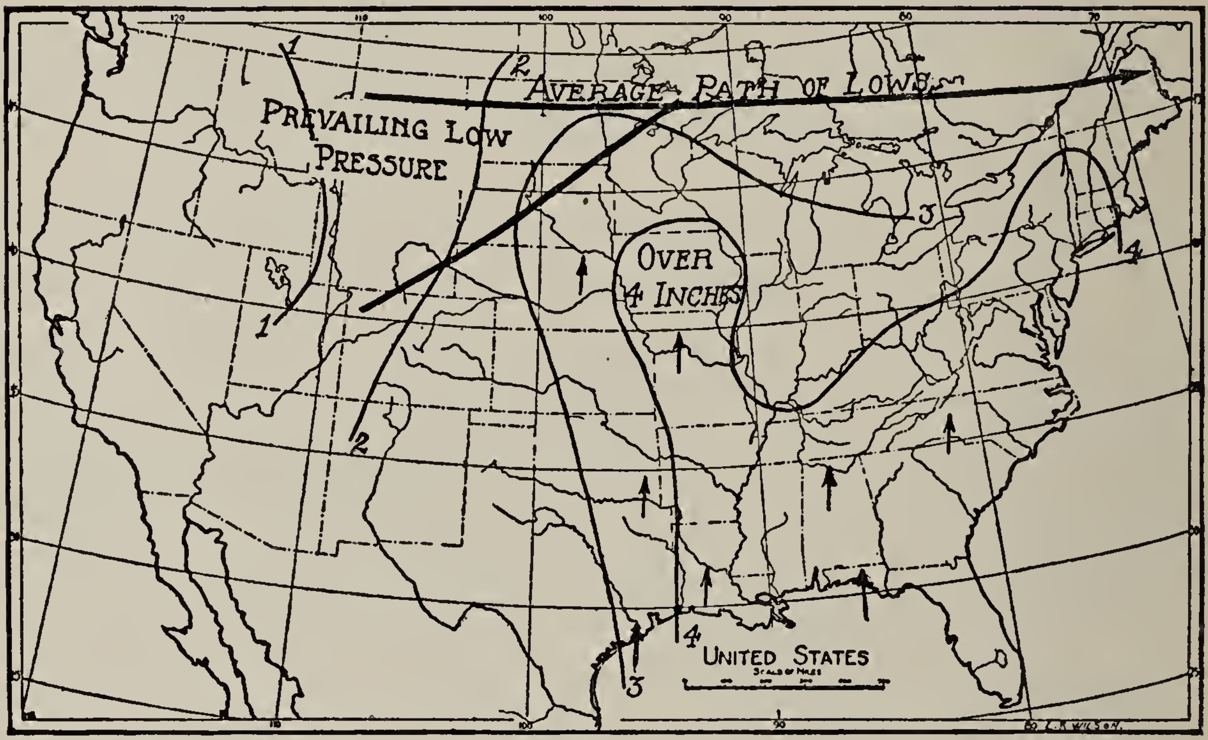


FIG. 164.—A summer month. Low pressure in interior. Storm tracks far to north. Prevailing southerly winds. Rain distributed far inland.

south winds of summer over the Mississippi Valley are caused in the same way. They are of great benefit, as they carry moisture from the Gulf and Atlantic far northward to supply

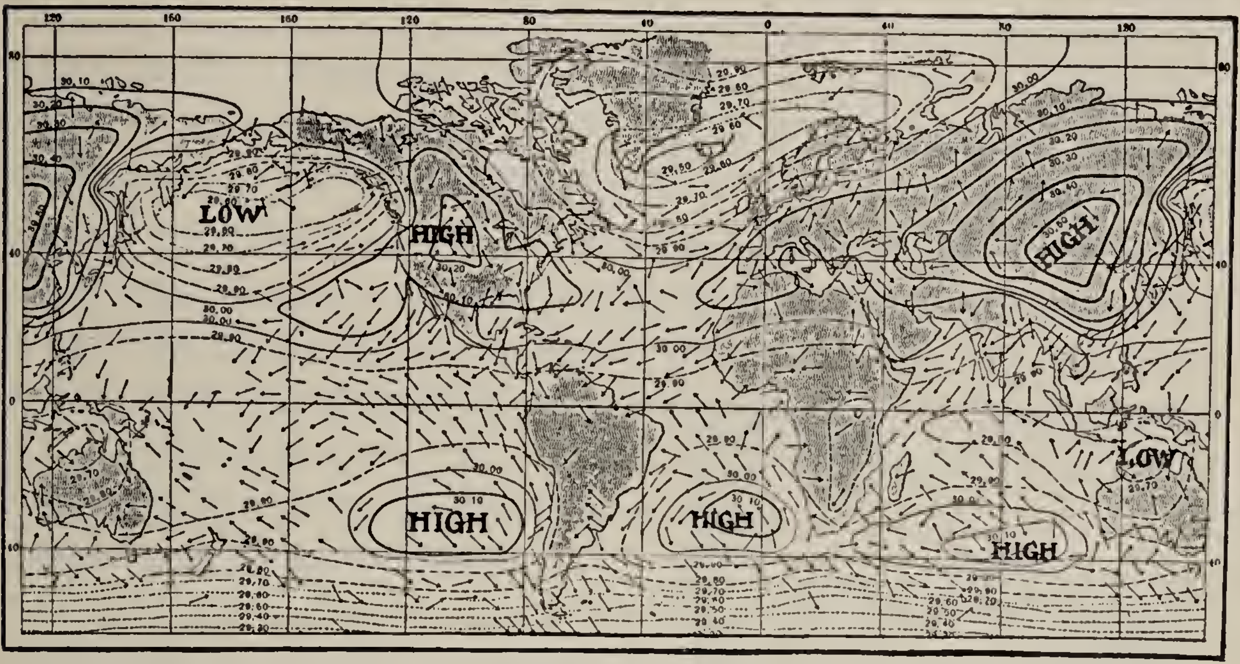


FIG. 165.—Pressure and prevailing winds of the globe for January. High pressure over lands, low pressure over oceans. Winds blow seaward.

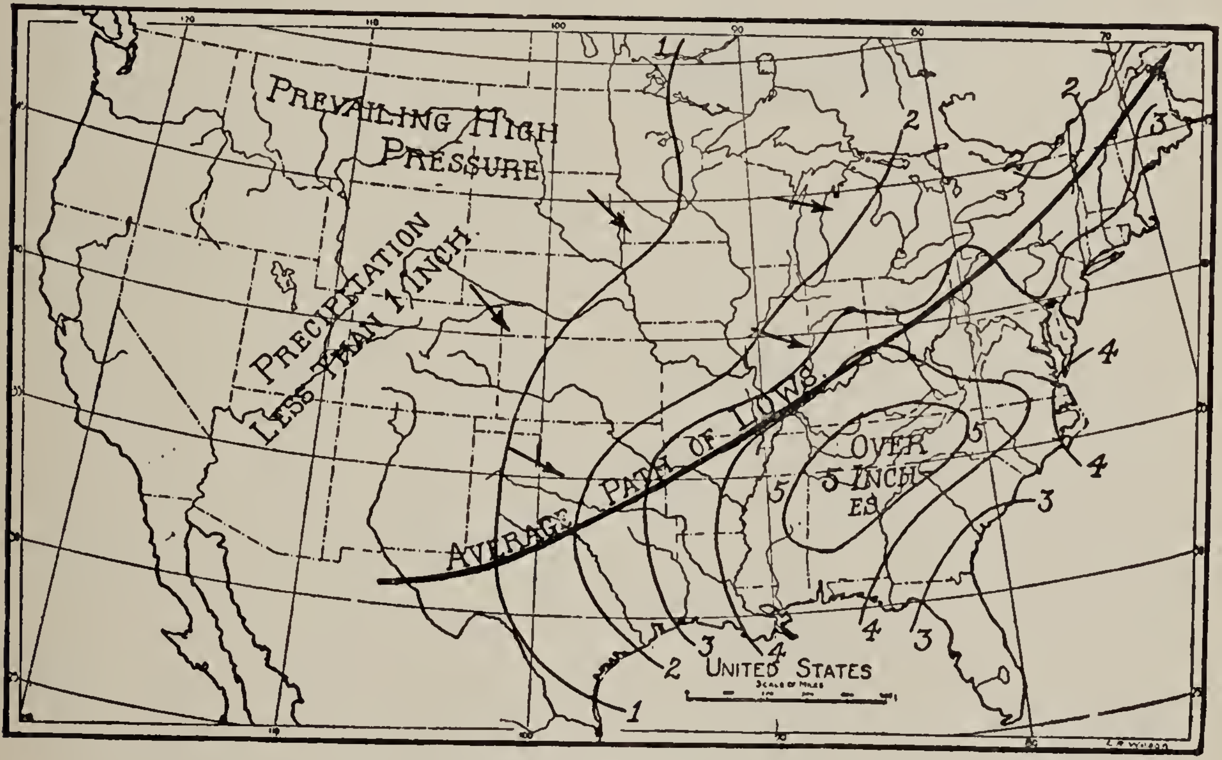


FIG. 166.—A winter month.

1. High pressure in interior.
2. Storm tracks farther south and southeast.
3. Prevailing northwesterly winds.
4. Rain or snow distributed mostly in southeast portion.

the summer showers of the Missouri Valley (Fig. 164). But for these winds, much of the corn and wheat belt of the plains and north-central states would be too dry for successful farming.

In winter, the land cools more than the ocean. That makes the lower air coldest over the land. This colder air fills less room than it did before. That lets the upper air settle down lowest over the land and permits upper air to run in upon it from over the ocean. That in turn leaves less air and lower pressure over the ocean and brings more air and higher pressure to the land. This higher pressure over the land (Figs. 165 and 166) crowds the bottom air outward toward the oceans, in winter. That gives prevailing northwesterly winds and much fair cold weather to our northern plains and upper Mississippi Valley, during the winter months. Similar outflowing winds occur on all continents in winter, except where other conditions may interfere.

CHAPTER IV

THE SEASONS—CLIMATE AND HEALTH

I. THE SUN—THE CAUSE OF THE SEASONS

219. The Sun's Altitude and Its Heating Effect.—The height of the sun above the horizon at noon is different for every different latitude upon any given day. It also is different for any given latitude upon different days of the year. The earth receives all its heat from the sun. We shall soon see that the nearer the sun is to being at the zenith (the point directly overhead), the greater is its heating power. *Therefore, the changing altitude of the sun is one of the principal causes of seasons.*

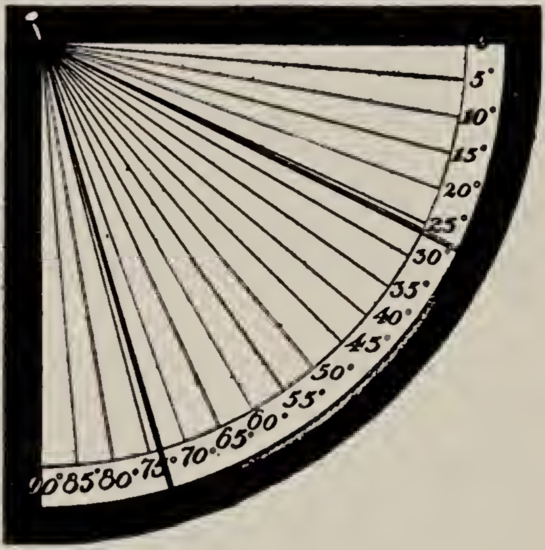


FIG. 167.

Exercise 49.—To Construct a Clinometer and to Measure the Altitude of the Sun

(a) On a piece of cardboard about 20 in. square, mark out the quarter of a circle as shown in Fig. 167. To do so, make a small loop at the end of a piece of wrapping twine. Slip a pencil point through this loop. Place one finger tightly upon the string so as to make the radius exactly 20 in. Draw the arc of the circle from 0° to 90°. Next mark off the scale by dividing the distance from 0° to 90° into eighteen equal parts. Each space will then represent 5°. If the radius is exactly 20 in., the distance from 0° to 90° around the arc is $\frac{1}{4}$ of $2 \times 20 \times 3.14$ in., or 31.4 in. Each of the eighteen equal parts will then be a trifle less than $1\frac{3}{4}$ in. These 5° spaces may then easily be divided into five equal spaces, thus marking off degrees.

(b) Tack this cardboard scale to a board about 2 ft. square. Drive a nail into the board at the center of the circle. Bore a hole in the board near its upper edge and in the center from right to left. Hang this instrument on the east side of the house where the sun can strike it at noon.

NOTE.—If the instrument is to hang on the west side of the house make the scale by beginning with 0° in the upper left-hand corner. If the laboratory or school room has a south window it is most convenient to mount the clinometer just inside the window. The students can then observe the altitude of the sun more easily and more frequently.

(c) See that the clinometer hangs in a north and south line, and that no trees or buildings prevent the sun's striking it at noon. At 12 o'clock one day each week, note where the shadow of the nail falls across the scale. Read and record with date the angle made by the nail's shadow with the 0° line. This angle is equal to the angular altitude of the sun above the horizon. Explain why. After making several readings, state what you have discovered.

220. Effect of the Sun's Altitude upon Its Heating Power.—In all portions of the United States the sun's rays are much more nearly vertical in summer than in winter. Throughout the United States the sun is at its highest altitude and its rays are most nearly vertical on June 21; it has its lowest altitude and the rays are most slanting on December 22. The highest and lowest altitude of the sun's rays vary with the latitude. At latitude 40°, which is about the latitude of Philadelphia, Columbus, Ohio, Springfield, Ill., and Denver, Colo., the highest altitude of the sun is 73½° and the lowest, 26½°.

Exercise 50.—To Measure the Length of Shadow When the Sun Is at a Known Altitude

Place a table or desk having a level top before a south window. Cut out a piece of cardboard just 1 ft. square. At 12 o'clock, noon, on a clear day read the sun's altitude from the clinometer. Then set the cardboard on edge in an east-and-west line on the table before the window (Fig. 168). Lean the top of cardboard toward the north till it exactly faces the sun. The cardboard will then form an angle with the table top which equals 90° minus the altitude of the sun.

Its shadow now falls upon the table top. Carefully measure and record the length of the shadow. Is the length of the shadow more or less than 1 ft.? How many square feet in the shadow on the table top?

If the sun were not so high in the sky, would the shadow then be longer or shorter than you find it to be? Would the area of the shadow be greater or less?

If the sun were higher in the sky, what would then be true?

How does the altitude of the sun affect the length and area of the shadow?

Do you see that if it were not for the cardboard 1 ft. square, or 1 sq. ft. in area, the sun's rays would fall upon that portion of the table top which is covered by the shadow?

Would the energy in 1 sq. ft. of sun's rays fall upon a larger or smaller area of table top if the sun were at a lower altitude?

What would be true if the sun were at a higher altitude?

When 1 sq. ft. of the sun's rays is spread over a large area, is that area heated more or less than when the rays are spread over a small area?

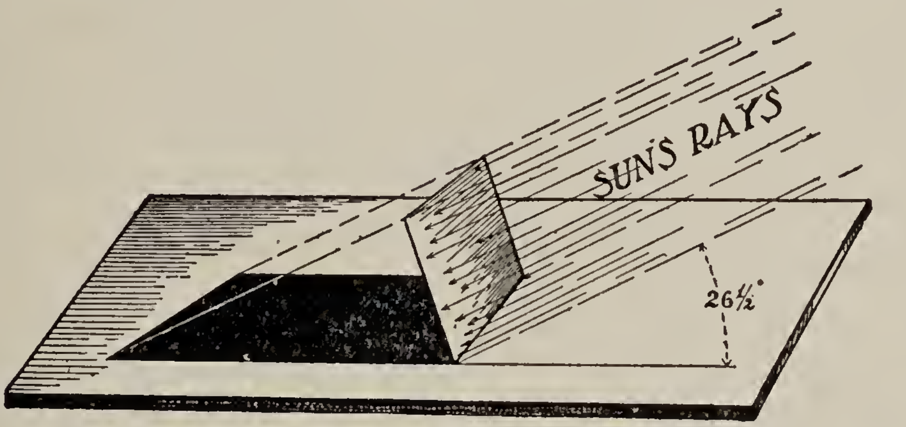


Fig. 168.—Measuring the board's shadow on December 22, at latitude 40°, North.

221. How the Sun's Heating Power Changes with Seasons and Latitude.—Since, at latitude 40°, the highest altitude of the sun is 73½° and its lowest altitude is 26½°, it is easy to show the area of the earth's surface over which 1 sq. ft. of sun's energy is distributed at the SUMMER SOLSTICE and at the WINTER SOLSTICE. In Fig. 169 the horizontal line represents the earth's surface. Two parallel lines, 1 centimeter apart, and cutting the horizontal line at an angle of 73½°, are drawn to represent the sun's rays June 21 and the two parallel lines also 1 centimeter apart, but cutting the horizontal line at an angle of 26½° represent the sun's rays December 22. It is evident from this figure that the sq. ft. of sun's rays is spread over just about twice as large an amount of earth's surface on December 22 as on June 21. It follows that the sun will heat the earth's surface but one-half as much on December 22 as it will on June 21.

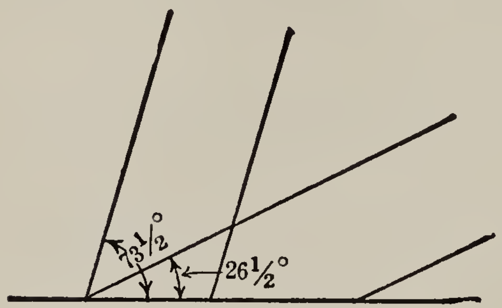


FIG. 169.—Slant of sun's rays at 40° latitude, June 21 and December 22.

In a like manner Fig. 170 shows how the area of earth's surface upon which 1 sq. ft. of sun's energy falls varies at latitude 49°, the north boundary line of the United States. On June 21, the altitude of the sun at noon at 49° north latitude is 64½°; on December 22, it is but 17½°. In Fig. 170 the two parallel lines are therefore drawn at angles of 64½° and 17½° to the horizontal. By measuring the distances between the two pairs of parallel lines it is seen that the 1 sq. ft. of sun's energy is spread over about three times as much of the earth's surface on December 22 as on June 21.

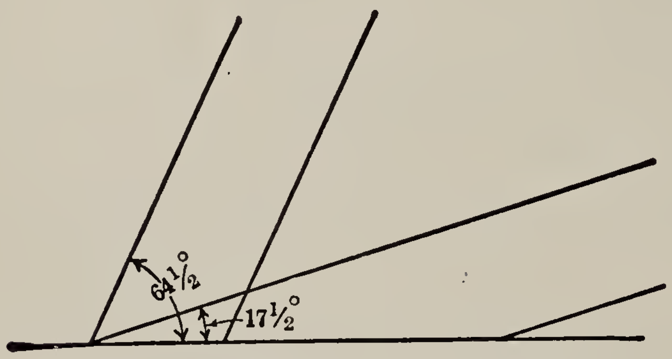


FIG. 170.—Slant of sun's rays at latitude 49° on June 21 and December 22.

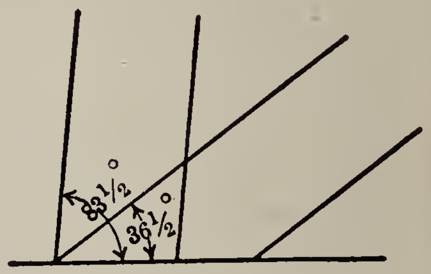


FIG. 171.—Slant of sun's rays at latitude 30° on June 21 and December 22.

Therefore, at north boundary of the United States the sun heats the earth's surface but about ⅓ as much at noon on December 22 as it does at noon on June 21.

In the same way Fig. 171 shows how the heating power of the sun varies at latitude 30°, approximately the south boundary of the United States. The altitude of the sun at noon, at 30° north latitude on June 21 is 83½°, and at noon on December 22, it is 36½°. It is seen from the figure that the sun's rays spread over about 1½ times as large an area of earth's surface in the winter solstice as at the summer solstice.

From these facts would you expect the greater difference in temperature between summer and winter in North Dakota or in Texas?

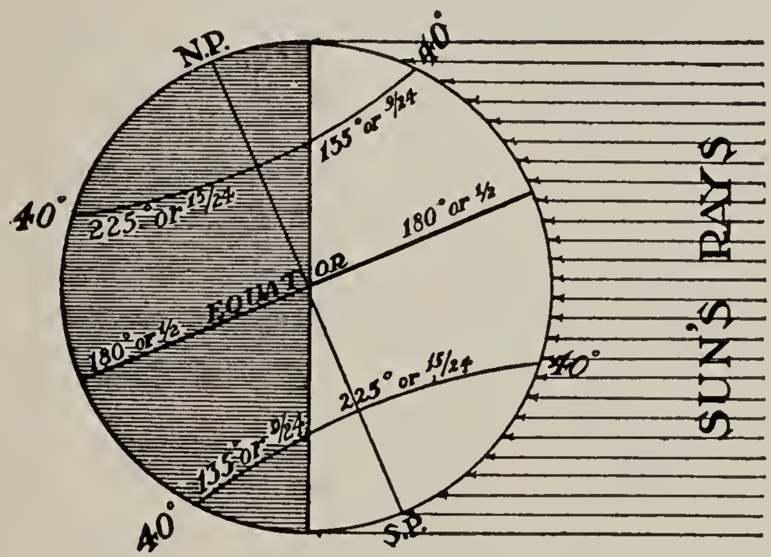


FIG. 172.—The length of day.

222. Length of Day and Its Effect upon the Heating Power of the Sun.—The days and nights are always equal in length at the equator, 12 hours each. The poles of the earth have six months day and six months night. Between the equator and the poles, the length of day and night is constantly changing. At latitude 40° north, the days vary in length from about nine hours on December 22 to 15 hours on June 21. The farther north we go the longer the summer day becomes till we reach the north pole when the day is six months in length. Just why this is so is easily shown by experiment.

Exercise 51.—To Show Why the Length of Day Varies at Different Places on the Earth's Surface

(*a*) Use an orange or a small schoolroom globe for this experiment, and perform it in the evening or in a darkened room. Place a lighted lamp upon the table and hold the orange a few feet from it. If you use an orange, let the stem and the bloom scars of the orange be the two poles and draw a line about the orange to represent the equator. Let the north pole be tilted toward the lamp 23½°. Now note as carefully as possible the position of the dividing line between the lighted and unlighted surfaces of the sphere. Draw a pencil line around the sphere to mark this line. If we now mark the 40th parallel of latitude on the sphere, we shall find that about 15/24 of it was lighted. This means that, if we rotate the sphere upon its axis, that any point upon the 40th parallel would be in the light during 15/24 of a rotation. Therefore, the day at the 40th parallel is 15 hours in length on June 21, or at the SUMMER SOLSTICE. At this same time the pole is constantly in the light, and just ½ of the equator is lighted.

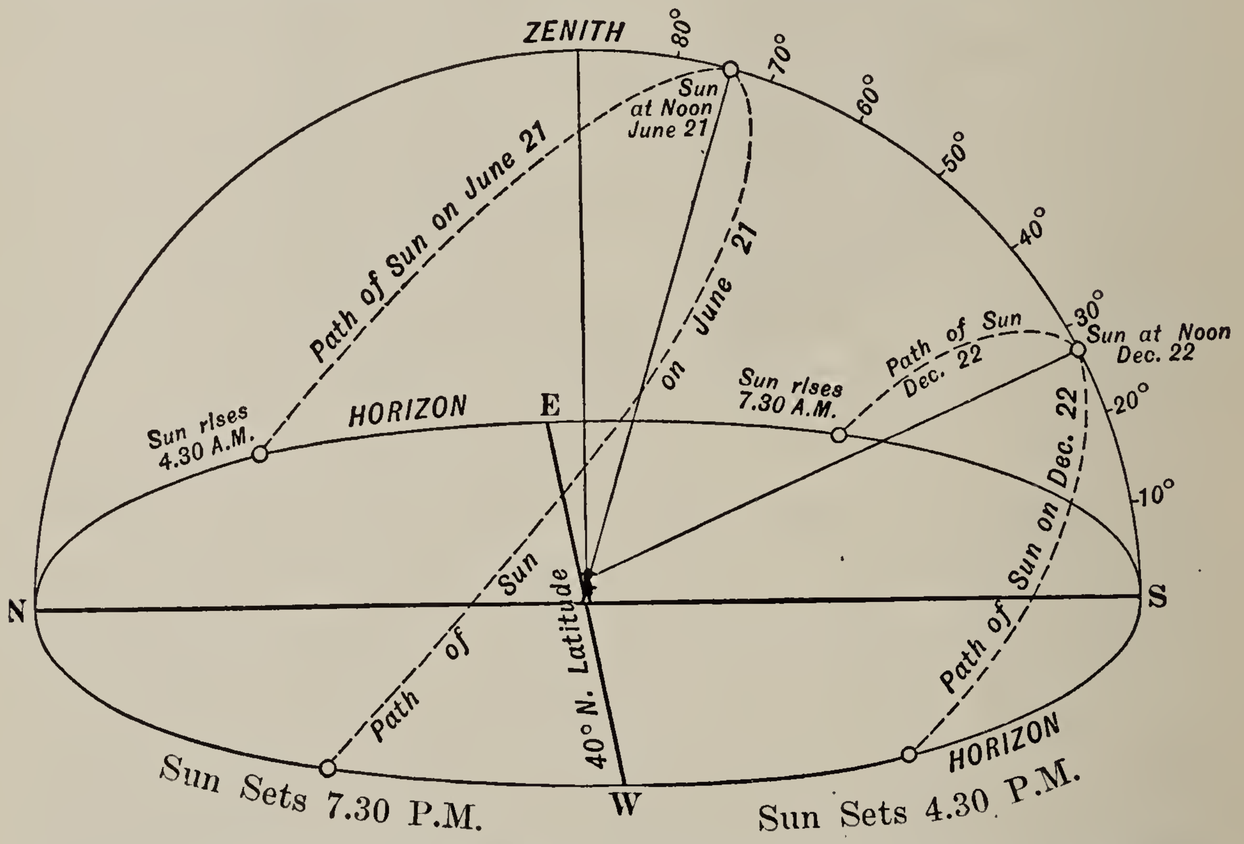


FIG. 173.—Showing the different positions of the sun at sunrise, at noon, and at sunset on June 21 and on December 22, at 40°, north latitude.

(*b*) Repeat the exercise with the north pole tilted 23½° away from the light. We then find that but 9/24 of the 40th parallel is lighted; that the north pole is without light; and that the equator is again exactly half lighted (Fig. 172).

This increased length of day greatly increases the sun's power of heating the earth's surface and the atmosphere in the north latitudes during our summer months.

1. *Notwithstanding the fact that the vertical rays of the sun never fall farther north than the Tropic of Cancer,* 23½° *north latitude, it still is true that for three months from May* 5 *to August* 5 *the zone of the sun's greatest heating is about* 41° *north latitude.*

2. *During the* 45 *days from May* 31 *to July* 16, *the region about the north pole actually receives more heat than does an equal area at any other portion of the earth's surface.*

3. *And again, it can be shown that, at the time of the* SUMMER SOLSTICE, *the region of the north pole is receiving* 36 *per cent. more heat than an equal area at the equator is then receiving during the* 24-*hour day.*

If these are facts, why does not the north polar region become warmer? 1. Because the north pole receives no heat whatever from the sun for six months each year. 2. Because nearly all of the heat furnished by the sun during the summer months is consumed in melting the ice and snow formed during the long winter months. During the following winter a fresh supply of ice and snow again accumulate in the polar regions.

Without a knowledge of these facts it is impossible to understand the seasonal changes of the weather of the United States.

The maximum temperature of a summer day in the United States rarely occurs in the southern states; it most frequently occurs in the region extending from Oklahoma and Illinois to South Dakota and Eastern Montana. Can you explain why this should be so?

Indian corn (maize) requires high temperature both day and night during about three months, or its growing season. Can you give some reasons why Illinois and Iowa are the greatest corn-producing states of the Union (Fig. 173).

223. Summary.—There are two chief causes of our summer and winter seasons in the United States: (1) The change in the altitude of the sun and the consequent change in its heating power; (2) the great difference in the length of day. Both of these are, of course, caused by the tipping of the earth's axis 23½° from the perpendicular to the plane of the earth's orbit, and the earth's revolution about the sun. Since these facts are studied in geography further study of them is omitted here.

II. CLIMATE AND LIFE

224. Meaning of "Climate" and "Weather."—By WEATHER, we mean the condition of the atmosphere at some particular time and at some particular place. The weather at Chicago frequently differs considerably from that at Buffalo or Albany upon any particular date, but the climate of these cities is quite similar. In speaking of the weather we refer to the temperature, the percentage of sunshine or cloudiness, the wind, and the precipitation upon a particular date.

By CLIMATE, we mean the *average* atmospheric conditions existing in a certain locality for a period of time, especially as they affect the animal and plant life of the region and the health and comfort of the inhabitants. When considering the climate of any region in reference to health we note:

1. The average temperature and the changes in temperature.
2. The average relative humidity and the changes in humidity.
3. The prevailing direction and strength of the winds and how they vary.
4. The average relative amounts of sunshine and cloudiness.
5. The average rainfall for the year and the particular seasons at which it is heaviest and lightest.
6. The prevalence of fogs and of dust and smoke in the air.
7. The altitude of the region and the consequent density of the air.

All these factors taken together determine, in a large measure, the plant and animal life of the region and the health and comfort of the inhabitants.

225. Plant Life Determined by Climate.—So completely does the climate of any region control plant life, that it is usually with considerable difficulty that man is able to grow plants in any other than their native land or one having a similar climate. The character of the soil has, of course, considerable influence in determining plant life, but climate is the chief factor. The trained botanist can tell, practically, the climate of a certain region by observing the native flora, or plant life, of that region. As the climate of a certain region changes, the flora of that region also changes. In ages past, during the Glacial Period, most of central North America north of the 40th parallel of latitude, was covered with ice. The climate then must have been similar to that of the arctic zone today. The flora, or plant life, which developed as the ice sheet retreated must have been similar to that now existing in British America near the arctic circle. In certain moist, cool canyons as far south as Illinois and Kentucky, specimens of this northern flora still linger, while the flora of the rest of the region long ago changed to that typical of the temperate zone.

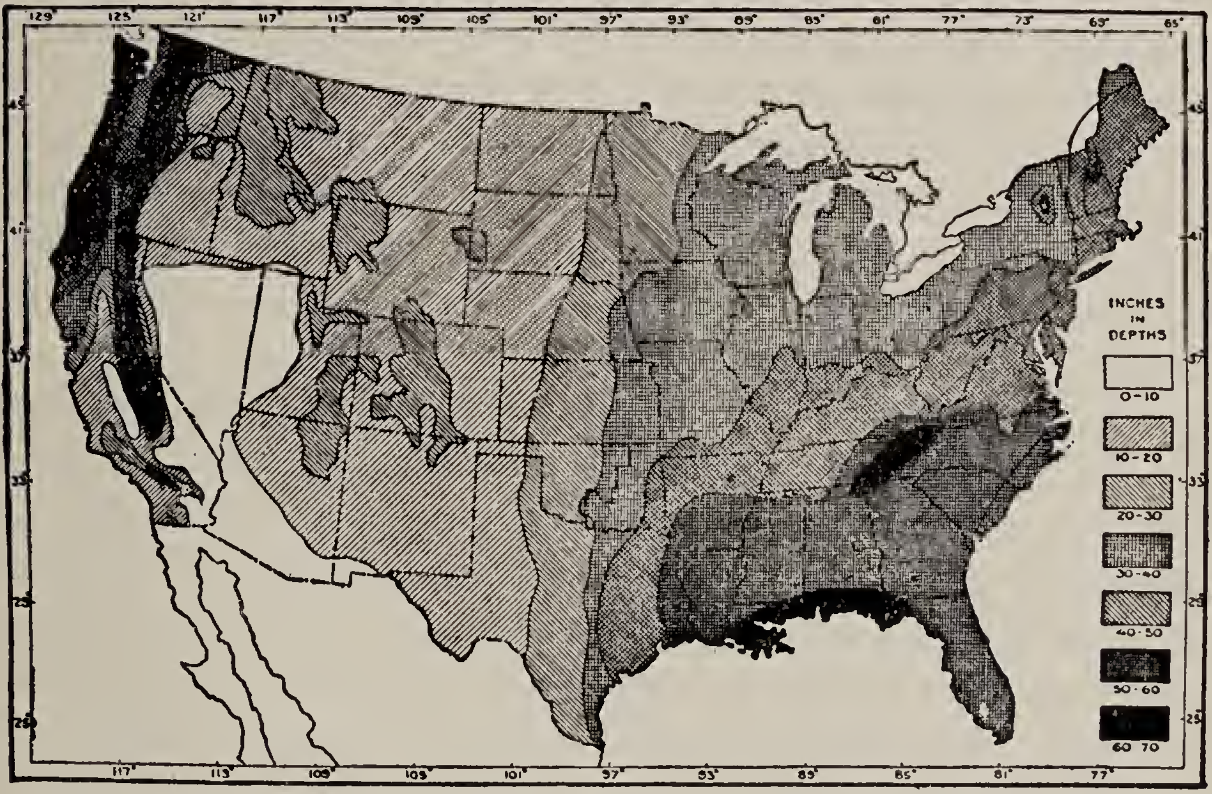


FIG. 174.—Average annual rainfall map of the United States.

While it is true that plants may survive when transplanted to a region having a climate somewhat different from that of their native haunts, they do not thrive; they develop only as dwarf and inferior specimens. The cactus and yucca, natives of our arid western plains, often survive when transplanted to the fertile plains of the Mississippi valley, but they little resemble the sturdy specimens growing in their native climate.

To the extent that man is able to control and modify the climate of a given region, he can raise successfully plants of almost any species anywhere on the face of the earth. In the green houses and conservatories of the temperate zone, tropical vegetation grows with luxuriance in the dead of winter. When irrigation is applied to our western plains, they blossom forth with all the productiveness of the most favored regions of the earth; yet, all that man has done is to devise a plan for supplying the moisture to take the place of the rainfall which is insufficient (Fig. 174, Rainfall Map).

226. Animal Life Dependent upon Climate.—Animal life is also largely dependent upon climatic conditions. The higher forms of animal life, however, show greater power of adaptation to changed climatic conditions than do the forms of plant life. While it is true that the polar bear of the arctics and the monkey and the parrot of the tropics live side by side in the zoölogical gardens of the temperate zone, it is not from choice, nor are they healthy, vigorous, happy, or comfortable while doing so. In a large measure man must provide a modified climate in order to save their lives. To the extent that either plants or animals become adapted to changed climatic conditions, we say that they have become ACCLIMATIZED.

227. Man's Relation to Climate.—By nature, man is one of the hardiest of animals. His power of endurance equals, if, in fact, it does not exceed, that of any other form of animal life. A lone man on foot has been known to run down and tire out the wild horse and the wild turkey. From choice, man dwells contentedly in almost every climate on the face of the earth. He even delves into the bowels of the earth and soars aloft among the clouds. He survives extreme exposure and retains his health, strength, and bodily vigor while engaged at the hardest labor for many hours each day. As long as he labors out of doors in the fresh air and in the sunshine, receives an abundance of nourishment, and sleeps eight hours each night in the open air, he outstrips nearly every other type of animal life in health, bodily vigor, and power of endurance.

Usually, it is when man violates one or more of these conditions that he becomes a puny, delicate creature, an easy prey for disease. The experience of every polar expedition in history is positive evidence of the truth of this statement. Pioneer life, with all its exposure and privations, has always developed a people of exceptional vigor and hardiness.

It is almost wholly man's unwise and unintelligent attempts to protect himself against the inclemency of weather and climate which have produced conditions favorable to the transmission of disease from one person to another and at the same time have so weakened his bodily resistance that he easily succumbs to almost any disease. Among all classes, from the wealthy to the very poor, two other causes of ill health are evident: (1) Lack of sufficient and suitable nourishment; and (2) lack of proper amount of sleep and rest. The wealthy suffer from these causes because of self-indulgence, the poor suffer because of their poverty.

III. THE FACTORS WHICH DETERMINE CLIMATE

A. Temperature

228. Seasonal Changes in Temperature.—

Exercise 52.—Study of the Average Temperature Maps of United States for July and January (Figs. 175 and 176).

What and where is the highest average temperature for July?
What and where is the lowest average temperature for July?
What and where is the highest average temperature for January?
What and where is the lowest average temperature for January?

In which month, then, July or January, is found the widest difference of temperature within the boundaries of the United States?

Review the study of the effects of the sun's altitude and length of day upon the temperature (Arts. 220 and 222) and explain why January should cause a wider range of temperature than does July.

Does New Orleans, La., or Grand Forks, N. D., have the greater variation in temperature between summer and winter? Why should this be so?

Why should the 70° isotherm bend so far south during July in Colorado and New Mexico? Trace the 70° isotherm throughout its length explaining all the bends in it. Remember that the principal factors in determining temperature are: (1) Altitude of the sun; (2) length of day; (3) prevailing wind direction; (4) proximity to bodies of water; (5) presence of mountain ranges.

Fig. 175.—Average temperature for July, 25 years.

What portions of the United States are so situated that the climate, especially the temperature, is largely determined by the ocean? (Recall the most frequent paths of LOWS and HIGHS across the United States.) Account in part, at least, for the temperature along the coast of California?

After studying the July and the January maps, state whether the

Atlantic or the Pacific Ocean has the greater effect upon the nearby portions of the United States. Why should this be so?

In studying such maps as these, we must learn to estimate the temperature of any locality on the map. Chicago, for instance, has an average temperature for July of about 71° or 72°; St. Louis, of about 76° or 77°; New Orleans, of about 82°. For January, Chicago has an average temperature of about 22°; St. Louis, of about 29°; and New Orleans, of about 52°.

About what average temperature has Boston for July? New York City? Baltimore? Charleston, S. C.? New Orleans? Santa Fé, N. Mex.? San Francisco? Denver? Bismarck, N. D.? St. Paul, Minn.? Portland, Oregon?

Estimate the average temperature of each of these places for January.

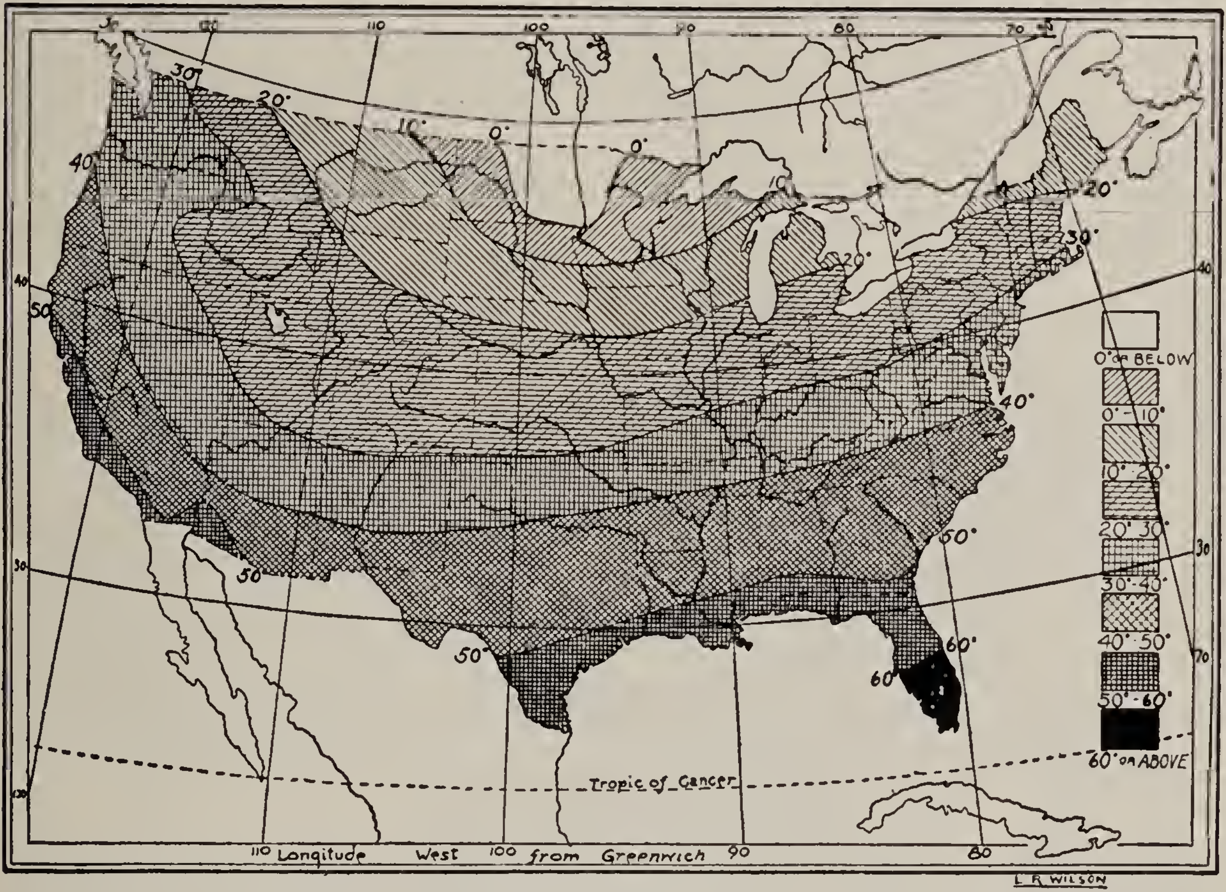


FIG. 176.—Average temperature for January, 25 years.

B. WINDS

229. Wind, Another Important Element of Climate.—The temperature and humidity may be the same for two different localities. But if one be a sheltered place where wind velocities are low while the other be exposed to high wind velocities, we know from experience that the exposed place seems to be much the colder and more uncomfortable in winter and much the cooler and more comfortable in summer (Art. 167). Protection against the chilling effect of the wind in winter is necessary. The clothing we wear, the wool, the fur and the hair of animals, and the feathers of birds, all serve as a protection against the chilling wind by retaining a layer or envelope of warm air next to the body. High winds disturb this layer of warm air, thus cooling the body.

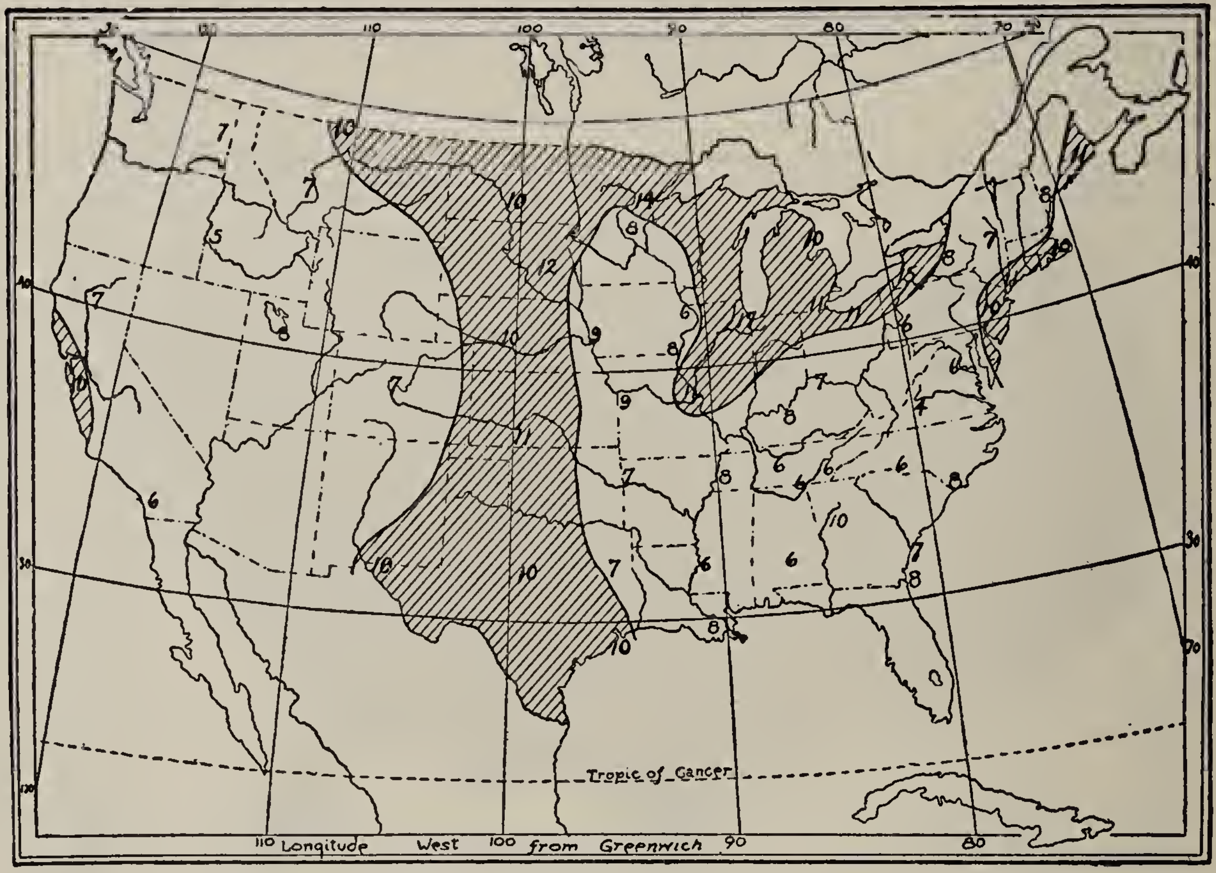


FIG. 177.—Average wind velocity, miles per hour. Shaded areas, above 10 miles per hour.

230. Wind Velocities in the United States.—The Weather Bureau records for years past give fairly satisfactory information regarding the wind velocities. The principal facts of wind velocity over the United States are easily shown (Fig. 177). From this map we see that the highest average wind velocities, *i.e.*, 10 miles per hour or more, are along the coasts, over the Great Plains Region east of the Rocky Mountains, and in the region of the Great Lakes.

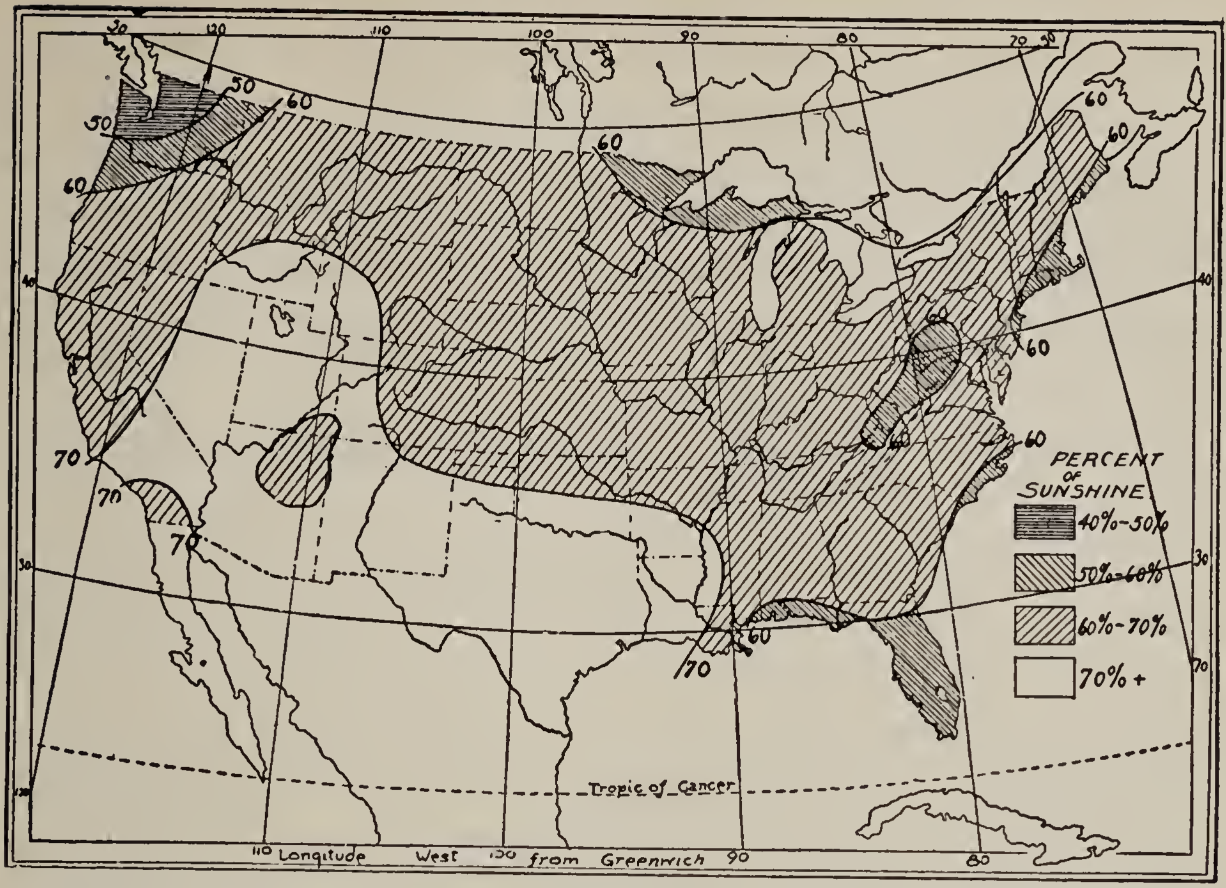


Fig. 178.—Sunshine average for 15 years, June, July, and August.

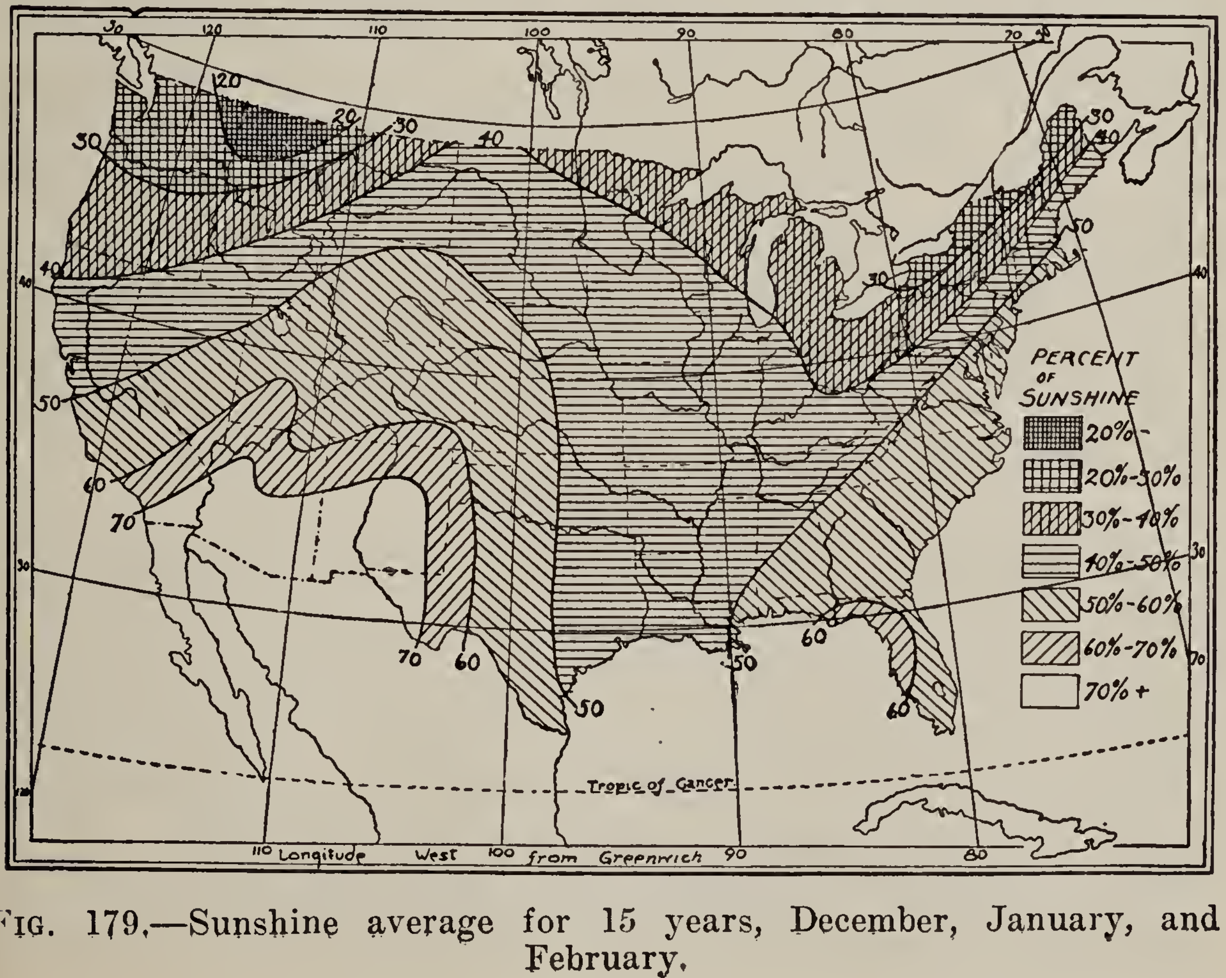


Fig. 179.—Sunshine average for 15 years, December, January, and February.

The records of the Weather Bureau also show these facts:

1. The lowest average wind velocities are found in the valleys of the interior.
2. The greatest wind velocities are found to occur in the months of March and April, while the lowest velocities occur in the months of July and August.
3. All high altitudes have a tendency toward high winds, the sharper the point, the higher the winds.
4. In general the west slope of mountain ranges has a higher average wind velocity than the east slope.

How do you explain each of these facts?

There are really two regions of relatively high winds in the interior of the United States: (1) The Lake Region, and (2) the region of the Plain States. The high winds of the Lake Region are to be accounted for, first, because this region lies in the path of the numerous northwest storms, and second, because the water surfaces offer less resistance to the moving air.

The high winds of the western plains may also be accounted for, first, by noting the even slope of the land from the Rockies eastward and the treeless character of this region, and second, the marked difference in the temperature of the mountain region on the west and of the Mississippi valley on the east during the summer months (see Fig. 177).

As an aid in selecting a location having a suitable climate little general information regarding winds can be given. Both their velocity and direction are largely determined by local conditions.

C. SUNSHINE

231. Sunshine.—Physicians, as well as all thinking and observing people, have great faith in the curative and health-giving power of sunshine. The sun bath is frequently prescribed in the treatment of many diseases. Direct sunlight is known to be one of the best of germicides; most disease germs die quickly when exposed to the direct rays of the sun. Even diffused sunlight is known to have great germicidal effects. So widespread and strong has become the faith in the beneficial effects of sunlight, that modern architecture has felt its influence. Modern dwellings as well as hospitals and sanatoriums are being constructed more and more with the view of admitting the largest amount of direct sunlight possible. Figs. 178 and 179 show the relative amounts of sunshine for the United States for the summer months and the winter months.

Exercise 53.—Study of the Sunshine Maps, Figs. 178 and 179.

What portion of the United States has the highest percentage of sunshine? What portion the lowest?

Is the percentage of sunshine greater in the summer or in the winter?

232. The Ideal Climate.—There is no such thing as a climate which is ideal for all people or for any person every month in the year. A climate which exactly suits one person may be unacceptable to another. Many people are well pleased with the climate of southern California near the coast. What are the characteristics of that climate, as regards: (1) Temperature, summer and winter; (2) annual rainfall; (3) sunshine, summer and winter; (4) altitude; (5) wind velocity; (6) evaporation?

For many years northeastern New Mexico has been regarded as the center of a very favorable region for the treatment of tubercular patients. What are the characteristics of that region?

233. Seeking Health in a Change of Climate.—Just as Ponce de Leon and other adventurers of the 15th and 16th Centuries were journeying over the earth in search of the "fountain of youth," so thousands of people are now constantly on the move in search of a climate which insures them better health. They spend their winters in southern California or Florida and their summers in the Adirondacks or on the northern lakes and are ever seeking renewed health. Sometimes these changes of climate are made at the advice of the physician. Probably many experience beneficial effects from such changes of climate and occupation. However, some questions may well be asked: Do the beneficial effects result entirely from the change in climate? Was that the only climate which would have benefited the patient? To what extent do other elements, such as change of occupation, rest from labor, change in habits, change in companions, and freedom from responsibility, enter as factors? Those who have given the largest amount of thought to this matter and who are best able to judge agree that these are difficult questions to answer.

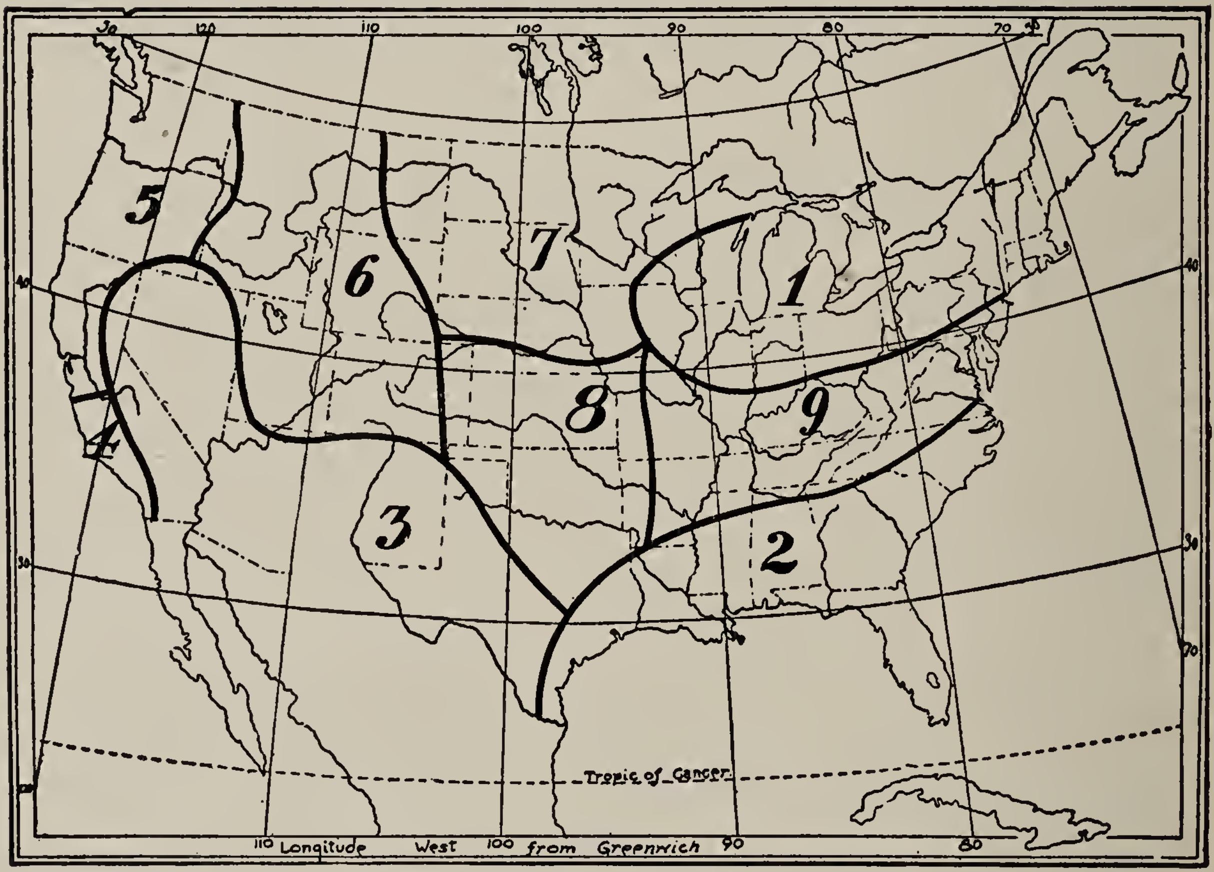


FIG. 180.—Climatic regions of the United States.

IV. CLIMATIC REGIONS OF THE UNITED STATES

234. Climatic Areas.—The area of the United States presents nearly every variety of climate to be found in the temperate zone. The United States may be divided roughly into nine fairly well-defined climatic areas. But within each of those areas there is considerable variation due to local causes. Altitude largely affects temperature and wind. Nature of the earth's surface largely determines wind velocity and direction and often rainfall. The proximity of cities, forests, and bodies of water largely determines the purity of the air, the presence of dust and smoke, the prevalence of fogs and of local winds (Fig. 180).

235. **First Region.**—The first region comprises southern Wisconsin, much of Iowa and Illinois, Indiana, Ohio, the Lower Peninsula of Michigan, Pennsylvania, New York, and New England. This region has an average temperature for July of 70° to 75° and for January of 20° to 30°. It has a summer humidity of about 70 per cent. and a winter humidity of about 80 per cent. It has about 60 per cent. of sunshine in the summer and 40 per cent. in winter. Its wind velocities range from moderate to high. It lies in the pathway of a large majority of the storms which pass across the United States and therefore is subject to sudden and severe changes of weather. Its average rainfall is about 40 in. In this territory live about 45,000,000 people, nearly one-half of the population of the United States. Here is found also more than one-half of the wealth and influence of the nation. With the exception of the Adirondacks, the White Mountains, northern Maine, and the lake shores of northern Michigan, this region is seldom frequented by the seekers after health.

236. **Second Region.**—This is the Gulf States Region, with its comfortable winter temperature and high humidity and its rather high percentage of sunshine. Portions of it are used as a winter resort by those who do not wish to face the rigor of a northern winter. The summer climate of the Gulf Region is unpleasant. Its high average temperature, high humidity and nearly 60 in. of rainfall are neither pleasant nor invigorating. Nevertheless, the higher altitudes of the mountainous regions of western North Carolina and Virginia receive high praise as health resorts.

237. **Third Region.**—This is the great semi-arid region of the southwest, including western Texas, New Mexico, Arizona, southern Utah, Nevada, and southeastern California. High

temperatures, high evaporation, high percentage of sunshine, low rainfall and low humidity characterize this region. For many years this region has been highly recommended for consumptives. Most of this region has the "throb and glow of the tropics."

238. Fourth Region.—Southwestern California has a climate of perpetual warmth, much sunshine, soft humid air with moderate rainfall. Dr. Woods Hutchinson says, "This region escapes the bane of the tropics, steaming days and sweltering nights, by virtue of the snow-capped mountains on the one hand and the cool blue sweep of the Kuro-Siwo, or Japan Current, on the other. Southern California has the sun electricity of the tropics, with the cool nights of the green rain belt, the fire of the South with the stamina of the North. The blue sea, bright sunshine and white mountains that made the glory that was Greece and the grandeur that was Rome, are also hers. She will some day be the Greece of the New World."

239. Fifth Region.—The Northwest Coast, comprising Washington, Oregon, some of Idaho and northern California, has a summer climate as delightful as the winter climate of southern California. The temperature is relatively even and moderate while during the winter season the humidity and rainfall are high and the percentage of sunshine correspondingly low.

240. Sixth Region.—This is the mountain climate of the United States, the climate of the "backbone" of the continent. In many respects this is a region of unsurpassed climate for those who wish life, vigor, and energy. It is characterized by moderate severity in winter and a pleasant warmth in summer. Its humidity ranges from 50 to 60 per cent. the year around. It has a high percentage of sunshine both summer and winter, and plenty of pure, relatively dry, crisp air, free from dust and fogs.

241. Seventh Region.—The Dakotas, Minnesota, and northern Wisconsin comprise most of this region. Lying as it does in the path of storms, this is a region of sudden and severe weather changes. Its winters are severe; its summers are fairly moderate but with high temperatures frequently during the middle of the day. The relative humidity of the eastern portion of this region is rather high the year around.

242. **Eighth Region.**—The eighth region comprises Nebraska, Kansas, Oklahoma, and northern Texas. It is characterized by high winds, low amount of rainfall, fluctuating temperature, rather low humidity, and high percentage of sunshine. It has the most characteristically continental climate of any region of the United States.

243. **Ninth Region.**—This region has some of the characteristics of the Eighth Region but has lower wind velocities and higher amount of precipitation. Its average temperature is fairly moderate, being affected in portions by the higher altitudes of the Appalachian Mountains. Its humidity is considerably lower than that of either the First Region or the Second Region between which it lies. It has an average summer temperature of 75° to 80° and an average winter temperature of 30° or 40°. The amount of rainfall is ample, about 40 or 50 in.

V. PROTECTION AGAINST UNFAVORABLE CLIMATE

244. **Accepting a Climate.**—Whether it is best so or not, the fact remains that it is impossible for most of us to choose the climate in which we would live. Most of us are obliged to spend all the year, if not all our lifetime, in the climate where we find our place of labor. Even were we convinced that a certain climate, southern California for instance, is the most favorable for our health and comfort, it is evident that we can not all take up our abode there. The First Region with its extreme climatic changes will never again, within the lifetime of anyone now living, be less densely populated than it is today. On the contrary the population of that region will doubtless double and redouble in the next quarter- and half-

century. The real question, then, is not whether the climate of this or any other region is the most healthful to be found. The real question concerning a climate is whether it is reasonably healthful. As a second question we should ask, Is it possible so to live, so to condition our surroundings, that we may be strong and healthy even in a region having an unpleasant climate?

245. Problem of Indoor Climate.—Only in recent years has the problem of protecting ourselves against severe climatic conditions received close attention. Most people, even now, give little or no attention to any element of indoor climate other than temperature. They make no special provision for fresh air and but little provision for direct sunshine in their rooms; they pay no attention to the humidity of the air in which they live. In the winter they shut themselves up in stuffy, nearly air-tight, often sunless, draught-stricken, overheated, dust-laden rooms. Their only thought is to maintain a temperature of 70° or more. The highest and best authorities say that about one-half of all deaths are the result of preventable diseases, and that a more intelligent and rational plan of protecting ourselves against the inclemency of climate and weather would materially decrease sickness and death from these causes. Those among us who disregard the laws of sanitation find their powers of resistance so weakened, their vitality so lessened, that they are easily attacked by colds, influenza, tuberculosis, pneumonia, and other diseases. And they, in turn, spread these diseases among all with whom they come in contact.

246. The Ideal Indoor Climate or Air Condition.—We all know how delightful and pleasant is the soft balmy air of spring and early summer. We know how we long to be out of doors in the sunshine on a spring day and what renewed life and vigor such conditions give us. *The ideal conditions for indoor air are those which closely resemble outdoor air of spring or early summer.* These conditions are: a gentle breeze, a flood of health-giving sunlight, a humidity of 50 or 70 per cent., air nearly free from dust, and, lastly, a temperature which varies with the occupation, clothing, habits, and age of the individual. We cannot completely control the amount of sunlight, but we can so construct our houses that we may enjoy all the sunshine there is; the other conditions we can usually secure without great cost or effort.

247. Why a Change of Climate May Be Beneficial.—The climate of the Southwest is chiefly beneficial during the winter months because one is most comfortable there when out of doors and, therefore, is inclined to remain out of doors. Even when indoors, one is most comfortable with the doors and windows wide open, therefore, the doors and windows are left open. In the severer climate of the North, during our waking hours and when engaged at ordinary occupations, we can not be comfortable with doors and windows open. We must, then, *condition the air* to approximate the ideal climate. During

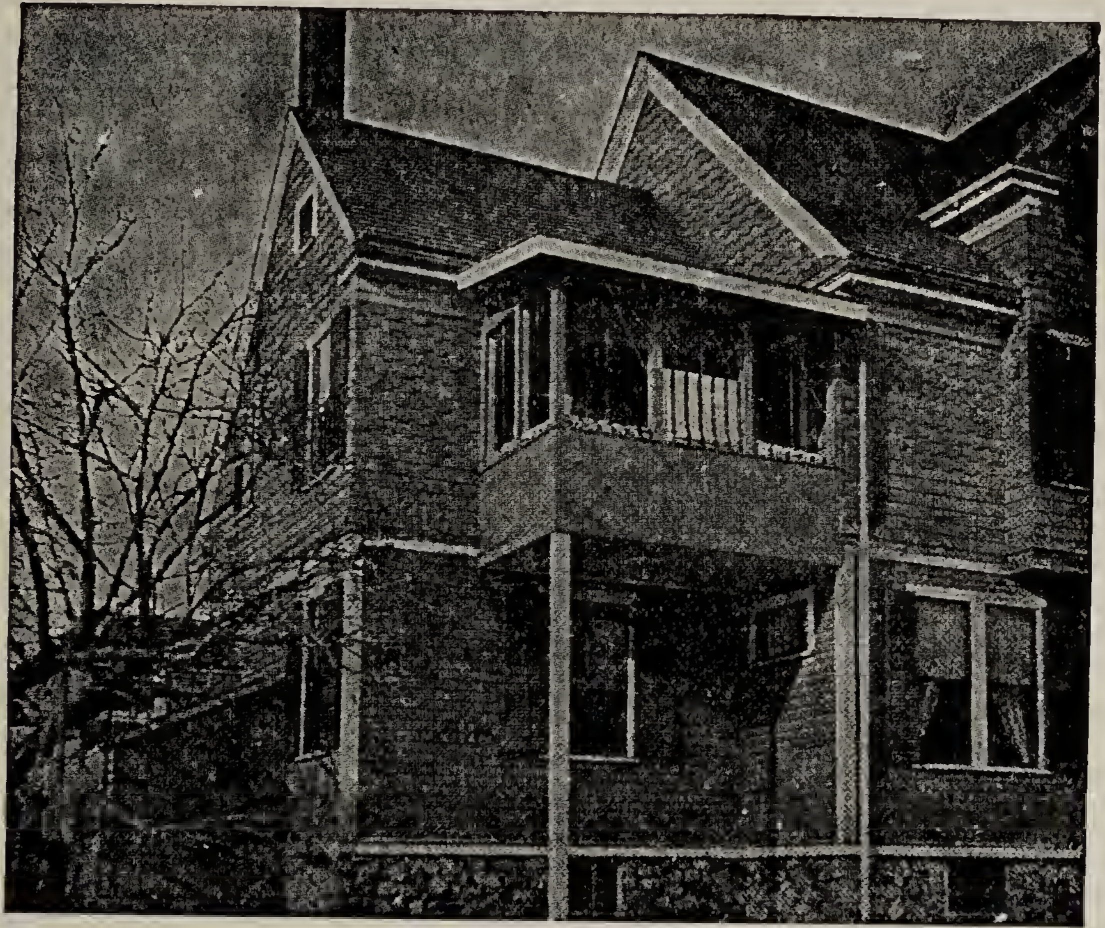


FIG. 181.—Sleeping porch.
(*Courtesy of Dr. S. A. Knopf.*)

our sleeping hours, however, we can be comfortable with open windows by using sufficient covers. We should, therefore, learn to sleep, summer and winter, with open windows and in the pure outside air.

Living and Sleeping in the Open Air

248. Open-air Rooms.—The open-air treatment has been found very beneficial in the treatment of both tuberculosis and pneumonia. In fact, the patient suffering from either of these diseases frequently lives and sleeps continually in the open air. There is every reason for believing that such open-air living is equally beneficial as a preventive measure. Well informed people have become convinced of this fact and many modern houses are being constructed with open-air living rooms, with sun rooms, and with open-air sleeping rooms.

It is usually an inexpensive matter to construct a sleeping porch such as shown in Fig. 181. Many houses have porches which may be easily screened in for living purposes.

Many devices have been perfected, especially for the accommodation of tubercular patients who can not afford to build sleeping porches or who live in rented houses. Most of these devices are fitted to the open window in such a manner as to permit the patient to breath the cool, fresh, outside air while resting and sleeping. One such device is a window tent in which the patient can be kept in the open air, and which can be folded up out of the way when not in use. This window tent has a celluloid window which enables the patient to see all that takes place in the room. Such devices are very useful for several reasons: (1) They are easily attached to, and removed from any window; (2) they are economical because they prevent the loss of any considerable amount of heat from the room; (3) in case of severe sickness, the attending nurse and the members of the patient's family are able to use the room with comfort even in the severest weather; at the same time the patient really lives in outside air.

CHAPTER V

VENTILATION

I. PRINCIPLES OF VENTILATION

249. Need of Ventilation.—While the beneficial effects of outdoor life are being more and more recognized, still many people must necessarily spend much of their lives indoors. School children must spend many hours each day in the schoolroom. Factories, shops, stores, and offices are filled with working men and women who find it impossible to spend much time in the open air. Often their chief recreation is a visit to an overcrowded theater or moving-picture show where adequate ventilation is seldom provided. Even when at home few people enjoy fresh air. Relatively few houses have been constructed with any recognition of the fact that fresh, pure air is of even greater importance than is warmth. For these reasons, what constitutes good ventilation and how it may be obtained should receive careful study.

250. Composition of Pure Country Air.—Pure country air is composed chiefly of nitrogen, oxygen, carbon dioxid, and water vapor. The proportions of these constituents vary slightly from day to day and at different places, by far the greatest variation being in the amount of water vapor present. Pure country air consists of about the following proportions:

Nitrogen	about 77 per cent. by volume
Oxygen	about 21 per cent. by volume
Carbon dioxid	about 0.03 per cent by volume

Water vapor—variable, from 0.3 per cent. to 3 per cent. by volume.

In addition to these constituents of air there are usually present more or less dust, smoke, pollen from plants, and microörganisms of different kinds.

251. Effect of Breathing upon the Composition of Air.—When man, or any animal, breathes this air, oxygen is consumed and carbon dioxid and water vapor are given off. When many people are gathered together in a closed, nearly air-tight room for some time, the air becomes much changed. We say that the air becomes VITIATED. If some of those present are suffering from colds, pneumonia, tuberculosis, or other communicable diseases, the disease-producing germs (see Chap. VI) are certain to be present in the air.

252. Theories Regarding Vitiated Air.—For many years the most objectionable factor in vitiated air was supposed to be small amounts of poisonous volatile matter, organic compounds, expelled from the lungs with the breath. This supposition gave rise to the term CROWD POISONING. Some years ago doubt arose as to the correctness of this supposition. Very careful experiments by skillful investigators employed by the government, failed to show the presence of this supposed objectionable matter. Few scientists now believe in the CROWD POISON THEORY of vitiated air. It is now generally believed and taught by teachers of hygiene and sanitary science, that, as far as there is any offensive odor in the breath, it is probably due to decayed teeth, effects of catarrh, decomposition of food in the mouth, or disordered stomach.

Moreover, it is now believed that most of the unpleasant odors noticeable when any crowd gathers indoors come from the unclean bodies and clothing of those present. The skin of even the cleanliest person is constantly giving off waste material. A considerable portion of the waste materials of the body is given off through the pores of the skin. The offensive odors so characteristic of theaters, moving-picture shows, schoolrooms, auditoriums, and churches are now generally believed to be caused chiefly by excretions from the skin, not from the lungs. In general, the theory of crowd poison has been abandoned.

253. Theories Regarding Ventilation.—As already stated, pure country air usually contains about 0.03 per cent., or 3 parts in 10,000, of carbon dioxid. It was *assumed* many years ago that air had become too vitiated for use when the proportion of carbon dioxid had been *increased* more than about 0.03 per cent., or 3 parts in 10,000, *due to breathing, i.e.*, when the proportion of carbon dioxid had been increased from 0.03 per cent. to more than 0.06 per cent. While it has been conclusively proved that the breathing of air containing as much as 5 per cent., or 500 parts in 10,000, of carbon dioxid, has not the slightest depressing effect, still the old rule laid down years ago is the rule which controls in nearly all ventilating systems today. Even those who admit that a large amount of carbon dioxid in the air is harmless and that the theory of crowd poison can not be proved, still maintain that the percentage of carbon dioxid in the air is a good indication of the wholesomeness or degree of vitiation of the air.

254. Calculation of the Amount of Fresh Air Needed per Minute by Each Person.—If we admit that the amount of carbon dioxid in the air *produced by breathing* must not be permitted to rise above 0.03 per cent., or 3 parts in 10,000, we need only to know how much carbon dioxid is exhaled per hour by each person in order to determine the amount of fresh air which must be supplied him. This is easily calculated as follows: Physiologists tell us that the average amount of the TIDAL AIR, *i. e.*, of the air inhaled and exhaled at each breath, is from 20 to 30 cu. in. and that a person ordinarily breathes about 17 times per minute. Now if a person does breath 17 times per minute and exhales 25 cu. in. at each breath, he exhales 17 times 25 cu. in. or 425 cu. in. of air each minute, or 25,500 cu. in. per hour.

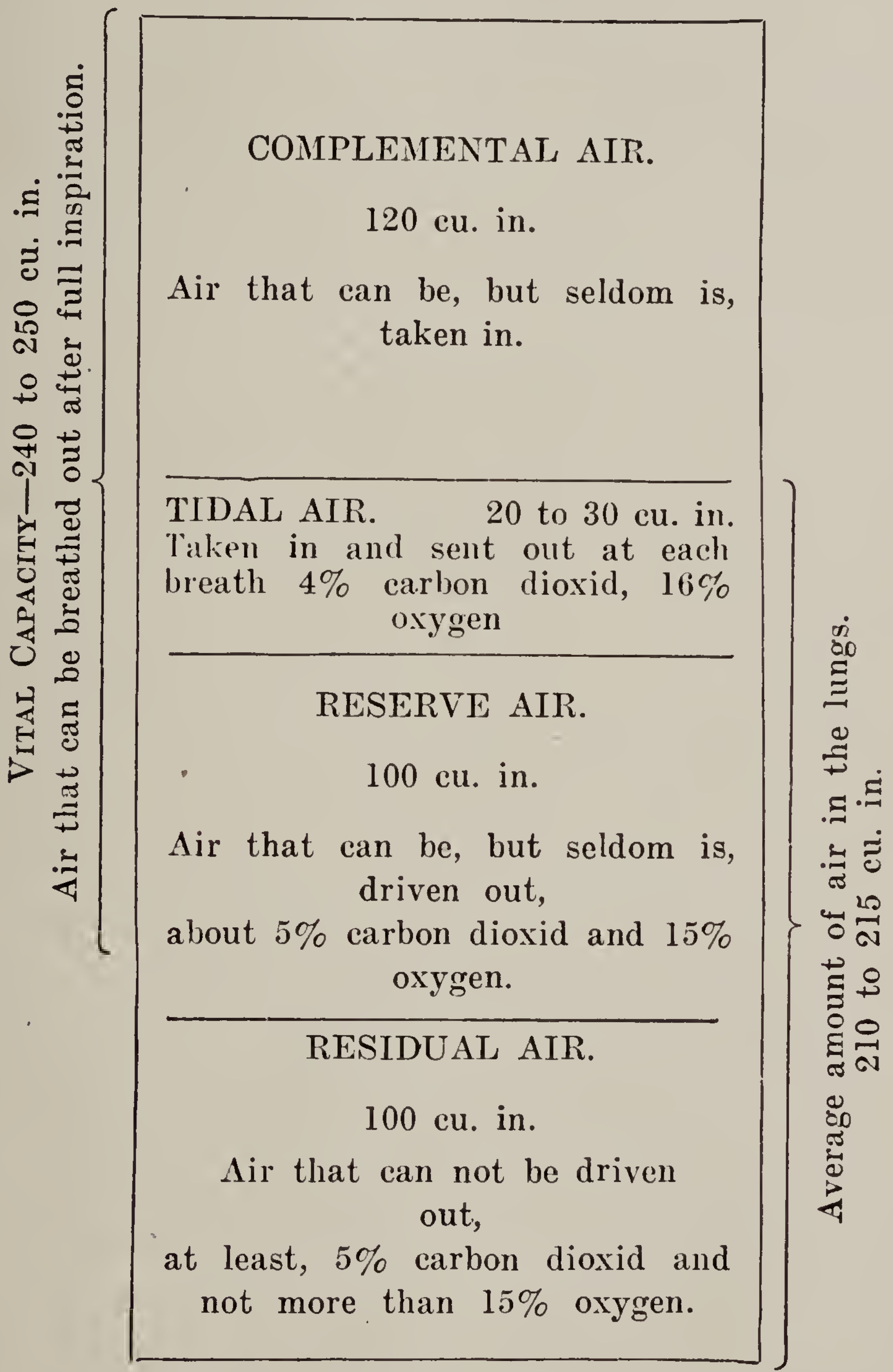
Many analyses of exhaled breath show that it usually contains about 4 per cent., by volume, of carbon dioxid. Now 4 per cent. of 25,500 cu. in. is 1,020 cu. in. Since there are 1728 cu. in. in a cu. ft., it is evident that a person ordinarily exhales about 6/10 of a cu. ft. of carbon dioxid each hour.

Now, if people are right in assuming that the air in the room must be so diluted by the admission of fresh air that the proportion of carbon dioxid *derived from the breath* shall not be greater than .03 per cent: or .0003 of the whole, we see that the .6 of a cu. ft. of carbon dioxid must not be more than .0003 of all of the air admitted to the room for each person during the hour. If, then, .6 of a cu. ft. is 3/10,000 of the whole, 1/10,000 is 1/3 of .6 or .2 cu. ft. and 10,000/10,000, or all of the air admitted, must be 10,000 times .2 cu. ft. which is 2,000 cu. ft. per person each hour.

Several years ago, Massachusetts enacted a law requiring that all schoolrooms should be ventilated on practically this basis. It was soon discovered, however, that such a requirement meant that practically every schoolhouse in the state would have to be rebuilt or remodeled. A compromise was therefore effected by which all schoolrooms were to be supplied with 1800 cu. ft. of fresh air per person each hour. Several other states have followed the example of Massachusetts. It is now common practice to provide 1800 cu. ft. of fresh air per person each hour in modern buildings. This means that, if a schoolroom contains 30 pupils and has a fresh air inlet of 4 square feet that the air must enter at the rate of 3.75 ft. per second. This is about the same rate of motion as that of wind blowing 2½ miles per hour, a very light breeze. (Prove the correctness of this calculation.)

255. Error of This Theory of Ventilation.—Students of sanitation are now generally agreed that this theory of ventilation, namely, *that air is necessarily so vitiated as to be unwholesome if it contains more than 0.06 per cent. of carbon dioxid, i. e., 0.03 per cent. as in pure country air plus 0.03 per cent. from breathing, is not scientifically well founded.* They are raising the question whether the system of ventilation in common use is, after all, the best. Some are inclined to question the necessity of providing so much fresh air as 1800 cu. ft. per person each hour. Nearly all are convinced that we should give much more attention to *temperature,* to keeping the *air in the room in motion,* and to the *proportion of water vapor* in the air than we are now giving, and that possibly these conditions are of even greater importance than the proportion of carbon dioxid.

In order to understand the reason for this growing belief we must consider the total lung capacity of a person and the volume of air he ordinarily inhales and exhales at a breath. The following diagram adapted from *Colton's Physiology* will aid us in our study.



COMPLEMENTAL AIR.
120 cu. in.
Air that can be, but seldom is, taken in.

TIDAL AIR. 20 to 30 cu. in.
Taken in and sent out at each breath 4% carbon dioxid, 16% oxygen

RESERVE AIR.
100 cu. in.
Air that can be, but seldom is, driven out,
about 5% carbon dioxid and 15% oxygen.

RESIDUAL AIR.
100 cu. in.
Air that can not be driven out,
at least, 5% carbon dioxid and not more than 15% oxygen.

Diagram Illustrating Lung Capacity

From this diagram, we see that the average amount of air in the lungs is 210 to 215 cu. in., while the tidal air is only 20 to 30 cu. in. Now, as already stated, it is known that exhaled tidal air contains about 4 per cent. carbon dioxid. It must be remembered that the exhaled tidal air is the very purest air in the lungs. The 100 cu. in. of RESERVE AIR is somewhat mixed with the 30 cu. in. of tidal air and therefore diluted by it. But the 100 cu. in. of RESIDUAL AIR, being the air in the vesicles, or air cells, of the lungs, is but slightly altered in composition by each inflow of tidal air. Considering these facts, authorities agree that the amount of carbon dioxid in the residual air can not be less than 5 per cent. Now this residual air in the lung cells, or vesicles, is the air which receives the carbon dioxid from the blood and gives up oxygen to the blood. In a very true sense, it is almost wholly this residual air upon which the efficiency of our respiration depends.

From the preceding facts we see that the lungs contain constantly over 200 cu. in. of air (100 cu. in. being reserve air and 100 cu. in. being residual air) containing, at least, some 5 per cent. of carbon dioxid. It is evident, therefore, that it matters little whether the 20 to 30 cu. in. of tidal air contains 0.04 per cent. or 0.06 per cent. or even 4 per cent. of carbon dioxid.

256. Same Reasoning Applied to the Other Constituents of the Air.—Fresh air is about 21 per cent. oxygen. Exhaled air is known to be about 16 per cent. oxygen. Evidently the oxygen in the residual air in the lungs can not be more than about 15 per cent. oxygen. Now, experimenters have shown that a person feels no discomfort when breathing air containing no more than 15 per cent. oxygen. *We are, therefore, forced to the conclusion that it is not the effect of breathing air with an increased percentage of carbon dioxid, nor with a decreased percentage of oxygen, nor of breathing air containing "crowd poison" which constitutes the chief cause of the evil effects of living in an atmosphere of vitiated air.* Investigators have come to believe that other factors have quite as much bearing upon the problems of ventilation.

257. Relation of Humidity of Ventilation.—Exhaled air contains much moisture—it is nearly saturated at blood temperature, or 98° F. Our bodies also give off considerable quantities of moisture in the form of perspiration through the skin. In poorly ventilated rooms where crowds gather, the humidity of the air rises rapidly. The result is that the evaporation from the skin is checked and we soon become uncomfortable. This effect of increased humidity is often greatly aggravated by increase in temperature due to the heat given off from our bodies. Taken together, the three conditions: (1) high humidity, (2) high temperature, and (3) foul odors soon produce headache and a feeling of weariness and exhaustion. Many recent experiments indicate that *these three conditions of the air, high temperature and high humidity, and disagreeable odors in crowded, ill-ventilated rooms are large factors in producing what we know as vitiated air.*

258. Control of the Temperature of the Body.—The temperature of the human body in health is maintained with great constancy at 98⅖° F. No matter what the fluctuations of external temperature, the mechanism of the human body is so delicately adjusted that, in health, it perfectly corrects the effects of all temperature changes. If the external temperature is low, the temperature of the body is kept up by an increase of heat production within the body. If the external temperature is high, the temperature of the body is kept down by the cooling device of increased perspiration, and the consequent increased surface evaporation and cooling. (Art. 12, Ex. 10; Art. 13, Law V and Art. 179.) But any effort which the body must thus put forth to counteract external temperature is necessarily a drain upon the vital forces of the body.

259. Metabolism.—By METABOLISM we mean a sort of double process: *On the one hand, the living cells of the body are built up and nourished by the food materials assimilated. On the other hand, it includes the breakdown of some of the living material of the cells into waste products.* This latter phase of the process is always accompanied by the liberation of energy. It is a term by which we express the entire process of nutrition, both the building up and the nourishment of the living cells and the production of energy. This whole process of metabolism, however, is closely connected with the control of bodily temperature.

260. Effect of External Temperature upon Metabolism.—In studying the effect of external temperature upon metabolism, experimenters have found that there is a certain temperature best suited to stimulate metabolism, and therefore best suited to keep the person healthy and comfortable. That best external temperature varies with the age, health, and occupation of the person. It is for this reason that we take so much pains to keep our houses and our schoolrooms, our churches and our stores comfortably heated.

The experience of stockmen shows that stock exercising but little, as is usually the case with dairy cows and with beeves and hogs being fattened for the market, thrive best when the temperature is moderate. Extremes of temperature, either high or low, reduce the flow of milk in the dairy cow and tend to prevent the fattening of the beef-cattle and hogs. In each case, nourishment taken by the animal is expended in effecting the control of bodily temperature. We also know that work horses are not able to do so much work in extreme temperatures as in moderate temperatures, although the best temperature for the horse at hard work is much lower than when at rest.

261. The Ideal Temperature of Indoor Air.—The best temperature for indoor air depends largely upon the occupation and dress of the occupants. The proper temperature for a gymnasium or a factory would certainly not be the proper temperature for a schoolroom or a church. Even the best temperature for a schoolroom or a church might prove to be too low a temperature for the home, owing to the fact that most people are likely to be more warmly clad when at school or church than when at home.

As will later be shown, the relative humidity of the air in the room also largely determines the proper temperature. Reasonably moist air at 65° F. is as comfortable as very dry air at 70°. The temperature usualy demanded by Americans is several degrees higher than that preferred by the English and Germans. Our own physical condition also largely determines the most agreeable temperature. In the morning when our vitality is highest, we are comfortably warm at a temperature which is uncomfortably low in the evening when our vitality is lowest. Still another factor affecting the most agreeable temperature of air is that of air movements. Air in rapid motion must be a few degrees warmer than quiet air in order that we may be comfortable. Why? (See Art. 167.)

The best temperature, then, depends upon many factors such as the occupation, dress, physical condition, and temperament of the occupants of the room, on the one hand, and the humidity and movements of the air, on the other hand. The effect of air motion and of high or low humidity should be further studied.

262. Some Changes in Temperature are Desirable.—A German, Flügge, seems to have proved that a perfectly uniform temperature is not desirable. Many students of ventilation now maintain that reasonable changes in temperature are necessary to stimulate us and to keep our physical and mental powers alert, awake, and active. A perfectly uniform temperature, even though it be the most agreeable, lacks the stimulating effect of a reasonably fluctuating temperature (see Arts. 159, 245 and 260).

263. Effect of Air Movement.—Dr. Leonard Hill of London and others, have shown that proper air movement is a large factor in ventilation. Dr. Hill placed eight healthy medical students in a small, air-tight, glass-sided box, or cage, 4½ ft. square and 8 ft. high. In a few minutes they became very uncomfortable. The temperature of the air in the cage had risen to 85° F. and had become nearly saturated with moisture. The air then contained about 4 per cent. of carbon dioxid and only about 15 per cent. of oxygen. Three electric fans in the top of the cage were then set in motion, causing the air to move rapidly. The students were soon greatly relieved and became again fairly comfortable, although the composition and the temperature of the air remained unchanged.

Students of ventilation generally agree that quiet air, no matter how pure it may be or what its temperature and relative humidity may be, does not furnish adequate ventilation for the body. In such cases, an envelope of highly heated, highly humidified air accumulates within one's clothing. Moreover, when many people are quietly seated in a room containing quiet air, as in the case of a schoolroom or a church, there is a strong tendency toward the forming of a layer of impure exhaled air at the height of the "breathing zone," *i.e.*, at the height of their faces. Authorities now agree that the air in any room should be kept moving with such rapidity that the air motion is perceptible to all.

A careful study of the relation of air motion to ventilation has led Dr. W. A. Evans of Chicago to declare that, "A drafty room is a healthy room—a windy city is a healthy city."

264. Importance of Proper Humidity.—It is now a generally accepted theory that just as there is a best average temperature from which there should be no great variation for any long period of time, so there is a best humidity from which there should be no great or sudden variation. Dr. Hill's students, enclosed in their cage, soon raised both the temperature and the humidity to such a point as to cause great discomfort. The heat from their bodies caused a rapid rise in the temperature of the confined air, while the moisture from their breath and from perspiration from their bodies soon raised the humidity nearly to the point of saturation. High temperature, too great humidity, still air, and offensive odors were probably the chief causes of their discomfort. Exactly in the same manner, the air in a crowded, ill-ventilated room is likely to be at too high a temperature, the humidity is likely to be too high, the air is almost certain to have but little motion, and soon offensive odors become noticeable.

Dr. Hill has stated the principle of good ventilation in a single sentence, thus: "The question of ventilation is primarily one of keeping the temperature, relative moisture, and movement of the air in proper state, so that the heat-regulating mechanism of the body works without strain, and the nervous system is stimulated by pleasant cutaneous [skin] conditions and the circulation, respiration and metabolism of the body is invigorated."

265. Humidity Sometimes too Low.—While in an ill-ventilated, crowded room the humidity is likely to be too high for the comfort and well-being of the occupants, in the best ventilated room or house, where artificial heating is required, the humidity is nearly certain to be too low, in cold weather, unless special effort is made to correct this tendency. It is generally accepted that the best indoor humidity is from 50 to 70 per cent.

When air is cold, it takes but a small amount of water vapor to cause complete saturation; when air is heated to the temperature that is comfortable indoors, it takes many times as much water vapor to saturate it. Now, the average outdoor temperature for December, January and February for that portion of the United States lying north of the latitude of 40° is 25° or lower. But we usually heat our houses to nearly 70°. It requires but 1.5 grains of moisture to saturate a cu. ft. of air at 25° while it requires about 8 grains to saturate a cu. ft. of air at 70°. If the outdoor air were fully saturated (which is seldom the case when the temperature is 25°) and we admit that air into our houses or schoolrooms without adding more moisture, we shall then have but 1.5 grains of moisture to each cu. ft. Since the air at 70° must have about 8 grains of moisture to the cu. ft. to be saturated, we see that the air is but $^{1.5}/_{8}$, or less than $\frac{1}{5}$ or 20 per cent., saturated. We speak of the air when in this condition as having 20 per cent. *relative humidity.*

During these three winter months the outside air in the northern portion of the United States has a relative humidity of about 80 per cent. If we add no water vapor to the air of our houses and schoolrooms, then, while we heat the air to 70°, we are almost certain to find that while indoors we are living in an atmosphere heated to 70° but with a relative humidity of but 20 per cent. or possibly 25 per cent. When we step out of doors we are living in air at 25° but with a relative humidity of about 80 per cent. This means simply that when within doors we are living in very warm air that is exceedingly dry but when we step out of doors we are in air which is cold but usually very moist.

We ought never to forget that if we do not provide for the addition of much water vapor to the air of a well-ventilated house anywhere north of the 40th parallel of latitude, that we are almost certain to be living in an atmosphere which contains but about ⅓ as much moisture as does the outside air in the very dryest climates of the inhabitable portions of the world.

Such dry air is greedy for water vapor and robs every object in the room of all available moisture. As a consequence, the floor-cracks open, the furniture begins to creak, every joint in woodwork and furniture opens, even pianos made of the best kiln-dried wood show the effects of the drought, leather backs of books become dry and sometimes crack, and house plants begin a struggle for life itself.

266. Some Evil Effects of Such Dry Air.—Is such dry air beneficial to the human system? Physicians say it is not. They tell us that such excessively dry air causes rapid evaporation from the nasal passages, and from the throat and bronchial tubes, and thus keeps the mucous membrane in a constant state of irritation; the mucous membrane thus irritated becomes swollen and spongy and affords an easy lodging place for disease germs.

Even physicians who do not object to very dry air, or even see benefits to be derived from living in a dry climate constantly, are among those who object most seriously to this desert-like air in our homes and schoolrooms in northern latitudes. They object most seriously to the *change* we necessarily en-counter when we are obliged to step from an indoor atmosphere heated to 70° with a humidity of 20 per cent. into an outdoor atmosphere at 20° with a humidity of 80 per cent.

267. Dry Air Requires High Temperature.—One has but to consider the effect of dry air upon the wet- and the dry-bulb thermometers to realize that a high temperature is necessary in order that we may be comfortable in a room having such low humidity. When the dry-bulb thermometer reads 70° and the relative humidity is 20 per cent., the wet-bulb thermometer reads 20° lower, *i.e.*, the wet bulb then reads 50°. Now, the human body is constantly moist; more or less evaporation is constantly taking place from the skin. While the clothing, by enclosing an envelope of air about the body, checks this evaporation somewhat, still, if the air in the room is in as rapid motion as it should be, we feel decidedly the chilling effect of evaporation. One is more comfortable in a room heated to 65°, or even 62°, with the humidity 50 per cent. than in a room heated to 70° with the humidity 20 per cent. This is especially true if the air be in motion. For this reason many physicians now advocate the use of the wet-bulb thermometer only, to determine room temperatures.

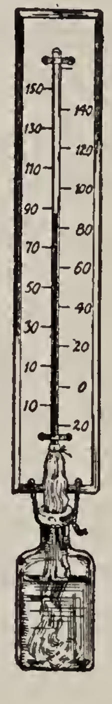


Fig. 182.—A home-made wet-bulb thermometer.

Any common house thermometer can be converted into a wet-bulb thermometer by suspending a 3- or 4-oz. bottle of water from the frame and wrapping the thermometer bulb with a wick of soft muslin (Fig. 182). Such a thermometer will closely indicate the actual temperature in which we are living.

268. Large Amounts of Water Must Be Evaporated.—Many people, who have become convinced that higher indoor humidity is desirable than is usually obtained during the winter months in the northern states, find difficulty in evaporating the necessary amount of water. In fact, much larger quantities must be evaporated than most people realize. By knowing the temperature and relative humidity of outdoor air and the temperature of the indoor air of a well ventilated room one can easily calculate the amount of water which should be evaporated. Experience proves the correctness of such calculations.

The air in the ordinary dwelling having 7 or 8 rooms can be kept reasonably moist, usually, by evaporating from 3 to 6 gallons of water daily. There are usually but few people living constantly in such a dwelling; moreover, there is usually more or less water evaporated in cooking and otherwise.

Schoolrooms are often better ventilated than are dwellings. To humidify a schoolroom properly, north of the 40° latitude in the United States, and well ventilated, requires the evaporation of much more water. It is safe to say that such a schoolroom containing 30 pupils and well ventilated, can be equally well humidified only by evaporating from 10 to 30 gallons of water during the school day of 8 hours during the 3 winter months.

Exercise 54.—Testing the Relative Humidity of the Schoolroom

During the months when artificial heat is being used, the relative humidity of schoolroom air should be determined frequently. If a hair hygrometer is used, it should occasionally be checked by using a wet- and dry-bulb hygrometer and be properly adjusted when found to be inaccurate (see Art. 181).

269. How the Necessary Amount of Water May Be Evaporated.—Where stoves are used to heat the room, it is usually possible to place a pan of water having a large surface on the stove and thus secure sufficient evaporation. In such cases, however, the percentage of humidity in the room is likely to vary much.

In buildings heated by steam it is generally possible to permit the live steam to escape from the system, thus furnishing the required water vapor.

Where hot-water heating is used, small stoves to evaporate the water appear to be the only adequate means of humidifying the air.

Furnaces are generally provided with water pans set in the casings, but they usually have little value as humidifiers. Any device used as a humidifier which will not readily evaporate 1 or 2 qts. of water per hour, in a well-ventilated residence having 6 or 8 rooms, is inadequate when used anywhere in the United States north of the 40th parallel of latitude. Most furnaces are so constructed that it is possible to equip them with a more nearly adequate humidifier easily and at slight expense. Fig. 183 shows how such a humidifier may be installed in a furnace by any furnace setter. A large, seamless galvanized iron or copper pan filled with clean sand is set on the top of the radiator of the furnace inside the casing. A galvanized iron pipe is passed through the casing. The inner end of this pipe is directly over the center of the pile of sand. The outer end of the pipe carries an "elbow," turned so as to open upward. A supply pipe (leading from

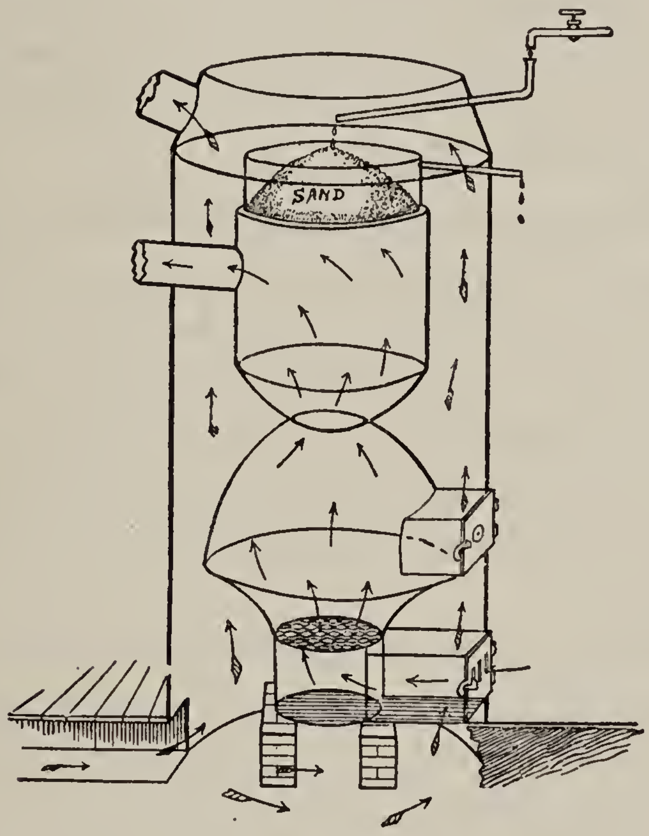


FIG. 183.—Humidifier.

the water system or from a supply tank) equipped with a valve for regulating the flow, is so adjusted that water drips into the upturned elbow. The operator can see exactly how fast the water is being supplied, and the amount delivered by the supply pipe per hour can be determined at any time.

Such a humidifier is nearly automatic in its operation. The sand forms a reservoir which is capable of holding a large amount of water. But it is evident that the sand becomes heated when the fire is burning up freshly. This heated sand then continues to evaporate water even when the fire has died down. In practice it is found that the humidity of the air delivered to the room above a furnace equipped with such a humidifier is fairly constant.

270. Humidifying the Air of Schoolrooms.—The humidifying device which is adequate for ordinary schoolroom use north of the 40th parallel of latitude must be capable of evaporating about 2 gal. of water per hour for each room. To evaporate this amount of water is difficult. Nevertheless, many schoolroom heaters are so constructed that a humidifier similar to that shown in the last article may be installed with good results.

271. Summary.—1. WHEN IS AIR VITIATED?

When its temperature is too high, when its humidity is too great, when foul odors are noticeable, or when it lacks motion so that one's body is continually wrapped in an envelope of unchanged air. The air may also be too low in temperature, or have too low humidity for good health and comfort. Any ordinary increase in percentage of carbon dioxid, or any ordinary decrease in percentage in oxygen is now considered relatively unimportant.

2. WHY DOES VITIATED AIR PRODUCE IMMEDIATE DISCOMFORT?

Because too high or too low temperature, or too high or too low humidity, or the lack of movement of air cause a disturbance of, and overtax the heat-regulating mechanism of the body, and fail to stimulate properly the respiration, circulation, and metabolism of the body. Vital energy is being consumed and when carried to extreme, great discomfort and physical exhaustion results.

3. WHY IS CONTINUOUS LIVING IN VITIATED AIR TO BE AVOIDED?

Because disturbance of metabolism means decreased vitality. Decreased vitality means decreased power of resistance to disease. Moreover, conditions which produce vitiated air are generally favorable for the spread of infectious diseases.

4. HOW IS AIR TO BE KEPT FROM BECOMING VITIATED?

It is not enough that the carbon dioxid in the air be kept down to 0.06 or 0.07 per cent. and the oxygen be kept up to 20.5 per cent. These conditions may be worth while, but in addition, the wet-bulb temperature should be kept near the point of greatest comfort, which will vary probably from 50° or 55°F. for the gymnasium, work shop and factory to 65° or 70°F. for the home library; the humidity should be maintained at 50 to 55 per cent., if possible, and the air should be kept in constant motion, this motion being sufficient to produce a pleasant, stimulating sensation very much like that of the early summer breeze.

Some authorities insist that moderate fluctuation in temperature is preferable to constant temperature. They prefer to have the room frequently "flushed out" to any system of ventilation based upon the constant dilution of the vitiated air (see the next section). Dr. W. A. Evans says, "A ventilating system based on the dilution of breathed air is inefficient and, at the same time, expensive. It is wasteful because it requires 2000 cu. ft. of fresh air per person per hour, while, if the temperature is kept down, the humidity up and the room blown out from time to time, a much less quantity gives better results."

5. WHAT THEN IS THE REAL PURPOSE OF VENTILATION?

Adequate ventilation prevents the accumulation of vitiated air about the body, thereby securing those conditions which are favorable to normal metabolism and the highest possible vitality. Secondly, in crowded rooms it is highly desirable to change the air either rapidly (constant dilution system) or frequently (flushing out system) because it is likely to be more or less laden with unpleasant odors and disease germs.

II. SYSTEMS OF VENTILATION

272. How Ventilation Was Obtained in Colonial Days.—With all its faults, the old fireplace of colonial days had its advantages. Even the one room in which the fireplace was located was rarely overheated. That room was certainly supplied with an abundance of fresh air. Great volumes of air swept up the wide, open-throated chimney, to be replaced by fresh air which crept in through the numerous cracks between the logs or around the loosely fitted windows and doors. This was all in marked contrast to our modern houses with their nearly air-tight walls, heated by means of stoves or radiators, often with no provision whatever for the entrance of fresh air or the exit of foul air. It is a fact worth noting that although the colonists did suffer greatly with the *cold* they did not suffer as we do today with *colds* and *pneumonia*.

273. Modern Systems of Ventilation.—Even the humblest dwelling, heated by means of stoves, may be fairly well ventilated by being flushed out at frequent intervals by throwing open doors or windows. Besides this flushing method, there are several systems of ventilation in more or less common use all of which are based upon the constant dilution of the vitiated air. They all fall into one or the other of two classes; NATURAL, or GRAVITY SYSTEM, and the FORCED SYSTEM.

SYSTEMS OF VENTILATION

1. Natural or Gravity System.	2. Forced Systems.
(*a*) By means of doors and windows.	(*a*) Air forced in by fans, "Plenum System."
(*b*) By means of special air shafts.	(*b*) Air moved by suction fans.
	(*c*) Combination of propulsion and suction.
Generally used in private residences and small buildings.	Generally used in large public buildings.

274. Ventilation of Dwellings.—The system of ventilation employed in dwelling houses is largely determined by the method of heating employed. When heated by means of stoves the dwelling is usually ventilated either (1) by frequent flushings or (2) by window ventilation. The latter is a form of the gravity system. The cooler, outside air is permitted to flow in at the bottom of the window and force the warmer, vitiated, inside air out at the top of the window. In this manner the vitiated air is being constantly diluted.

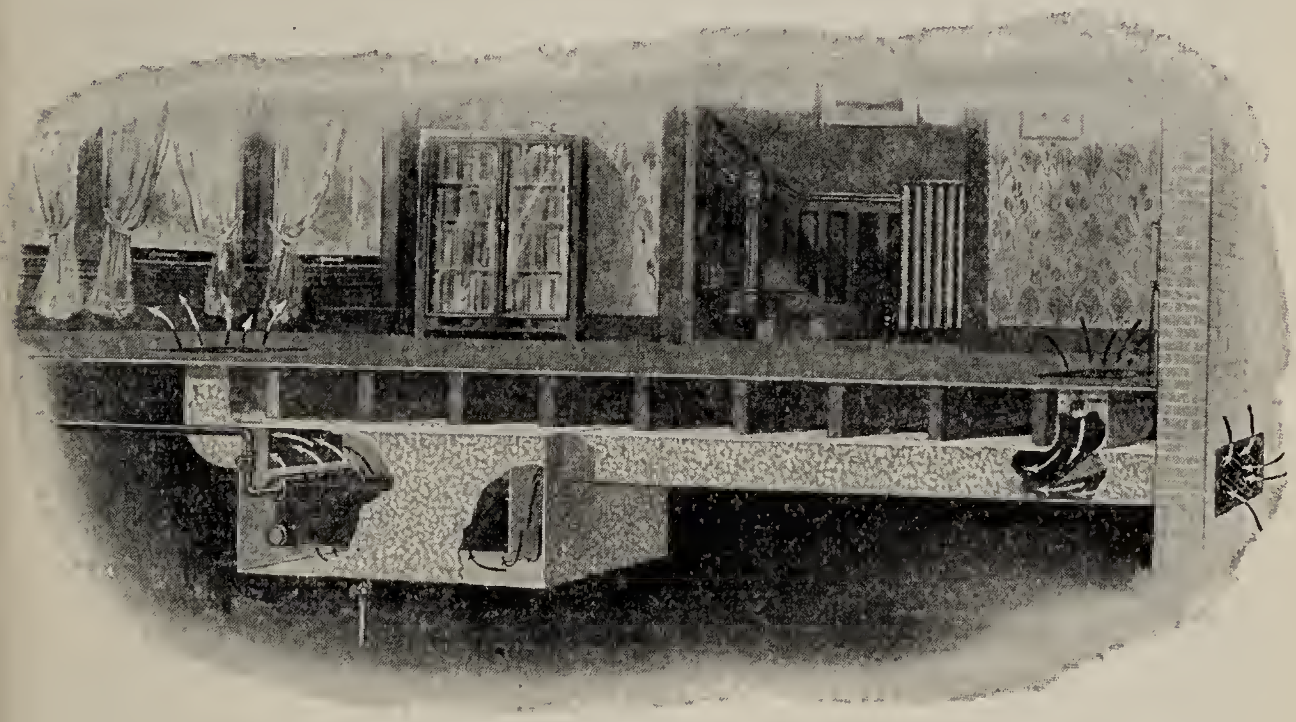


Fig. 184.—Indirect radiation.

When the dwelling is heated by means of a furnace, the fresh air is admitted by means of a fresh-air flue, or intake, entering the base of the furnace (Art. 119). The circulation is maintained by the convection currents (Chap. II, Sec. IX). It is evident that an outlet must be provided for the foul air. The most efficient outlet is provided by an open grate, or fireplace, especially if a fire is maintained in it. Explain why this is so.

When a dwelling is heated by steam or hot water it may be ventilated at the same time if what is known as the INDIRECT RADIATION SYSTEM is used.

In the DIRECT SYSTEM of heating by steam or hot water, the radiator stands in the room to be heated, usually in the coldest portion of the room, beneath or near a window. No provision is made for taking in fresh air; the radiator merely heats the air in the room.

In the INDIRECT SYSTEM, the radiator is suspended beneath the floor of the room to be heated. It is surrounded by a sheet iron casing. From an opening in the outside wall a sheet iron pipe leads the fresh air to the box surrounding the radiator. Another similar pipe leads from the radiator box to the register. When the air around the radiator is heated it becomes lighter and is forced up through the register by the colder, outdoor air or by the colder air of the room as shown in Fig. 184.

275. Ventilation of School Buildings.—The problem of ventilating school buildings is also largely determined by the size of the building and the mode of heating. The usual mode of heating a one-room school is by means of a stove, occasionally by means of a furnace, and rarely by hot water or steam. The heating of large, many-roomed school buildings is usually by means of steam heat, sometimes by hot water, rarely by means of stoves or furnaces.

Exercise 55.—A Study of the Ventilating System of the School Building

The class should examine carefully the heating and ventilating system of the schoolroom or school building. Note where the fresh air is admitted, how it is heated. Can fresh air enter the room unless provision is made for the impure air to escape? Find where and how the impure air is permitted to escape from your schoolroom. Write a short description of the way your schoolroom is heated and ventilated.

276. Heating and Ventilating the Several-room School Building.—Forced systems of ventilation are generally used in modern school buildings containing several rooms. As was the case in the one-roomed school, so here we find that the heating and ventilating systems are usually combined. When such large quantities of air must be moved the gravity system is not adequate, the forced system must be employed. Moreover, school buildings containing several rooms are likely to be heated by steam and steam power is therefore available for driving the FAN, or BLOWER, if desired.

Forced systems of heating and ventilation may be of the propulsion type, known as the PLENUM SYSTEM, or it may be the SUCTION SYSTEM, or a combination of the two systems.

277. The Plenum System.—In the PLENUM SYSTEM the blower or fan is usually placed in the basement and forces all the fresh, heated air needed for heating and ventilation through air ducts into the various rooms. The air in all the rooms is, therefore, somewhat compressed, that is, the air in all the rooms is under somewhat greater pressure than is the air outside the building. Hence the name PLENUM meaning FULL.

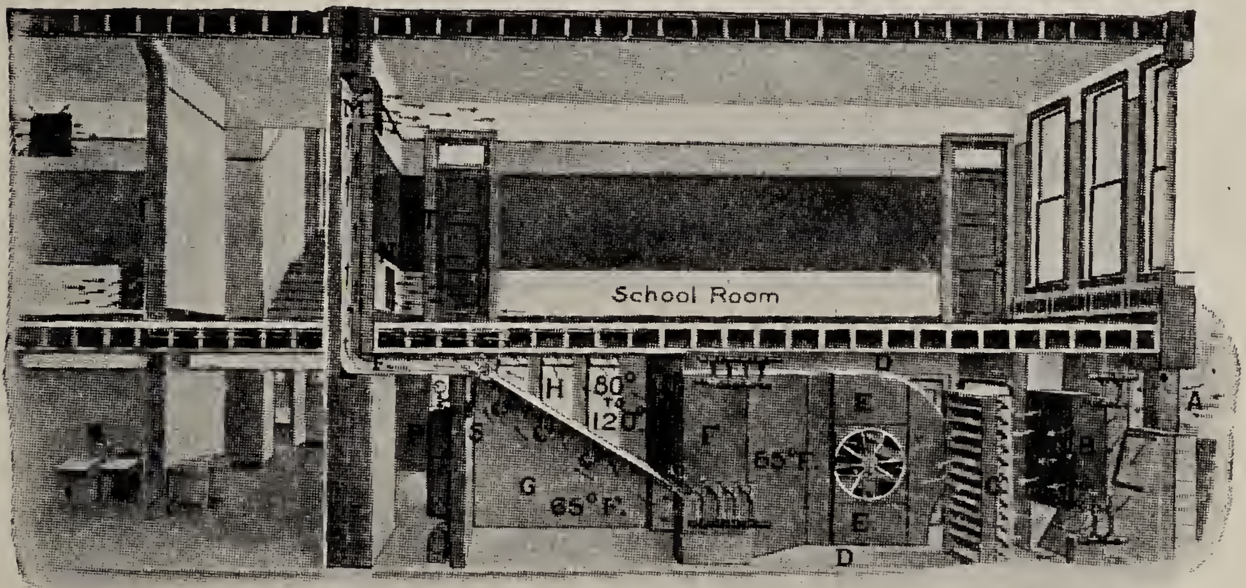


FIG. 185.—Showing the plenum system for warming and ventilating a school building. A tempering stack is shown at the right, next (to the left) is an air washer to insure pure and reasonably moist air, next is a fan or blower, and following that a re-heater, which warms the air to any desired temperature.

Figure 185 shows the usual construction of the plenum type of heating and ventilating systems. The fresh air enters at the window *A*. It then passes through a bank of steam pipes called the TEMPERING COILS, or TEMPERING STACK, *B*. Here the temperature of the air is raised to about 65°F. It then passes through a washer, a spray of water, *C*, which washes the air removing all dust particles and increasing the humidity. The air thus warmed to about 65°, washed and humidified, passes into the TEMPERED AIR ROOM, *D*. It then passes into the BLOWER, *E*, which forces it, blows it, strongly to the left. The upper two-thirds of the exit from the blower contains another bank of steam pipes called the HOT COILS, or RE-HEATER, *F*. Just beneath the hot coils is a horizontal partition, or false floor. The air from the blower may pass through the re-heater into the HOT ROOM, *H*, or it is equally possible for it to pass beneath the false floor directly into the second TEMPERED AIR ROOM, *G*. In both of these rooms, *G* and *H*, the air is under increased pressure due to the force with which the blower forces the air into them. The air in the hot room, *H*, however has been re-heated as it passed through the hot coils, *F*. The temperature of this heated air depends upon the outside temperature. It may be 80° or 85°F. on a mild day, or 110° to 120°F. on a cold day. The air in the tempered room, *G*, remains at about the same temperature as in the first tempered air room, *D*. From the rooms, *G* or *H*, or both, the air passes through the flue *F*, to the wall register, *M*, thence into the room to be heated. The foul air escapes from the room through the other wall register, *N*, into a flue which extends up through the roof.

278. The Thermostat Control of Temperature.—The plenum system is operated on the principle of maintaining a constant temperature. It is necessary, therefore, to control the proportion of heated air from the hot room, *H*, and of tempered air from the tempered air room, *G*, which passes through the flue *F*, to any room. This control is accomplished automatically by a THERMOSTAT SYSTEM.

In the plenum system all of the air which enters the building is fresh, outdoor air. The thermostat system is, therefore, merely an ingenious device by which the tempered air and the hot air are mixed in the proper proportions so as to keep the air in the room at the desired temperature.

279. The Suction System of Heating and Ventilating.—In the suction system the fan, or blower, is usually placed in the attic of the building. The purpose is to suck the air out of the building (see Art. 284). The air within the room is then under less than 1 atmosphere of pressure. The suction system is not often used alone; it is often used in connection with the plenum system to secure more perfect ventilation of laboratories, toilet rooms, kitchens, or other rooms.

III. DUST AND ITS DANGERS

280. Live Dust and Dead Dust.—All dust may be classified as LIVE DUST OF DEAD DUST. While all dust looks alike to the housekeeper and the janitor, it is now known that the chief danger to man lies in coming in contact with live dust. We shall see in Chap. VI that many communicable diseases such as tuberculosis, pneumonia, colds, grippe, diphtheria, and others are caused by living microörganisms. These and other similar organisms constitute live dust. Most, if not all, of these disease germs die quickly when exposed to direct sunlight or high temperature. Therefore, the dust blown in from the street, or the fine ashes coming from the stove or furnace, can not be looked upon as particularly dangerous, no matter how annoying such dust may be.

281. House Dust.—House dust is almost certain to consist of both live dust, living organisms, and of dead dust. It is of great importance, therefore, that so far as possible *all dust* be removed from rooms where people live or congregate, not simply because it looks bad, but principally because it endangers the health of the occupants. Ordinary sweeping with a broom or carpet sweeper does not remove the most dangerous portions of the dust. Dusting the room with a dry dusting cloth does not remove much of the dust. Such methods remove only the large particles of dirt which are not particularly dangerous, merely unsightly, and remove the finer dust from the more exposed surfaces allowing it to settle again in the unobserved places. No system of house cleaning and dusting is effective or much worth while, so far as health of the occupant is concerned, unless it really removes the dust from the house.

Exercise 56.—Observing Dust in the Air of a Room

Darken a room by drawing the window shades (either a living-room at home or the schoolroom will do) leaving a small crack at one window through which the direct sunlight may enter. Observe the dust particles floating in the air. Why is it that they now become visible? With a broom sweep the floor or carpet near the window. Does the amount of dust floating in the air increase? With a dry dusting cloth wipe the walls or furniture and shake the cloth in the ray of sunlight. Note the result.

Remember that this is the air which we are constantly breathing and which is constantly coming into contact with our food as it is being prepared in the kitchen or served upon our dining table.

282. Carpets, Drapery, and Bric-a-brac Dangerous.—Carpets are exceedingly difficult to keep free from dust. Ordinary sweeping removes but little of the fine dust from the carpeted floor; much of the fine dust lodges in the carpet or passes through it. One has but to recall the condition of the floor as it appears after the carpet has been taken up for the annual or semi-annual cleaning, in a house where the floors have been cleaned by sweeping with a broom or carpet sweeper, to see that ordinary sweeping is unsanitary. If the floors are to be kept clean by sweeping they should be oiled, painted or waxed and then covered with rugs which are easily removed and beaten. Such floors may be kept in a sanitary condition. Drapery and bric-a-brac on the walls

Fig. 186.—Carpet sweeper—type of vacuum cleaner.

are dust catchers and very difficult to clean. The more thoughtful people of today are using fewer bric-a-brac to decorate the walls and hang fewer draperies than people did a few years ago. The fewer dust catchers there are in any living room, or any sleeping room the easier it is to care for it and the more sanitary it may be kept.

283. Vacuum Cleaning.—In recent years many devices for vacuum cleaning have been put upon the market. They range from simple, inexpensive devices, operated by hand, or electricity, for use in private dwellings, to large, expensive plants, operated by electric motors or steam engines for the cleaning of the largest hotels, railroad stations, office buildings, school buildings, and stores. They all operate by producing a partial vacuum. In most large types a tube or pipe leads from the machine to the cleaning tool. This cleaning tool fits closely to the carpet or other surface which is to be cleaned. Air pressure causes a strong current of air to

Fig. 187.—Hand Electric Vacuum Cleaner.

rush into the vacuum carrying dirt and dust with it. On its way to the pump where the vacuum is produced, the dust-laden air passes through a thick, closely woven cloth, or is washed by a spray of water, thus removing all dirt and dust. The air which actually passes through the pump is, therefore, practically dust free.

In the sweeper type (Fig. 186) the vacuum is produced by bellows, or movable diaphragms, operated by the friction of the wheels upon the floor or carpet. In this type of cleaner the cleaning tool is a part of the machine itself.

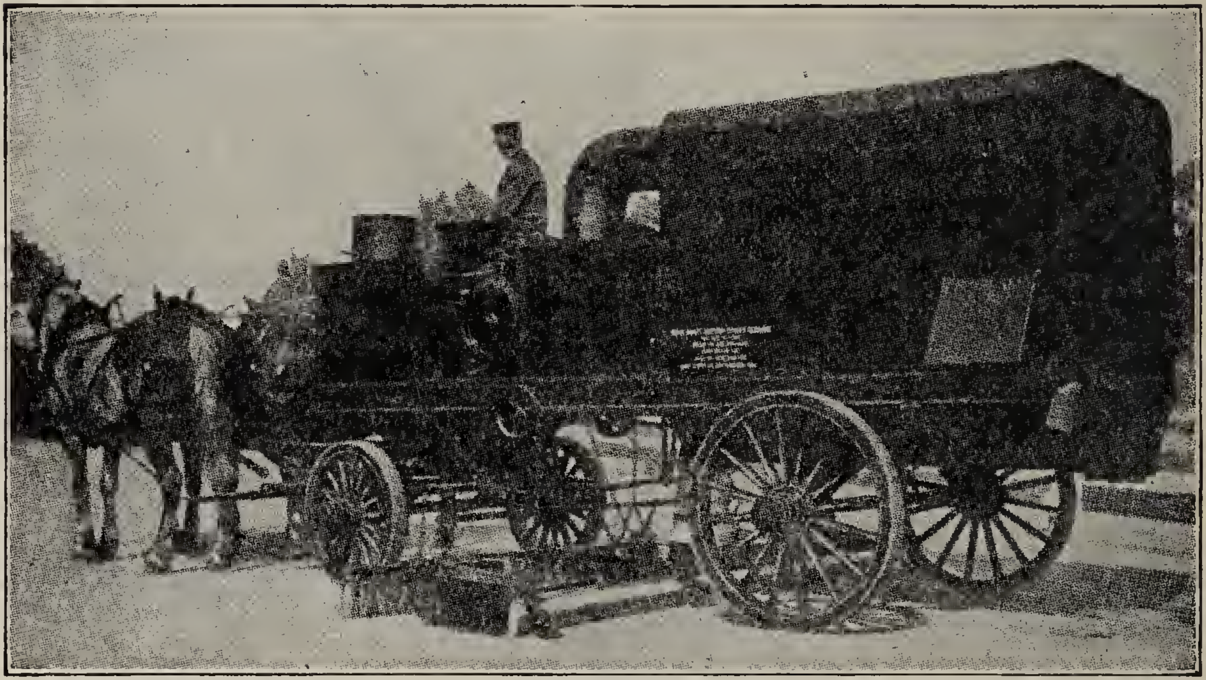


Fig. 188.—A street vacuum cleaner. (By permission of the *Municipal Journal.*)

Many modern dwellings, churches, auditoriums, office buildings, stores and school buildings are equipped with stationary vacuum cleaners. In such cases the machine is usually located in the basement and the suction pipes are run to the various rooms of the building. Rubber hose carrying the cleaning tool may be attached to the suction pipes at convenient points throughout the building. In some cities vacuum cleaners have been successfully used in street cleaning (Fig. 188).

284. Meaning of Suction.—Many people use the word

SUCTION without knowing its real meaning. The words SUCTION and SUCKING are good, common English words, and express ideas not easily expressed in other words. When we use these words we ought, however, to know just what they mean. Suction does *not* mean *drawing* or *pulling* as many people believe. Sucking soda water up a straw does not mean drawing it up the straw. Liquids and gases can not be drawn or pulled; they must be moved by being pushed.

DEFINITIONS.—SUCTION *is the process by which a partial vacuum is produced into which a fluid, either a liquid or a gas, is forced by outside gaseous pressure, usually the pressure of the atmosphere.*

SUCKING *is the act of producing a partial vacuum into which the surrounding atmospheric pressure tends to flow.*

When we suck soda water up a straw we merely enlarge the mouth cavity and thereby produce a partial vacuum into which the atmospheric pressure forces the soda water. When we clean a carpet by means of a vacuum cleaner, the tool fits tightly against the top surface of the carpet. In entering the tool the air must come up through the carpet; as it does so it carries all loose dust and dirt with it.

Exercise 57.—A Study of Vacuum Cleaners

Study several different types of home vacuum cleaners, determining exactly how they work. Write a description of one or more of the cleaners studied.

CHAPTER VI

MICROÖRGANISMS—THEIR RELATION TO OUR FOOD SUPPLY, TO THE SOIL, AND TO OUR HEALTH

285. The Energy of Living Beings.—Every living being, whether animal or plant, requires energy with which to carry on its life processes. All such living organisms get this necessary energy from foods. It is well known that the only living things which can manufacture food out of the simple materials found in air and in soil are the green plants (Art. 373). All foods and all food materials which can give energy to other forms of living things have first been in the form of green plants. The green plants are the food makers of the world.

Since this is true, it follows that all animals and all non-green plants, such as molds, yeasts and bacteria, which we shall study in this chapter, must constantly be striving with each other for the food materials which have been produced by green plants.

Most animals live upon about the same kind of food that man does. Many animals live upon corn, wheat, oats and other grains just as man does. Birds, mice and insects do not hesitate to help themselves to the food that man has collected for his own use and for the use of his domesticated animals.

286. Plants That Attack Our Foods.—People do not generally know, however, that the worst competitors man has for the food he wishes to keep in store are the non-green plants. We have all heard people complain that food, especially cooked food, spoils or decays. They speak in this way because they do not know that what really happens is that very small non-green plants are consuming our food as their food. These minute plants generally escape our notice because they are so small that they can be seen only by the use of the microscope. Because they are so small they are grouped together with a host of minute animals under the general name *microörganisms*—organisms that can be seen only with the help of the microscope.

In Section I of this chapter we shall study some of these plant organisms and the conditions under which they grow most rapidly. We shall also study the methods man has devised to ward off the attacks of the microörganisms upon our food supplies and upon other useful materials which we wish to preserve. We shall also learn that these little microörganisms are not altogether harmful to man. We shall find that they are often very valuable, for they consume materials which are worthless to man. They change all the organic waste materials which are produced where man and the higher forms of life exist back into the raw materials upon which green plants live. In this way they keep up the fertility of the soil. But for the work of these microörganisms in reducing the waste materials of man, of animal life and of the higher plant life back into raw or *inorganic* material—but for their work, all higher forms of life would soon perish from the earth.

287. Saprophytes and Parasites.—The microörganisms of which we read in the last article live upon food supplies and the waste materials of man and the other higher forms of life. They do not live within the bodies of the higher forms of plant or animal life. They are called *saprophytes* (*sapros,* Greek meaning rotten and *phyton,* Gr. meaning plant). That is, saprophytes are plants which live upon dead or rotting materials.

We shall see, however, that there are other microörganisms which live only *within the bodies* of man and the higher forms of animal and plant life. Such organisms are called *parasites.* Modern medicine teaches that it is on account of the presence and activities of these parasites within the bodies of the higher animal and plant life that they suffer and often die of bacterial diseases. This story will be told in Sec. II of this chapter.

I. SAPROPHYTES—PLANTS WHICH LIVE UPON DEAD ORGANIC MATTER

288. Plant Relationships.—It is a fact well known to botanists that the many different kinds of plants are really related to each other much as the different individuals of the human race are related. We group certain plants together because of their having strong likenesses and speak of all of the individual plants as belonging to a certain *species*. All of the plants belonging to a certain species have descended through long ages from a common ancestor. We all know that the individual plants of a certain species are not exactly alike. As the ages go on, the plants of a certain species doubtless will ever tend to vary in many ways.

FIG. 189.—Bacteria. Extremely small even when compared with yeast or mold.

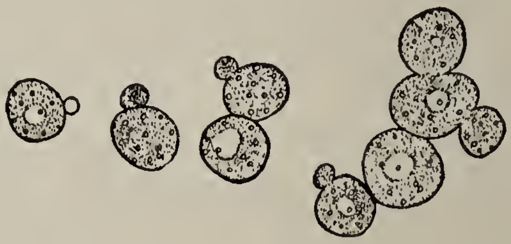


FIG. 190.—Yeast cells, showing the budding of the cells. Greatly enlarged.

If we think back through the ages to the time when a certain individual plant gave a start to a certain species, we shall easily imagine that there were other individual plants growing near by. Each of them resembled, more or less, the ancestor of the certain species just mentioned. A few of those individuals resemble each other very closely. The descendant plants from two or more of these ancestral plants which closely resemble each other will have certain resemblances today. It is such plants which have "blood relationships" which we group together in what we call a *genus* of plants.

To compare with relationships as we know them in the human race, a species of plants includes the brothers and sisters of a family; a genus of plants includes all of the near cousins; a *family* of plants includes all the closely related genera. By *species* of plant life we mean an inner circle of very closely related plants; by genera a somewhat larger circle which includes several species all more or less related; and finally, by family, a still larger circle including all the related species of several genera.

289. Basis of Classification of Plants.—In classifying plants into these groups, botanists rely mainly upon similarities in the organs and processes of reproduction. It is fair to suppose that plants which reproduce by the same methods today have descended from a common ancestor. In classifying some of these minute plants into three classes, *molds, yeasts,* and *bacteria,* botanists depend chiefly upon a study of their different modes of reproduction.

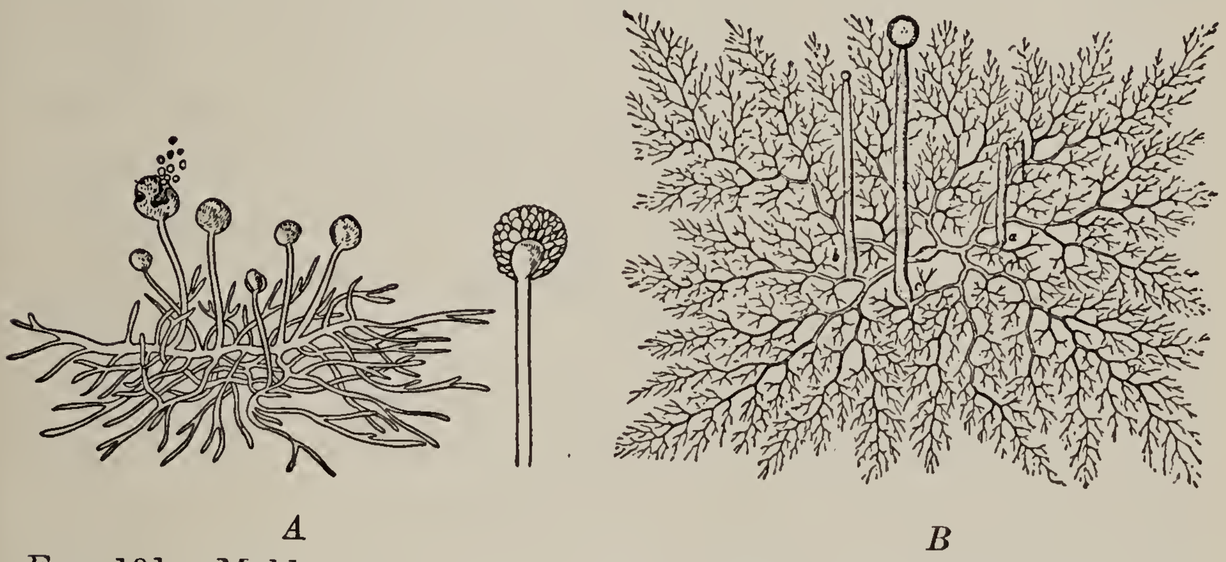


Fig. 191.—Mold—mucor. *A*, common mold, often growing on bread and fruit. *B* shows a diagrammatic representation of mucor, showing the profusely branching mycelium, and three vertical hyphæ (sporophores), sporangia forming on *b* and *c*.

The *ordinary method* of reproduction among *molds* is by means of *spores.* The *ordinary method* of reproduction among *yeasts* is by *budding.* The *only method* of reproduction among *bacteria* is by *cell division.*

We shall want to study each of these classes of plant life somewhat in detail. As we study them, these different modes of reproduction as well as other important characteristics will become clear to us (Figs. 189, 190, and 191).

MOLDS

290. Molds Reproduce by Means of Spores.—As has been stated, the usual way molds reproduce is by spores. As is true of all higher forms of life, the plant body of molds consists of many cells, some of which differ from others. Certain portions of the plant body produce great numbers of small, usually oval-shaped cells, which the wind easily blows off and scatters broadcast when they are matured. These cells are called *spores,* and it is from them that new mold plants grow when these spores light upon suitable soil, and suitable conditions of warmth and moisture exist. The new mold plant thus produced always closely resembles the mother plant.

This method of reproduction reminds us of the usual method of reproduction in the higher forms of plant life, *i.e.,* by seeds. The botanist, however, sees a great difference between spores and seeds which we need not discuss here.

291. A Study of Molds.—

Exercise 58.—Growing Molds

Soak several pieces of bread in water until they become saturated, and then place them under glass vessels where they will remain moist. Set the vessels in a warm place and observe daily for the growth of mold on the bread. When the mold first begins to grow, it will appear as a soft, white, felty mass over the surface of the bread extending up from the surface resembling a piece of very light gray fur. After a day or two, the mold will begin to show some color. It may be pink, green, brown, black, blue, or almost any color, depending on the kind of mold that you chance to get. The plant body of the mold is always of the whitish-gray color that appears first. The color, which appears later and which helps us to distinguish the different kinds of mold, is in the spores.

Exercise 59.—Collecting Molds

Search the garbage can at home, the fruit and vegetable cellar, and the back yards of grocery stores for molds growing on decaying fruits and vegetables. Almost any decaying material of this kind is likely to contain mold, whether the mold is apparent on the exterior or not. Place the material collected in this way in moist, enclosed vessels for further growth of the mold. Transfer some of the spores from the different kinds of mold that you collect to fresh pieces of soaked bread and thus raise as many kinds of mold as you can on the bread. Note how rapidly the mold grows and how soon a new growth produces spores. Can you suggest some reasons why molds are able to grow so rapidly? Considering the fact that molds can grow only when supplied with an abundance of moisture, do you see that it is essential to the success of molds that they be able to grow rapidly and come to fruit in a short time?

Exercise 60.—Study of Molds under a Microscope

When you have a good collection of different kinds of molds, make a comparative study of them under the microscope. You will observe that the plant body consists of numerous, very small and, usually, very much branched threads. These threads are called HYPHÆ (singular, *hypha*) and the whole network formed by the branching hyphæ is called the MYCELIUM (Fig. 191). In some molds, you will note that the hyphæ are broken up into distinct cells by numerous cross walls. In others these cross walls are missing and the whole hypha is one continuous tube-like structure. If you study under the microscope a very small piece of the pulp of a badly decayed apple or banana which shows some signs of mold on the exterior, you will find that the mycelium of the mold has completely permeated the pulp of the fruit.

292. Digestion by Molds.—We know that food generally needs to be digested before it becomes available as nourishment for a living organism and we know something of the nature of digestion. Molds digest their food in essentially the same way as animals do but they have no organ like a stomach, or alimentary tract in which this process is carried on. The molds secrete, produce and give out, certain fluids called *digestive enzymes.* These enzymes diffuse, or spread out, into the material in which the mold is growing. These enzymes prepare the food materials for absorption and assimilation by the molds much as the gastric juice of our stomachs prepares the food materials in our stomachs for absorption and assimilation by the walls of our stomachs. We, perhaps, might well say that the entire exterior, or outside, surface of the mold is its stomach.

Thus, when we say that molds have caused an apple to decay, we might describe more fully what happens if we were to say that the molds have digested and absorbed and grown on the foods contained in the apple. We can not say that the mold eats the apple for, as we commonly use that term, it involves chewing and swallowing and this the mold does not do. In the light of this discussion of the way in which a mold gets its food, can you suggest how it is that the delicate hyphæ of the mold are able to make their way through the solid pulp of an apple?

Fig. 192.—Aspergillus.

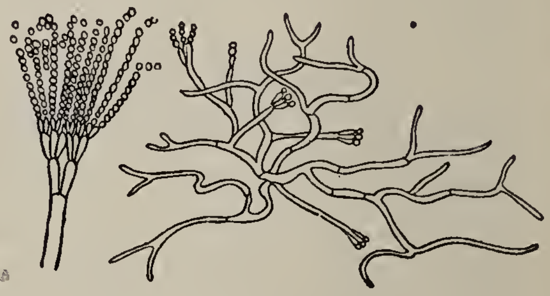


Fig. 193.—Penicillium. A common mold. The spores give it a greenish color.

293. Methods of Spore Production.—

Exercise 61.—Microscopic Study of Molds

After you have studied the mycelium of a given mold under the microscope, mount a little of the portion of it which is just beginning to show spores and observe the character of the structure which bears the spores. The spores are generally borne on vertical branches of the mycelium which extend some distance above the substratum, or mass of food, within which the main body of the mycelium is growing. At the top of this vertical branch which is called a SPOROPHORE, the spores are borne in different ways in different kinds of molds. The accompanying figures illustrate the manner in which some common molds produce spores (Figs. 191, 192, 193 and 194).

Note the countless number of spores that you get on your microscope slide from a very small quantity of the material. Remembering that these spores are always borne up in the air above the substratum, and that they are light and powdery, do you wonder that the spores of mold are abundant everywhere? Do you see that the molds are highly fitted to compete with us for possession of our food?

In this way, study all the different kinds of molds that you have collected. Your instructor will be able to tell you the names of several of the different kinds of molds that you study and you will be able to identify some of them by comparing them, as you study them, with the different figures in the text.

Exercise 62.—Identifying Molds on Different Materials

After you have learned to identify several different kinds of molds, select one or two of them and see how many different kinds of material you can find them growing on. If you select the common green mold, PENICILLIUM, for example, you should find it growing on a great variety of different substances (Fig. 193). Cheese, cured meats, stale bread, old clothing, old shoes, indeed, almost any kind of plant or animal matter may afford food for this mold. Note that the general appearance of a given mold varies considerably as it grows in different situations.

294. Conditions Which Favor Mold Growth.—If we are to be successful in warding off the attacks which molds make on the things which we wish to preserve, we must understand the conditions which are favorable for mold growth. Everyone is familiar with the fact that molds do not grow on materials which are quite dry. One of the earliest methods which man ever devised for the preservation of food is that of drying it. *A certain amount of moisture must be present before molds can grow at all and a considerable amount is necessary for a luxuriant growth.* When there is barely enough moisture present in a given material to support a mold growth, the mycelium development is very slight and there is little visible evidence of the presence of the mold except the spores. The spores are borne on very short sporophores and present a powdery appearance over the surface of the substratum. It is common to speak of mold when it presents this appearance as MILDEW. Mildew is simply mold which has grown on a scant moisture supply. During most of the year, the out door air and the air in houses is relatively dry. Consequently, dry objects in this air are too dry for the growth of molds. In the damp, sultry weather of the summer time, however, the air sometimes becomes so damp as to give sufficient moisture to dry objects, such as clothing, carpets, and the like, to permit a growth of mold on these materials.

FIG. 194.—Antenaria. Note how differently it bears its spores when compared with mucor, aspergillus, or penicillium.

Clothing hung in closed closets and the carpets of unused rooms which are closed up, are more likely to suffer from mold growth during damp, warm weather than if they were well aired, for *it has been found that air movement is detrimental to the growth of mold.*

Molds will grow to some extent at comparatively low temperatures, some even growing a little at only a few degrees above freezing. *For any rapid growth, however, a rather high temperature is usually necessary.* We take advantage of this fact in keeping our food from molding between meals and over night by putting it into a refrigerator. We should remember, however, that the temperature of a refrigerator is sufficiently high to permit of some mold growth, and for this reason we should not attempt to keep food in a refrigerator very long.

The four necessary conditions for rapid growth of molds, then, are: *Plenty of moisture, quiet air, a moderately high temperature, and food.*

295. Effect of Mold Growth on Food.—Food is not necessarily ruined by the growth of mold in it. In fact, every time we eat an apple that is partly decayed, we are likely to eat a considerable quantity of mold which has already penetrated the apparently sound parts of the apple. Similarly, when we eat apple sauce, or other similar food, which has stood in a refrigerator for a day or more, we are likely to eat some mold even though we are unable to detect it. An abundant growth of mold in food will give it a changed flavor which we may not like, but we are not likely to be harmed in any way by eating food even when mold can be tasted in it. When mold grows in food, the food loses some of its value, for the mold consumes some of the food which we might otherwise have had, and our consumption of the mold does not wholly make up for this. Ultimately, the molds, and the bacteria which are likely to accompany them, will completely consume the food and render it worthless. On the other hand, the growth of some molds in certain foods greatly enhances their value by giving them a delicate flavor which we very much desire. If you have ever eaten Roquefort cheese, you have had experience with one of these useful molds.

YEASTS

296. The Prevalence of Yeasts.—Yeasts have been used by man for raising bread and for making fermented liquors since before the time of historical records. Yet, notwithstanding this, the actual relation which yeasts bear to these processes was never clearly demonstrated until after the middle of the nineteenth century. We do not even need to put yeast into fresh fruit juice in order to make a fermented liquor out of it, for yeasts, like mold spores, are widely distributed and are always sure to be present wherever there is suitable material for them to feed on. Similarly, it is possible to make raised, or leavened, bread without putting prepared yeast into the mixture. Probably you have eaten what is called ''salt rising'' bread. This bread is made by putting a little salt into some milk and allowing it to stand in a warm place for a time, and then using this milk for mixing the bread. The salt keeps other organisms from growing in the milk, and wild yeasts fall into it and multiply until they are numerous enough to cause the bread to rise.

In essentially these ways, yeasts have been used for many centuries, but it was not until after the perfection of the microscope that men were able to find out much about them. In recent years we have learned many interesting things about yeasts, but there are still many things that we do not understand about them. You will doubtless be interested in learning some of the things that are known about these little plants that play so large a part in our lives.

297. Study of Yeasts.—

Exercise 63.—Growing Yeast

Mix about 2 tablespoonfuls of molasses with a quart of warm water in a glass vessel. Stir the mixture thoroughly and then add about one-half of a cake of compressed yeast, breaking the yeast cake into small particles. (If compressed yeast is not available, dried yeast cake will answer, but it will be very much slower in action.) If possible, keep the mixture at a temperature of from 70° to 90° F. Note the bubbles of gas that soon begin to rise in the mixture. Mount a small drop of the mixture on a microscope slide and study under the high power of the microscope. Note the size, shape, abundance, and general character of the yeast plants. In this fresh mixture, you will probably not find any budding cells for, in the yeast cake, the plants are more or less dormant, or inactive. If you study in the same way an older mixture of the same kind which your instructor may have prepared a couple of hours or more before class, you will find many budding plants.

Exercise 64.—Growing Yeast Produces Carbon Dioxid

Fill a small bottle about two-thirds full with the yeast mixture. Fill another small bottle up to the neck with clear lime water. Put a one-hole rubber stopper into the bottle containing the yeast mixture and connect the two bottles by a U-shaped glass tube as shown in Fig. 195. As the gas which you have observed rising from the yeast mixture accumulates above the liquid, it will be forced through the glass tube over into the limewater. Observe the white, milky cloud that forms in the limewater near the open end of the tube. The white substance which forms as the gas from the yeast mixture is forced into the limewater is essentially the same as common chalk. It is formed by the chemical action of carbon dioxid on limewater, and, therefore, its appearance here indicates that the gas which the yeast mixture is giving off is carbon dioxid. You are familiar with the fact that your own breath contains carbon dioxid. Take some fresh clear limewater in a small bottle or test tube and by means of a small glass tube, force your breath through the limewater. (Review Arts. 75 and 76, especially Ex. 26.)

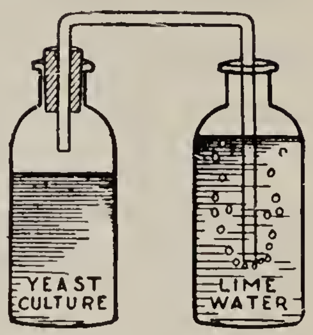


Fig. 195.—Carbon dioxid produced by growing yeast.

Exercise 65.—Growing Yeast also Produces Alcohol

Permit your original yeast mixture to stand in a warm place for several days until signs of fermentation have about ceased. Now, taste the mixture to see if you can detect the sharp sting and the sweet taste of alcohol. Place the mixture in a distilling flask and distill the alcohol as in Ex. 17, Art. 24. What is the first of the distillate? Do you secure enough alcohol vapor to burn?

298. Yeasts and Fermentation.—All the practical uses which we make of yeasts center in the peculiar relation which they bear to sugar. In the first place, sugar seems to be their natural food. It has been found possible to grow them in certain mixtures which do not contain sugar but in all the practical processes in which we use them, a sugar solution of some kind is used as a CULTURE, or material in which to grow them.

Under certain conditions it is known that yeasts use sugar as food, digesting, absorbing and assimilating it just as animals do. Under other conditions, especially in the absence of oxygen and in an excess of sugar, the yeast digests and absorbs the sugar. But when it is taken into the body of the yeast plant it is probably acted upon by an enzyme which merely breaks the sugar molecules up into molecules of alcohol and carbon dioxid. The alcohol and carbon dioxid is then thrown off from the yeast plant into the culture medium.

This process of breaking sugar up into alcohol and carbon dioxid by the yeast plant is entirely distinct from the use of sugar as food by the yeast plant. It is, and always has been, something of a mystery as to what benefit the yeast plant derives from the process. Possibly the yeast plant gets a little energy from the process, if so, it is very little; perhaps the process is Nature's way of affording protection to the yeast plant, for up to a certain concentration, the alcohol does prevent the growth of other organisms, but is not detrimental to the yeast; possibly the process is of no material benefit to the yeast plant at all.

299. Yeasts and the Production of Alcoholic Liquors.— All intoxicating liquors derive the alcohol they contain from the process of alcoholic fermentation carried on by yeasts. In the making of all the different kinds of liquors, a sugary solution of some kind is always provided. This is INOCULATED with a quantity of yeast and kept at a suitable temperature until the fermentation has gone as far as desired, or until the accumulating alcohol has killed the yeast and stopped the process.

In the case of wines, beer, and ale, the mixture is next put into bottles or kegs and is ready for use. In some of these undistilled liquors, the bottling is done before fermentation has entirely ceased, and thus a considerable quantity of carbon dioxid remains in the liquor. This adds to the flavor of the liquor and is responsible for its sparkling quality. The color and part of the flavor of wines is derived from the fruit juices used in making them.

In the making of distilled liquors, such as whiskey, rum, and brandy, the process of fermentation is carried as far as possible and then some of the water of the mixture is removed by the process of distillation (see Art. 24).

In making liquors from cereals, such as corn, rye, and barley, the starch of the cereal is first changed to sugar by the process described in Art. 420, and then the sugar is fermented by yeasts.

300. Yeasts and the Making of Bread.—It is the carbon dioxid which results from fermentation which is of use in making bread. The flour which is used in making bread contains some sugar and usually a little more sugar is added to the dough as it is mixed. The yeast that is mixed with the dough ferments this sugar and produces both alcohol and carbon dioxid. The flour also contains a considerable quantity of a protein substance, GLUTEN (Art. 413). The gluten gives the dough its sticky character and makes it more or less impervious to gases. Consequently, as the yeast produces carbon dioxid throughout the dough, the gas collects and forms little cavities in the dough making it light and porous. You have seen (Art. 12) that alcohol is a very volatile substance. Consequently, in baking the bread, all the alcohol is vaporized. As the bread is baked, the gluten of the dough is so changed in character as to become quite porous to gases. It, therefore, allows both the vaporized alcohol and the carbon dioxid to escape.

You thus see that we use yeast in making bread, primarily, for a sort of mechanical effect which it produces on the bread, making it light and porous, and on this account more easily digested. In addition to this, the yeast adds a nut-like flavor to the bread which we like very much.

If the knowledge of the rôle that yeast plays in bread making is of any practical value, it lies in the fact that the bread maker will realize that she is dealing with living organisms. If she has this fact in mind, she is likely to be more intelligent in providing favorable conditions for the growth of the yeast. In general, it may be said that the best bread results from a moderately rapid fermentation, but the details of managing yeast for bread making are too numerous for us to enter into here.

301. Wild and Cultivated Yeasts.—All the different kinds of yeast used in bread making, except that used in making salt rising bread, and all that are used in the breweries and distilleries, are what may be called CULTIVATED YEASTS. These consist of several distinct species and varieties which vary in their usefulness for different purposes. All have been in use by man for so long a time that their origin from the wild state cannot be traced. In addition to these, WILD YEASTS of several kinds are widely distributed in the soil and air and it is these that are used in fermenting fruit juices in making wines.

Exercise 66.—Study of Wild Yeast

Place a little fresh apple cider or other available unfermented fruit juice in a glass tumbler and allow it to stand in a warm place for several days. After the fruit juice has shown signs of fermentation, mount a drop of it on a microscope slide and examine it under the high power of the microscope for yeasts. You will probably be able to notice that the yeast cells differ in shape somewhat from the tame yeasts that you formerly studied.

302. Yeasts and the Preservation of Foods.—Wild yeasts are floating everywhere in the air. They are constantly falling into our foods. They are consequently always coming into competition with us for our sugar-bearing foods. Such foods as apple sauce, fruits of all kinds, and other sugar-containing foods are always in danger of being fermented by wild yeasts. We protect them somewhat by keeping them at low temperature in a refrigerator and sometimes in other ways.

It is a rather peculiar fact that some foods which contain *much* sugar are seldom attacked by yeasts. This is true of syrups, rich preserves, and jellies. While sugar is the principal food of yeasts, strong concentrations of it serve as a preventative against both yeasts and bacteria. When yeasts and bacteria fall into strong concentrations of sugar, so much water is drawn from their bodies by the sugar that they are killed. This does not occur in weak solutions of sugar.

This fact is sometimes used in the home treatment of wounds. Bacteria can be prevented from getting into an open wound by pouring a considerable quantity of granulated sugar on to the wound just before it stops bleeding. The sugar makes a thick syrup with the blood. This syrup will usually kill all bacteria which would otherwise enter the wound. If the wound is then wrapped up and kept clean it usually will heal without the least inflammation.

FIG. 196.—Louis Pasteur.

FIG. 197.—Robert Koch.

BACTERIA

We have seen that molds and yeasts are rather important factors in our environment. In some ways they render us important service and in other ways they are the cause of great inconvenience to us. Bacteria are of tremendously greater importance to us in both these ways than are either molds or yeasts. Bacteria are the smallest of living things and they are doubtless the most widespread in their distribution. We might well consider ourselves fortunate that we are living in these days since the perfection of the microscope which has enabled men to learn something of this teeming invisible world of life which touches us on every hand.

303. Development of the Science of Bacteriology.—The first authentic report which we have of bacteria having been seen by man was in 1683. Anthony Van Leeuwenhoek, a Dutch linen weaver, who spent his leisure time in grinding lenses and in using them to study various materials, was the first man to see and to describe these wonderful little living creatures (minute plants, not animals) which you are soon to have the privilege of seeing. In a letter to the Royal Society of London, he said: "I saw with wonder that my material contained many tiny animals which moved about in a most amusing fashion." Are you going to see these organisms for the first time "with wonder," or are you going to consider it a commonplace experience just as we do many wonderful things in these days? Very little progress was made in the study of bacteria for nearly two centuries after Leeuwenhoek's discovery. It was not until the latter half of the nineteenth century that the science of bacteriology had its wonderful development. This development of a science from the faintest beginnings to one that ranks in the very forefront of the various branches of knowledge within the time of a single generation, was very largely due to the work of two great men. These men are Louis Pasteur (Fig. 196) who may be called the father of bacteriology and Robert Koch (Fig. 197) who may be said to be the man who made bacteriology an independent science. You should improve the first opportunity to learn something of the personal lives and of the work of these men.

Exercise 67.—Study of a Hay Culture

Fill a large glass jar with water, preferably water from some pond or stagnant pool, and put a good sized handful of timothy hay into the water. The hay should be cut into small pieces before it is put into the water. Place the jar in a warm place and continue to study the organisms that appear in it for several days. If the temperature of the water does not fall below 70° F. you should find it teeming with bacteria at the end of 24 or 48 hours. Bacteria will continue to be abundant in the culture for several weeks. If you study a sample of the water about every other day for a period of two or three weeks, you will find that different forms of bacteria will be most abundant at different times. If the jar is allowed to stand for a month or two, all bacterial action will finally cease and the water will become quite clear. Can you suggest the reason for this?

304. **Life History of a Hay Culture.**—Along with the different kinds of bacteria which from time to time will appear in the culture, you will find a great many different kinds of microscopic animals. As you study the culture from time to time, you will find that each kind of animal, like each kind of bacterium, will seem to have its day and then gradually disappear to give place to some other form. The reason for this shifting panorama of life which a culture like this exhibits is found in the varying chemical conditions of the culture which are brought about by the organisms themselves. Thus, a given organism becomes the leading type whenever the conditions of the culture are most favorable for it. This type of organism gradually consumes the food available to it and at the same time contributes harmful waste materials to the culture. When this continues for a time, the conditions of the culture become gradually more unfavorable for this particular form, but at the same time it becomes more favorable for a succeeding form of life. This succeeding form then becomes the leading type in the culture for a time and then, in its turn, in the same way, and for the same reasons, gives way to a new successor.

Now, if you can imagine, not one line of succession like this, but many such lines going on at the same time, you will have a fairly accurate picture of what is going on in your culture. Not only this, but this picture of change in your culture is a fairly accurate picture of what is going on in nature everywhere.

The story is thus: Green plants feed upon the simple inorganic compounds found in the soil, air and water. They build these into complex compounds of organic matter within their bodies. They die. Bacteria feed upon the dead bodies of these higher forms of life reducing the complex organic compounds again to simple inorganic compounds. These in turn become food for another generation of green plants. This is the ceaseless round of life and death.

305. Decay in General.—It is a long and interesting story from the planting of an acorn to the final dissolution by natural processes of the body of the giant oak that results. One might think that the story is ended when the tree has come to its death, but with this picture of your culture in mind you will see that probably the most interesting part of the story begins with the death of the tree. Thousands of different forms of life take part in its destruction. It is in this work of the dissolution of organic bodies that microörganisms play their most important rôle in the life of the earth.

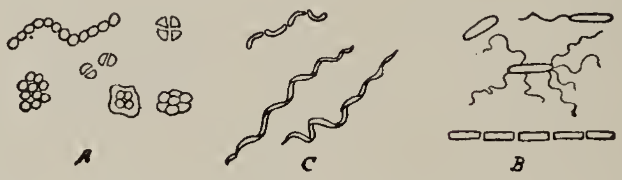


Fig. 198.—Cocci, spirilla, and bacilli.

Were it not for the work that these organisms do, the earth would become strewn with the dead bodies of animals and plants, and the chemical elements which composed these bodies would never again become available for succeeding forms of life.

306. Forms of Bacteria.—As you study your culture from time to time, you will have opportunity to observe the three different forms of bacteria (Fig. 198, A, B, C). Sometimes you will have all three forms on your slide at once. The three forms are: first, spheres, called *cocci* (pronounced coc-saī), (singular, coccus), *A;* second, rods called *bacilli* (singular, bacillus), *B;* spirals called *spirilla* (singular, spirillus), *C.* Some of each of these forms have swimming organs, thread-like appendages, *B,* and these are able to swim through water. Most of them lack these organs and are, therefore, non-motile, or without the power of self-motion. The bacilli are most numerous, the cocci rank next, and the spirilla are least numerous. Migula, the German bacteriologist, in 1900 described 833 different bacilli, 343 different cocci, and 96 different spirilla.

It is a most difficult task to distinguish these different kinds of bacteria. Two different bacteria may look for all the world alike under the microscope, and yet the waste products they produce may be very different. These products from one may be a violent poison in our bodies while the products from the other may be perfectly harmless to us.

307. Where Bacteria May Be Found.—It would be easier to say where bacteria are not found for they are found almost everywhere. They are doubtless absent in the midst of deserts, in the depths of the sea, in the frigid regions near the poles, and in the tissues of healthy animals and plants, but in almost any other place on or near the surface of the earth they are present in great abundance. Bacteria are ever present in the soil, water, and air, in the food and, consequently, in the mouths and alimentary tracts of animals, and in all decaying organic substances everywhere.

They are never growing and active, however, unless they are supplied with an abundance of water, a suitable food supply, and a favorable temperature. In the ordinary form, they can endure drouth and remain alive for some time; the different kinds vary greatly in this power, however. Some kinds have the power of forming SPORES which endure drying for many months, some even for many years, and still retain the power of growing whenever they fall into suitable conditions. In the formation of these spores, the whole living part of a bacterium contracts into a spherical body within the original cell wall; a new and thicker wall is secreted about this body; the original wall bursts and the spore is set free. The spore is thus a means of living over an unfavorable season, or of resting until suitable conditions for growth return. The fact that bacteria are able to endure drought either in the spore form or in the ordinary form, accounts for their wide distribution and for the fact that they are present and ready to begin active growth whenever and wherever any suitable material is found for them to grow in.

1. Soil Bacteria

308. Study of Soil Bacteria.—

Exercise 68.—Soil Bacteria

Procure some rich soil from a stable lot or a garden. Fill a glass tumbler half full with the soil and then fill the tumbler to the top with water. Stir the mixture thoroughly and allow it to settle. After the soil has settled, examine a drop of the water under the high power of the microscope for bacteria. Examine a drop of clean well water in the same way and compare the number of bacteria in the two samples of water.

You will get the idea from this experiment that the soil contains myriads of bacteria. In the water taken from the tumbler containing the soil, you will doubtless find some microscopic animals similar to those you found in your hay culture. The two kinds of organisms in the soil bear the same relations to each other as they do in the hay culture. That is, the bacteria of the soil feed on the dead organic matter of the soil, and the microscopic animals in turn feed on the bacteria.

309. The Nature of Soil.—Before taking up the relation of bacteria to the soil, it is necessary for us to know something of the nature of soil. Geologists tell us that the outer crust of the earth was originally solid rock, and that through the influence of weathering agencies, such as the sun and wind, freezing and thawing, and the flowing of water, much of this crust of rock has been ground into exceedingly fine particles. These fine particles now make up a deep layer of soft material which we know as clay, sand, and gravel and which covers the deeper solid rock of the earth's crust. For a few inches or feet below the surface, this clay and sand and gravel is, in most places, well mixed with decaying remnants of the bodies of plants and animals. It is these few inches or feet on the surface of the soft blanket of the earth that are well mixed with organic matter that we call SOIL. It is in this thin layer of soil, mainly, that the materials are contained which the higher plants take in through their roots and use in building up the more complex foods with which they nourish themselves and the rest of the living world. The organic matter in the soil is collectively spoken of as HUMUS and it is this humus which supplies food to the soil bacteria.

310. **Soil Bacteria and Carbon.**—The soil bacteria complete the work of destruction of the particles of plant and animal matter which fall into the soil. All these materials contain large quantities of carbon combined with other chemical elements and when the bacteria have digested, absorbed, assimilated, and respired them, the carbon escapes to the air in the form of carbon dioxid gas. This you will remember is the form in which the green plants take up carbon from the air and again combine it in a form which serves as food. Thus it is that bacteria, and other agents, such as other non-green plants and animals keep constantly returning carbon dioxid to the air where it becomes available for the green plants.

311. **Soil Bacteria and Nitrogen.**—We shall see in Chap. VII, Art. 370, that only a comparatively small number of chemical elements are needed to make up the numerous chemical compounds that constitute the human body. This is true of all living bodies. Among these few necessary elements there is none that gives us greater concern than nitrogen. This element constitutes about four-fifths of the atmosphere, but it is not found in a combined form in the *natural* rock of the earth. *It is therefore not in the soil in a combined state except as it has been put there by living organisms.*[1] On this account, the nitrogen supply of the soil is

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[1] Note: Small amounts of combined nitrogen are carried down by rain during storms, especially thunder showers. Lightning causes some of the nitrogen and oxygen of the atmosphere to unite into chemical compounds, gases, which are absorbed by the falling rain.

usually more limited than that of the other soil elements which were present in the original rock of the earth from which the soil was made. At the same time no living thing can exist without nitrogen for it is one of the necessary elements in the makeup of protoplasm.

The green plants take up the nitrogen from the soil in certain definite chemical compounds, usually in the form of NITRATES, such as potassium nitrate. The green plant has the power of combining the nitrogen in this form with other elements to form proteins (Art. 384). These proteins are food for the green plant and for other organisms. The nitrogen which is thus formed into protein compounds by green plants is practically the only available supply of nitrogen for the animal world. Animals do not have the power of making proteins out of nitrates or other similar compounds. We get proteins when we eat the flesh of other animals, but this, in turn, may always be traced back to proteins formed by some green plant (see Art. 374).

312. Some Classes of Soil Bacteria.—Now, it is probably evident to you why we are so greatly concerned about the supply of nitrogen in the soil in a form available to the green plants. With this thought in mind, you will doubtless be interested to know the part that the soil bacteria play in keeping up this supply of available nitrogen in the soil. The bacteria which do this work may conveniently be divided into three groups: (1) The NITRIFYING BACTERIA, (2) the NITROGEN FIXING BACTERIA, and (3) the NODULE BACTERIA.

313. The Nitrifying Bacteria.—The NITRIFYING BACTERIA transform the various nitrogen-bearing compounds of the soil humus into the nitrate form. This is not a simple process, as you might suppose, but consists of three distinct steps. Each step in the process is performed by a different set of bacteria, but several different species of bacteria are known for each step.

The first step in the process is the changing of the proteins and other nitrogen-bearing compounds of the humus into ammonia. If you turn over a rapidly decaying mass of organic matter, you can usually detect the characteristic odor of ammonia along with various other odors.

The second step in the process is carried on by an entirely different set of bacteria and results in changing the ammonia to NITRITES. Nitrites differ, chemically, from nitrates in having relatively less oxygen in their composition.

The process is completed by another set of bacteria which changes the NITRITES to NITRATES.

It is evident that these bacteria which simply *transform the nitrogen-bearing compounds of the soil humus into a form available for the higher plants do not actually add any nitrogen to the soil.* They only transform nitrogen that is already there. If you recall the fact (Art. 311) that the original rock of the earth does not contain any fixed nitrogen, you will see that we so far, have no means of accounting for the origin of the present nitrogen content of the soil. *The bacteria of this group only aid in keeping the nitrogen in circulation, they do not add to the total stock.*

314. Nitrogen Fixing Bacteria.—A second group of bacteria which have to do with the nitrogen content of the soil consists of several species which recently have been discovered and proved to be able *to take the free atmospheric nitrogen and fix it in compounds which finally become available for the higher plants.* These bacteria live in the soil and derive their carbo-hydrate food from the humus just as others do. If fixed nitrogen, *i.e.,* nitrogen in the form of nitrogen compounds, is abundant in the soil, they also use this. *In the case, however, of the scarcity or absence of fixed nitrogen, they are able to draw on the great ocean of free atmospheric nitrogen. Unlike the first group discussed above, these bacteria are thus able to add to the total nitrogen content of the soil.* It is doubtless true that these organisms have been important factors in bringing about the gradual increase in the nitrogen content of the soil that has occurred during the ages.

In ancient times the custom of FALLOWING land was largely practised. This consists of cultivating the land for a season to keep down the weeds without attempting to raise a crop on it. It was believed by the ancients that in some way through this practice, the land was enabled to produce a very much better crop the following season, and this belief was abundantly supported by practical experience. We now have, at least, a partial explanation of this fact in these bacteria which add atmospheric nitrogen to the soil.

315. Nodule Bacteria.—The third group of bacteria that affect the nitrogen of the soil, like the second group, have the power of *fixing atmospheric nitrogen* but they seem to be able to do this only when they live within the root tissue of certain higher plants, mainly those that belong to the botanical family which includes clover, alfalfa, beans, peas, and the like. When these organisms grow in the roots of the host plant, they cause little outgrowths, or knots, to form on the roots, which are called NODULES, and the bacteria themselves are often spoken of as NODULE BACTERIA (Fig. 199). The nitrogen in the soil air is taken in by these nodule bacteria and combined with other chemical elements. The new materials thus formed become available food for the host plant. When the host plant finally dies and decays, the nitrogen fixed by the nodule bacteria becomes a part of the soil.

It has long been known by practical farmers that plants belonging to the clover family tend to increase the productivity of the soil. It is only recently, however, that the discovery was made that it was not the higher plant, the clover, itself, that was the cause of the increase in the nitrogen content of the soil but that it was the work of the nodule bacteria.

316. Summary of the Work of Soil Bacteria.—There are three groups of soil bacteria which tend to increase the nitrogen content of the soil: 1. Nitrifying bacteria; 2. Nitrogen fixing bacteria; and 3. Nodule bacteria.

The first group, nitrifying bacteria, are merely the active

Fig. 199.—Roots of red clover (above) and of soy bean (below), showing nodules formed by nodule bacteria.

agents which return to the soil the nitrogen which has been a part of the bodies of higher forms of life. Nitrifying bacteria do not in any way add to the total amount of nitrogen in the soil and in the bodies of the higher forms of life. They merely keep the nitrogen in circulation. We shall study them further under the head of DECAY.

The other two groups, nitrogen fixing and nodule bacteria, actually seize upon atmospheric nitrogen and so combine it with other elements that it becomes available as food for the green plants.

317. Effect of Cropping on Soil Nitrogen.—In a state of wild nature, in which all plants which grow upon the soil, die where they stand and soon decay, returning their nitrogen to the soil, there is a gradual but constant increase in soil nitrogen. This should mean a gradual increase in the fertility of the soil. This increase in fertility of soil should mean a gradual increase in the luxuriance in plant growth. This, in general, we believe has been the history of the world.

Under the usual methods of agriculture, however, a large portion of the crops grown on the land is often removed. As a natural result we should expect that the soil nitrogen, and therefore the fertility of the land is reduced. If the amount of nitrogen carried away in the crops removed, together with the nitrogen which is carried off with the drainage, is greater than the amount of nitrogen which is added to the soil by the soil bacteria and manures and fertilizers which may be added, there must be a decrease in the amount of nitrogen which remains in the soil year after year.

If the practice of removing more nitrogen from the soil than is added to it is kept up for many years, the soil becomes ever poorer and poorer and in the end will become so unproductive that it no longer pays man to till it. This thing has actually happened in the case of many originally fertile soils of the world. All the older states of this relatively new country contain abandoned farms. These farms have become so exhausted of nitrogen, and probably of other necessary elements, that they no longer produce crops which pay. The owners have ceased to till them.

318. Interrelations of Soil Bacteria.—In this account of the relation of bacteria to soil fertility, we have given only the mere thread of the story. Many interesting interrelations exist between the different kinds of soil bacteria which our limited space will not permit us to consider.

Some different kinds of bacteria are helpful to one another. In some cases they are almost powerless to carry on their processes without this mutual aid. In other cases, different kinds seriously interfere with one another, not only competing for food, but through their wastes and secretions hindering one another's development. Some even undo the work that others do. For example, there are great numbers of bacteria in barnyard manure and some of them in the soil generally that have the power of breaking up the nitrates of the soil and setting the nitrogen free in the atmosphere. These are called DENITRIFYING BACTERIA and they tend to undo the work accomplished by the three groups discussed above.

Some of the soil bacteria must have free gaseous oxygen supplied them for respiratory purposes, while others can not only get along without free oxygen, but can not carry on their processes in its presence. These latter obtain the oxygen which they use in respiration from chemical compounds which contain it. The kinds of bacteria that must have free oxygen are known as AEROBIC BACTERIA; those that do not require it are known as ANAEROBIC BACTERIA (See Chap. X, Sec. V).

Many other details like these are known to bacteriologists and doubtless there are very many more important relations that exist among these organisms and between them and their environment which have not yet been discovered. Furthermore, other soil elements are affected by bacteria in ways very similar to those in which nitrogen is affected, and numerous complex relations exist among these different soil elements and among the organisms that affect them. Thus you see that the soil is not the dead, inert, and unchanging thing that you might suppose it to be. It is teeming with life and endless change. It presents an endless list of problems to man for solution and as fast as man is able to solve these problems, he is able to deal with the soil more intelligently. Our knowledge at present is very incomplete but it is sufficient to enable us greatly to increase the productivity of the soil if the men who till the soil only knew and practised what is known to men of science.

2. Bacteria and Decay

319. Real Meaning of Decay.—So far, we have considered bacteria mainly from the standpoint of the services they render us and the rest of the living world, by keeping up the fertility of the soil and by helping to keep in circulation the chemical elements which living organisms need. We shall now change our point of view, for a time, and consider how they tend to destroy many things which we wish to preserve.

The disintegration of organic materials through the agency of bacteria or other fungi is commonly spoken of as DECAY, ROTTING, SPOILING, or PUTREFACTION. These different terms came into use before the real nature of the process referred to was recognized and they are still used to some extent, though more or less vaguely, to represent different forms of the process. Thus, for example, when disagreeable odors result from the process, as often occurs in the disintegration of proteins, the process is often spoken of as putrefaction. All of these terms really mean the same thing; they are different names for a single process by which the nature of matter is changed. They are different terms applied to the chemical changes brought about by microörganisms. Hence, we shall use the single word DECAY to represent the process in all its forms.

Doubtless, you have already recognized the disintegration of the soil humus as decay. In this instance, we are interested to have the decay go forward at a rate sufficiently rapid to supply our growing crops with an abundance of mineral salts. So it is with many things that are useless to us; we are quite willing that they shall be disintegrated and not allowed to encumber the earth (see Sewage Disposal, Chap. X). There are many other things, such as our food, clothing, and lumber which we wish to preserve and which the bacteria and other fungi stand ready to consume.

3. CONDITIONS WHICH FAVOR BACTERIAL GROWTH

320. **Warding off Attacks of Bacteria.**—We can ward off the attacks of bacteria by so conditioning the material which we wish to preserve that bacteria can not grow in it. In doing this, we need to know the conditions which favor bacterial growth. These briefly stated are as follows: (1) *a suitable food*, (2) *an abundance of water*, (3) *a favorable temperature*, (4) *suitable chemical conditions*, (5) *absence of bright light for most of them*, (6) *presence of free oxygen for some*, and (7) *absence of free oxygen for others.* We shall consider these briefly in separate paragraphs.

321. **Food for Bacteria.**—Bacteria can feed on a wide range of substances. Almost all organic compounds are food for one or more different kinds. Almost all species of bacteria can feed on protein substances and yet some can get along with no protein at all in their diet. Since the organic materials which we wish to preserve are almost always a mixture of many different kinds of compounds, we may be quite sure that any of these things of plant or animal origin are subject to the attacks of bacteria.

322. **Water Necessary for Bacterial Growth.**—A mass of food material, in order to support an active growth of bacteria, must contain from 25 per cent. to 30 per cent. of water. This is considerably more water than is required to support a growth of mold. Many materials will be found to mold when they are entirely free from bacterial action.

The high percentage of water required for bacterial growth enables us to preserve many materials from their attacks by merely drying them. It is by drying out when ripe and remaining dry for long times that seeds of plants naturally avoid being consumed by bacteria during the resting period before germination. Many kinds of foods, such as fruits, vegetables, and the seeds of plants can be kept indefinitely by drying them out and keeping them dry. Building materials which are of plant origin, such as lumber, may be preserved indefinitely against the attacks of bacteria if they can be kept dry. We paint our houses largely for the purpose of making the lumber shed water and remain dry, and thus avoid the attacks of bacteria.

323. Temperature Required.—Bacteria vary widely in their temperature relations. Some are able to grow at almost the freezing temperature, while others thrive at temperatures as high as from 160° to 190°F. Three temperature limits may be distinguished for each bacterium as follows: a MINIMUM or the lowest temperature at which growth is possible; an OPTIMUM, or the temperature at which they grow best; and a MAXIMUM, or the highest temperature at which growth is possible. In some species the range between the minimum and maximum is wide, while in others it is comparatively narrow. The minimum temperature of some species is higher than the maximum of others.

Considering this wide range of temperature relations, it is evident that it is very difficult entirely to prevent the action of bacteria, through the agency of temperature, in substances which are injured by freezing. At very low temperatures, just above the freezing point, very few bacteria are active and none are very active. This fact makes possible the preservation of many kinds of food for comparatively long times by the method of cold storage (see Chap. VIII, Sec. III).

324. Necessary Chemical Conditions.—Many chemical substances have been found to be detrimental to, or destructive of, bacterial life. Most bacteria, for example, do not thrive in acid media and on this fact rests the preserving power of vinegar and other organic acids. Common salt, saltpeter, and other similar materials used in preserving meats *prevent the growth of bacteria but, in ordinary concentration, do not kill them.* Such a substance is called an ANTISEPTIC.

On the other hand, certain substances like corrosive sublimate, carbolic acid, and formaldehyde, *even used in comparatively weak solutions, are deadly to bacteria.* Such a substance is called a DISINFECTANT.

325. Antiseptics.—Antiseptics of many kinds are widely used in the preservation of food. Common salt, vinegar, spices, and sugar are the ones most commonly used in the household. Sugar is a good food for some bacteria and particularly so for yeasts and molds, but in very strong concentration such as is found in jellies, preserves, and the like, neither yeasts nor bacteria can grow. Molds, however, are more able to endure these strong concentrations of sugar. Boric acid is sometimes used in the preservation of meats and butter; formaldehyde in the preservation of milk; and benzoate of soda, in the preservation of jams, catsups, and the like, but most authorities are agreed that these and several other substances like them are, in the long run, injurious to the health of the consumer and therefore their use is unwise.

326. Disinfectants.—Disinfectants are used, not only for the destruction of bacteria in houses after a case of bacterial disease, but also in the preservation of lumber, railroad ties, fence posts, mine props, and the like. Among the disinfectants used for these latter purposes are creosote and zinc chloride. The material to be preserved is soaked in a solution of the disinfectant and this prevents, not only the action of bacteria, but also the attacks of wood borers and other insects.

327. Effect of Light upon Bacteria.—Most bacteria are readily killed by direct sunlight or other bright light. Even strong diffused light is highly detrimental to their growth.

This fact, however, is of little value in the preservation of materials, for the bacteria in the interior of the substances are effectively shielded from the light.

328. Oxygen and Bacteria.—We have mentioned in Art. 318, the fact that some bacteria require free oxygen in order to be able to carry on their processes, while others can not only get along without free oxygen, but can not thrive in its presence. The only importance that this fact has in connection with the preservation of food is that it shows that we can not hope to preserve the food by shutting it away from free oxygen. *As far as the oxygen relation is concerned, the anaerobic bacteria find ideal conditions within a sealed can of fruit or vegetables.*

4. PRESERVATION OF FOOD BY CANNING

329. Why We Can Food.—We know that one of the most extensively used methods of preserving food at the present time is that of canning. This consists of putting the food into cans, heating it to a high temperature for a time sufficiently long to kill both the active growing bacteria and the more resistant spores, and then sealing it air-tight.

Canning has been practised to some extent as a household industry for about a century, but the large canning factories which now preserve annually immense quantities of food have come into existence during the last 25 or 30 years. The importance of canning and other modern methods of preserving food as means of cheapening the cost of living is very great. Before these methods came into use, many kinds of food could be used only while it was fresh and in season, and a large percentage of each crop was allowed to go to waste for the lack of suitable methods for preserving it. Now, the whole crop may be saved and be sold at reasonable prices throughout the year.

It is a remarkable fact, however, that, during the same period of time in which the process of canning and other methods of preserving food have been brought to their present high state of development, the cost of food has greatly increased instead of decreasing. The increase in the cost of food has come about, however, in spite of the perfection of these processes which naturally have the opposite effect. Food would doubtless be much more expensive today than it is if we did not have these modern methods of preserving it.

330. Domestic Canning.—As stated above, the canning of certain things, such as fruits and some of the vegetables, has been practised in the homes for a long time. This practice began long before the development of the science of bacteriology and, therefore, the reasons for the success of the methods used were not understood. The methods ordinarily used in the home are successful only with fruits and with certain vegetables like tomatoes which contain a considerable quantity of acids. You will recall the fact that acids are generally detrimental to the growth of bacteria. It is doubtless on account of the influence of these acids that food, which contains them in sufficient quantities, may be canned successfully with the moderate degree of heat available in the ordinary household.

It is difficult to heat food in the ordinary household to a temperature higher than that of boiling water. This temperature is not sufficient to kill, in a reasonable length of time, the resistant spores of certain bacteria which are always found on such foods as green corn, beans, and peas. Consequently these foods are seldom successfully canned in the home.

There is a method, however, by which such foods may be successfully canned in the home without special apparatus. This consists in heating the food in the cans to the boiling temperature for about a half hour on each of three successive days and then sealing up the cans with lids and rubbers which have also been heated along with the vegetables. *The heating the first day kills all active growing bacteria and probably serves to stimulate the spores to begin to grow. These then are killed with the second heating, and the third heating serves to kill any that may have escaped the first two heat-*

ings. If the fuel and labor used in this process is expensive, it is likely that the food canned in this way will, in the end, cost as much as it would cost to buy the same amount of food which has been canned in a factory.

331. Factory Canning.—As has been stated, the canning process as ordinarily carried on in the household, finds its limitations in the fact that the temperature of boiling water, the highest temperature conveniently obtainable without special apparatus, is not sufficiently high to kill the more resistant spores of molds and bacteria in a reasonable length of time.

Canning factories, however, are equipped with special apparatus by means of which the food that is canned may be raised to any desired temperature. Such apparatus consists of what might be called a large steamer of boiler iron construction. A large number of cans containing the food are placed in this steamer and then steam is turned into this apparatus until a certain pressure is reached. You are familiar with the fact that steam arising from boiling water is practically of the temperature of the boiling water; that when the steam is under 1 atmosphere of pressure its temperature is 100°C., or 212°F.; but when steam is held under pressure, the temperature increases with the pressure. Consequently, by surrounding cans containing food with steam under pressure, the food may be raised to a temperature sufficiently high to kill in a few minutes the most resistant spores of microörganisms.

When the cans are placed in the heating apparatus, they are generally sealed up except for a very small hole in the top of the can. As soon as the cans come from the heating apparatus, a drop of solder is dropped on this hole and it is sealed. This hole is left in the can while it is being heated for the purpose of permitting the air which is contained in the can to escape as it is expanded by the heat. Since the hole is sealed up while the contents of the can are still very hot, and therefore more or less expanded, the contents of the can will shrink slightly on cooling and the ends of the can will become slightly concave or sprung in, as a result of the atmospheric pressure on the outside. This fact is important as it affords a means of detecting cans which have not been perfectly preserved. Some kinds of bacteria are gas producers and when they begin action on the food in a can, they soon set free sufficient gas to cause the ends of the can to bulge out and become convex. Cans which thus show this swelling are discarded before they leave the factory. Some kinds of bacteria, however, do not produce gases by their action and so the failure of a can to swell is not an absolute guarantee that the food is perfectly preserved.

In ordinary practise in canning factories, the food is heated to a temperature of from 110°C. to 125°C. for from 20 minutes to a half hour. The time and temperature vary with the kind of food that is being preserved and with the size of the cans. Equipped with this power to destroy by heat the most resistant forms of microörganisms, the canning factories are able to preserve any kind of food that is not seriously injured by the high temperatures. Fruits and vegetables of every kind, milk, meats, soups, and many other forms of food prepared ready for use are now preserved by canning.

These foods are preserved when they are in season and, generally, in the part of the country where they are produced. They then become available throughout the year and in every part of the country. Before the introduction of canning, the food of the people naturally varied considerably at different times of the year. Fruits and vegetables were abundant in the summer time and scarce in the winter. Now we may have practically the same variety of foods throughout the year at very little added cost.

Canning factories, like most other modern factories, have many forms of labor-saving machinery which help to cheapen the cost of their products. A discussion of these, however, would take us outside our present topic, and besides this, you could learn more in an hour's visit to a neighboring factory than we could tell you in several pages.

332. Sterilization and Pasteurization.—It is evident from the foregoing that *the process of canning depends on the complete destruction of all forms of living organisms in the food.* The process of killing all microörganisms in a given substance is known as STERILIZATION.

Most of moist foods are favorable foods for bacteria to thrive in. If such foods are to be kept for any considerable time, they must be completely sterilized and thoroughly sealed from bacteria. If a single living bacterium or a single living spore is left in the food, it will soon multiply and the food will be destroyed.

Many times, however, we care to preserve food for only a short time. In such cases complete sterilization is not necessary. Furthermore, some foods, like milk, are seriously injured by the high temperature necessary for complete sterilization.

If milk is heated even to boiling, some of the proteins which it contains are coagulated and the flavor of the milk is greatly changed. The coagulated protein is not so easily digested as it is in the fresh state and the changed flavor makes it less palatable than fresh milk. Consequently, since milk is usually consumed within 24 to 48 hours after it is drawn from the cow, the bacterial action which might otherwise cause it to sour within that time may be effectively prevented by heating the milk after it is bottled to a temperature sufficiently high to kill only the active growing bacteria which it contains. If milk is heated to 60°C., or 140°F., for 20 minutes, all the active bacteria in it will be killed, but the milk will not be changed essentially in flavor or digestibility. Such an amount of heating is not sufficient to kill the bacterial spores in the milk and these will soon begin to grow and multiply and the milk will finally sour. The souring is delayed by this process, however, and this delay usually makes it possible for the milk to be delivered to the consumer and consumed before the souring occurs.

This process of heating food to a temperature sufficiently high and for long enough time to kill the active bacteria but not to kill the spores, is called PASTEURIZATION. You will note by the spelling of the term that it is named for PASTEUR (see Art. 303). Pasteur did not originate the process, but he perfected it and applied it in several practical ways and succeeded in inducing people to make use of it.

333. **Pasteurization and the Spread of Disease.**—This delay in the souring of milk is by no means the most important result of the practice of pasteurizating milk. A far more important result lies in the fact that disease-causing bacteria which the milk may chance to contain are effectively killed by the process. Milk is an ideal food for most bacteria and, for this reason, it often becomes a means for the spread of bacterial diseases, such as typhoid fever, tuberculosis, and diphtheria. *None of the bacteria which cause the more common contagious diseases are known to form spores and, therefore, any such bacteria are effectively killed by pasteurization.*

II. PARASITES—ORGANISMS WHICH LIVE WITHIN THE BODIES OF OTHER LIVING ORGANISMS

334. **Parasites and Their Hosts.**—You will recall the statement made in Art. 287 that organisms which live and find their food within the bodies of other organisms are known as PARASITES. The organism within whose body a parasite lives is known as the HOST. Parasites often produce certain poisons, or TOXINS, in the body of the host. These poisons attack certain parts of the body of the host and thus the parasites become the cause of what we commonly call diseases.

The larger animals are affected by many kinds of animal parasites, such as tapeworms, trachina, and the malarial parasite, but most of the common diseases are caused by plant parasites and the bacteria are by far the worst offenders in this way. A good many different kinds of bacteria, how·

ever, are known to live and thrive within the mouths and alimentary tracts of man and of other animals which are not known to cause any harm to their hosts. Indeed, it is thought by some bacteriologists that some of these bacteria are of benefit to their hosts in some unknown way.

335. **Former Theories of Disease.**—Before taking up a discussion of the nature of bacterial diseases, it might be well to consider briefly some of the early theories that have been held concerning the cause of disease. One of the earliest of these theories consisted in a belief that the diseases were caused by an ''evil spirit'' which entered into the body and behaved in such a manner as to bring pain and suffering to the patient. Such a theory was more or less of a natural inference from a superficial study of the symptoms of an ordinary disease. This theory seems to have fitted particularly well as an explanation of diseases accompanied by high fevers and a delirious condition and in cases of insanity. This theory was held longest in regard to diseases of this type.

Two different lines of treatment were followed in attempting to cure diseases according to this theory. It was thought that the spirit could either be *coaxed* to leave the body of the patient by sacrifices or promises, or it could be *forced* to leave by charms, by the beating of tom-toms, or by torturing the body of the patient, and thus making it uncomfortable for the intruder. You have doubtless read of some of the strange customs practised by savage tribes today in the treatment of their sick. Most of such customs grow out of some form of this theory of disease, for it seems that most present-day primitive peoples, as well as the savage ancestors of civilized man, hold to this theory in some form.

336. **Semi-scientific Theory of Disease.**—Hippocrates, a Greek philosopher, who was born about 460 B. C. and who is often called the ''Father of Medicine,'' announced a new and semi-scientific theory of disease. According to this celebrated theory, the body contains four humors: blood,

phlegm, yellow bile, and black bile. Health consisted of a proper mixture of these four humors and disease consisted of an improper mixture. The treatment of diseases according to this theory, consisted in an effort to keep the humors in a proper relation to one another. This was done by administering powerful drugs. This theory soon gained world wide acceptance and it was the theory of disease generally accepted throughout the whole of the dark ages. Indeed, its influence is still seen in much of the current thought and practice in medicine. By the giving of drugs of many kinds for many kinds of diseases, a large number of really valuable medicines which are in wide use today were thus empirically discovered, *i.e.,* discovered by experiment. Quinine, for example, was known to be a cure for malaria long before it was known that the disease is caused by a little microscopic animal which is killed by the quinine.

It must be some little surprise to you to realize that it was not until a comparatively recent date, when the GERM THEORY OF DISEASE began to be generally accepted, that the practice of medicine really began to be placed on a sound scientific basis. The year 1876 is a memorable year in the history of medicine. It was in that year that Robert Koch succeeded in proving beyond the possibility of a doubt that a certain disease of domestic animals was caused directly by a certain rod-shaped bacterium which is now known as BACILLUS ANTHRAX. Since this is a typical bacterial disease and one about which a great deal is known, we shall use it to illustrate the nature of a bacterial disease.

1. ANTHRAX

337. Animals Affected.—ANTHRAX, or SPLENIC FEVER, as it is sometimes called, is, in nature, primarily a disease of cattle and sheep though it sometimes attacks a large number of other animals including man. Horses, hogs and dogs have a relatively high degree of resistance to the disease though none of them are entirely free from occasional attacks of it. Rabbits, guinea-pigs, and white mice are extremely susceptible, especially so when the bacteria are injected under the skin of the animal. A single bacterium injected under the skin of a white mouse is sufficient to cause the death of the animal. Carnivorous, or flesh-eating animals are, as a rule, more resistant to the disease than are herbivorous, or plant-eating animals. The former are not entirely free from attacks, however, as epidemics have at different times broken out in zoölogical gardens among leopards, lions, bears, and other animals of this class. Wild deer, elk, and goats are subject to occasional outbreaks.

338. Symptoms of the Disease.—In cattle, sheep and other animals which the disease attacks readily, the bacteria multiply rapidly, become enormous in numbers, and swarm throughout the entire body of the animal. They float in the blood and accumulate in large numbers in the spleen, liver, kidneys, and lungs. Internal hemorrhages, or bleeding, occur in different parts of the body, a high fever results, and death occurs very suddenly.

FIG. 200.—*A*. Bacillus anthrax. *B*. The same with spores.

In animals which offer a high resistance to the disease local infections in the form of large carbuncles develop. If these are lanced and kept cleaned out, healing and recovery usually occur. Men who handle hides from infected animals often have these carbuncles on their hands or shoulders where they carry the hides. In such cases, the spores of the organism are supposed to enter the body of the victim through the skin.

Men who handle wool from infected sheep often contract the disease in a form which is known as WOOL-SORTER'S DISEASE. In this case, the spores are taken into the lungs and cause a disease resembling pneumonia.

339. Character of the Bacterium (Bacillus anthracis).—The organism which causes this disease is a rod-shaped bacterium and one of the largest of the known PATHOGENIC, or disease-causing, bacteria (Fig. 200A). Under certain conditions, it forms spores which have remarkable powers of endurance (Fig. 200B). Spores have been known to remain alive in pastures and still be able to cause the disease for as long as 30 years. The bacteria can be grown artificially on GELATIN CULTURES and, if grown at a suitable temperature (their optimum temperature 37°C., or 98⅗°F., the temperature of human blood), they retain their virulence, or disease-causing power, and will speedily cause the death of a susceptible animal if injected into its body.

340. Methods of Prevention and Cure.—Since the discovery of a method of preventing this disease was an event of unusual importance in the history of medicine, you will be interested in knowing something of the circumstances which led to its discovery. The great "Father of Bacteriology," LOUIS PASTEUR, discovered the principle involved in the method in the year 1880 and perfected the method of preventing anthrax during the following year. After ROBERT KOCH had established beyond all possible doubt that *Bacillus anthracis* is the specific cause of the disease anthrax, PASTEUR turned all his powerful energies and his genius to the study of infectious diseases.

At this time, anthrax was known and dreaded all over the world and in some years it had caused a loss in France alone of 20,000,000 francs, or 4,000,000 dollars. The burden of the scourge fell heavily upon the peasants or farmers, many of whom had suffered the loss of their entire flocks. Pasteur, some years before, had been of great service to the peasants of his country by showing them how to avoid the terrible silk-worm diseases which had nearly ruined the silk industry of the country. He now longed to find some method of combating anthrax.

He had in his laboratory many cultures of different kinds of pathogenic bacteria and among these were cultures of the bacteria that caused the common disease, chicken cholera. He had labored so hard and so long with his experiments that he was finally forced on account of ill health to take a short vacation. This he dreaded to do for he feared that lack of care would cause all his valuable cultures to die.

When he returned to his laboratory, you can imagine his dismay when he found that all his cultures were apparently ruined. This would have meant that much of his labor had been lost and that the final result which he hoped for would have been delayed. He made every effort to revive his cultures by transferring them to new culture media and among other things, he inoculated some chickens with one of these old cultures of the bacteria that cause chicken cholera. These chickens failed to develop any symptoms of the disease. Pasteur considered the cultures lost.

He was greatly surprised, however, to find that later when he inoculated these same chickens from fresh virulent cultures, they failed to take the disease. He quickly prepared other cultures and allowed them to stand in test tubes as these original ones had done and then repeated the experiment of first inoculating chickens with the weakened cultures and then later inoculating the same chickens from fresh virulent cultures. He was thus soon able to prepare weakened, or ATTENUATED, cultures, as he called them, which would regularly serve to prevent the chickens from taking the disease when inoculated from strong virulent cultures.

This method of treating, or VACCINATING, chickens, as the process has come to be called, has never come into general use, for later experience showed that some fowls are really given the cholera by it. It served, however, to give Pasteur a principle to work on. He was soon able to produce a

VACCINE for anthrax which has proved to be of great value.

Pasteur grew the anthrax bacillus under almost all possible conditions and then used them to inoculate well animals. He finally discovered that, when the bacteria are grown at a temperature of from 42° to 43° C., or 107⅗° to 109⅖° F., they gradually lose their VIRULENCE, or disease-producing power, but do not lose the power to stimulate the animal to build up its resistance to the disease.

341. Preparation and Application of Anthrax Vaccine.—In the ordinary practice of preparing the vaccine, bacteria whose virulence has been tested by inoculation experiments on rabbits or guinea-pigs, are grown at the temperature of from 42° to 43° C. for varying lengths of time. Whenever it is found that the culture has been so weakened that it will just kill white mice but not quite kill guinea-pigs, about ¼ c.c. of the culture is injected into cattle and half this amount into sheep. About twelve days later, a similar dose of a culture that will just kill guinea-pigs but not quite kill rabbits is injected. After this, virulent cultures may be injected with impunity, and the animal so treated will not contract the disease in any natural way.

342. Nature of Immunity.—When an organism is free from liability of attack by a given disease, it is said to be IMMUNE or to possess IMMUNITY from the disease. All organisms are naturally immune to certain diseases that affect other organisms. Thus man is not at all susceptible to chicken cholera or to a good many other diseases that affect domestic animals and, on the other hand, the domestic animals are not affected by very many of the diseases that affect man. We call this sort of immunity, NATURAL IMMUNITY.

But you are familiar with the fact that when you have once had an attack of measles or whooping cough you are not likely to have these diseases again, even though you be repeatedly exposed to them. You are thus rendered immune to these and other diseases by having had them. This kind of immunity, we call ACQUIRED IMMUNITY.

You will note that the method of vaccinating an animal with an attenuated culture of the organism that causes a certain disease gives the animal an *acquired immunity* against the disease without the necessity of the animal's having the disease.

343. Results of Anthrax Vaccination.—Professor Chamberlain was made responsible for the production and distribution of anthrax vaccine. After twelve years, in 1894, he reported that 3,296,815 sheep and 438,824 cattle had been vaccinated in France. Only 1 per cent. of the sheep and .34 per cent. of the cattle had died. At that time it was estimated that the average annual loss from anthrax among unvaccinated sheep was 10 per cent. and among unvaccinated cattle was 5 per cent.

This single discovery by Pasteur has been, and will be for all time to come, of enormous value to stock raisers, throughout the world. Vaccination of sheep and cattle and sometimes of other animals is now regularly practised in all countries where the disease occurs.

2. Vaccination and Smallpox

You are familiar, in a way, with vaccination against smallpox. Since the principle involved in this is essentially the same as that in vaccination against anthrax or any other disease, a little discussion of smallpox vaccination will serve to make the process clearer to you.

344. The Origin of Smallpox Vaccination.—Prior to about the year 1800, smallpox was an extremely common disease. It was so very common that few people escaped having it sometime during life, and it has been estimated that fifty million people died of it in Europe during the eighteenth century. In the early part of the eighteenth century, it was discovered that, if a little of the pus taken from a patient suffering with the disease is injected under the skin of a healthy person, a mild form of the disease generally results. This has the same immunizing result as a more virulent attack of the disease which might be contracted in some natural way. This practice was introduced into England in the year 1717 and for over a hundred years was widely practised until it was prohibited by an act of Parliament in 1840. The danger of this practice lies mainly in the fact that persons artificially infected in this way become new centers for the spreading of the disease in the virulent form.

In 1796, Edward Jenner, a country physician, in England, observed that persons who had been affected with cow-pox, a mild eruptious disease of cattle, were very unlikely to contract smallpox even when repeatedly exposed to it. This led him to recommend, and to practise on his patrons the use of the virus of cow-pox, instead of that of smallpox as a means of producing immunity to the latter disease. His method proved to be a remarkable success and soon came into general use.

At present, the vaccine is produced by inoculating a healthy calf with the cow-pox VIRUS and then after about five days, the virus of the pustules, which develop near the place of inoculation, is removed, mixed with glycerine and kept until it is proved to be free from bacteria and other organisms, and then it is ready for use in vaccination.

345. **Cause of Smallpox Not Known.**—You will note that this method of vaccinating against smallpox was discovered more or less accidentally long before the germ theory of disease came to be generally accepted. Consequently, at the time of its discovery, no one had any idea of the nature of the process by which the immunity is brought about. We have not even yet been able to discover the organism which is the cause of this disease, and our only reason for believing that it is caused by some microörganism, is its general resemblance to other diseases that are known to be thus caused. Since we do not know the organisms, we can judge of the nature of the immunizing process only by comparison with other better known diseases. From this point of view, it is the opinion of most students of the subject, that the organism

which causes cow-pox is the same as the one which causes smallpox. They believe that in passing through the body of the calf, the organism becomes attenuated, or weakened, so that it is unable to produce smallpox when introduced into the human body, but is still able to stimulate the body to build up its defenses against the virulent form of the organism.

346. The Effectiveness of Smallpox Vaccination.—The infrequency of smallpox in recent years, in most countries, as compared with the eighteenth century is ample evidence of the effectiveness of vaccination as a preventative of the disease. More striking evidence, however, can be found in countries which require all persons to be vaccinated.

In 1870–71, during the Franco-Prussian war, the armies of both Germany and France were attacked by smallpox. Vaccination had been compulsory in the German army since 1834 but was not compulsory in the French army. As a consequence, the French lost 23,000 soldiers from smallpox and the Germans lost only 273 from that cause. Vaccination has been compulsory in Sweden since 1810. From 1774 to 1801, smallpox had caused an annual death rate of 2,050 per million of inhabitants in that country. During the years from 1810, when vaccination was made compulsory, to 1855, the death rate had fallen to 169 per million, and in the period from 1884 to 1894, the average annual death rate was only 2 per million.

This shows that, if all countries would follow the example of Germany and Sweden in requiring that every citizen be vaccinated, smallpox might entirely disappear from the earth. It shows further that as long as frequent outbreaks of the disease are allowed to occur as they do every winter in this country an individual is very foolish if he does not submit to vaccination as often as it will take.

For about 10 years there has been a rather active campaign against vaccination by people who style themselves adherents of personal liberty in all health matters. According to statistics given by one of the largest life insurance companies, this campaign against vaccination has produced increased laxity in the practise of vaccinating and there has been a corresponding increase in the prevalence of the disease. The statistics given are these, from 20 states:

CASES OF SMALLPOX.

State	1916	1917	1918	1919	1920
California	234	329	1,069	1,992	4,503
Colorado	103	323	1,680	1,714	2,878
Illinois	*	4,996	3,842	3,971	6,617
Indiana	1,158	4,593	5,582	3,620	6,775
Kansas	2,085	2,623	7,130	2,130	3,900
Louisiana	819	835	950	1,120	1,558
Maryland	69	98	219	212	176
Massachusetts	32	65	27	32	29
Michigan	1,365	2,929	4,417	2,885	4,848
Minnesota	1,270	2,718	2,252	2,280	5,447
Mississippi	1,401	1,530	3,601	2,511	4,148
Nebraska	*	*	3,906	2,861	4,135
New Jersey	9	6	65	66	181
North Carolina	*	*	899	1,880	2,961
Ohio	1,921	5,243	10,227	3,924	7,228
Oregon	119	122	493	2,381	2,828[1]
Pennsylvania	97	380	612	198	215
Texas	*	1,350	4,338	*	1,547
Washington	637	390	1,676	4,372	5,997
West Virginia	*	413	1,266	2,214	2,619
Totals	11,319	28,943	54,451	40,363	68,590

* No data available.

[1] Up to November 30, 1920, only.

347. How Often Should One be Vaccinated?—In a report of the Board of Health of the city of Berlin, the following sentence may be found: "Vaccination in infancy, renewed at the end of childhood, renders the individual practically as safe from death from smallpox as if that disease had been survived in childhood, and almost as safe from attack." In a recent report of the Illinois State Board of Health, occurs the following sentence: "A recent successful vaccination is a positive protection against an attack." *Evidently, then, everyone should be vaccinated in infancy and at least once* *after reaching maturity.* Anyone who travels or mingles much with people in the winter time should be vaccinated every four or five years.

3. Diphtheria

There is probably no other serious bacterial disease which attacks the human race whose story is so well known as is that of diphtheria. Our knowledge of the details of this disease and of its cure and prevention is well-nigh perfect. In constitutes the most complete triumph of the science of bacteriology. This being the case, a somewhat detailed account of the disease will serve to acquaint us with the general theory of bacterial diseases, their cure and prevention.

348. Discovery of the Organism and Its Relation to the Disease (Bacillus diphtheriæ).—In 1883, Klebs discovered the organism. In the following year Löffler succeeded in obtaining pure cultures of it from the throats of patients suffering from the disease. This seemed to indicate plainly that the organism is the direct cause of the disease. Löffler himself was at that time inclined to doubt this, for he had found the same organism in the throats of perfectly healthy children and at the same time had failed to find it in the throats of some patients who showed strong symptoms of the disease. These causes for doubt have since been completely cleared away. It is now known that certain other bacteria can cause a condition of the throat which is practically indistinguishable from that caused by the *diphtheria bacillus.* Again, it is now known that some people carry *diphtheria bacilli* about in their mouths and throats and yet are entirely unaffected by them. This latter fact is an important factor in the spread of the disease, for people who thus carry the organisms about may give the disease to more susceptible persons.

The final discovery which proved beyond all doubt the relation of the organism which Klebs had discovered to the disease was made in 1888–89 by Roux and Yersin. These men showed that the organism forms a toxin, or poison, which may be separated from the organism and which when injected into a susceptible animal, causes all the characteristic symptoms of the disease.

349. Symptoms of the Disease.—The organism usually finds lodgment and develops on the mucous membrane of the throat, nose, and rarely of the lungs. Even the eyes or the middle ear may become the seat of infection, though, in the great majority of cases, it is the pharynx that it affected. The form of the disease that is sometimes called MEMBRANEOUS CROUP is an affection of the larynx. In rare cases, the organisms enter the general circulation and spread throughout the system. Usually they are confined to some local area of the mucous membrane where they develop and secrete their toxin, causing a white membrane to develop. The toxin is absorbed into the system where it attacks certain vital organs, principally the heart, nerves, and kidneys. In these organs, it causes a fatty degeneration and, therefore, a weakening of the organs.

FIG. 201.—Bacilli diphtheria.

350. Character of the Organism.—The diphtheria bacillus is a slender rod-shaped organism of moderate and somewhat variable size (Fig. 201). When it is stained, it presents a sort of beaded or granular appearance which is so characteristic that a trained bacteriologist can recognize it with certainty. This makes possible certain diagnosis of the disease and enables the physician to determine with certainty when a patient may safely be freed from quarantine.

The organism grows readily on several kinds of common food, especially milk, if kept at a suitable temperature. This fact is important in the spread of the disease, for many epidemics have been known to have been caused by the handling and distribution of milk by persons suffering with a mild attack of the disease.

The organism is not known to form spores but it has a high resistance to drying. It has been known to live and retain its virulence for several months in dried membrane or sputum. This makes necessary the disinfection of houses in which cases have occurred.

351. **Nature of the Toxin.**—When the bacteria are grown in a broth, a soluble toxin is produced in the broth. The broth is now passed through a fine porcelain filter. The filter retains the bacteria but allows the broth and soluble toxin to pass through.

This soluble toxin, without the bacteria, when injected into the body of a healthy animal, produces all of the symptoms of the disease except the formation of the false membrane in the throat. The membrane is formed, in normal cases, by the bacteria themselves. The absence of the bacteria accounts for the failure of the membrane to form although all other symptoms are present.

Little or nothing is known of the chemical nature of the toxin, or of the manner in which it is produced. It is only known that it is a powerful poison thrown out from the bodies of the bacteria and that it attacks certain tissues of the animal body.

352. **The Antitoxin.**—In 1890, *Behring and Kitasato* took the next step in the mastery of this disease. They discovered a method of producing an *antitoxin* which is both a cure and a preventive of the disease. They experimented with rabbits, first inoculating them with attenuated (weakened) cultures of the bacteria and later with more virulent cultures. This treatment made the rabbits entirely immune from the disease. Next, these experimenters discovered that the blood serum of these rabbits which had been made im-

mune from the disease, when injected into the bodies of other rabbits which had been inoculated with virulent cultures of the diphtheria bacilli, had the power of neutralizing, or destroying, the toxin produced by the bacilli.

In other words, they discovered that the blood serum of the rabbits which had been made immune from the disease by being inoculated with the bacteria contained some substance which destroyed the toxin produced by the diphtheria bacilli. It is believed that the diphtheria toxin always stimulates the body of an animal to produce this neutralizing substance, the *antitoxin,* as it is called.

The next problem was to cause the body of an animal which stood a chance of being exposed to the disease to produce this antitoxin in sufficient quantities to prevent his contracting the disease. That is, to use the antitoxin as a preventive of taking the disease.

It is now known that the body of a well animal can be made to produce this antitoxin by inoculating it with toxin although there is no bacteria in the inoculating serum. An animal whose body is producing antitoxin, rarely, if ever, contracts the disease when exposed to diphtheria bacilli. The virulence of the disease is also greatly lessened by the use of the serum if inoculation is made as soon as the patient contracts the disease.

353. Preparation of the Antitoxin.—The antitoxin for the treatment of diphtheria today is manufactured in the bodies of healthy horses. The methods by which this antitoxin is secured are of the most painstaking and careful kind. Every possible precaution is taken to insure the purity and safety of the antitoxin. The story is too long and technical to be told here. The use of the diphtheria antitoxin is, however, universal in the treatment of the disease.

354. Results of the Use of Diphtheria Antitoxin.—Ever since the early nineties of the last century, the horse serum for the treatment of diphtheria has been in common use throughout the civilized world and its effect on the death rate from this disease has been remarkable. This is shown by the following table which shows the average death rates, from diphtheria, per 10,000 of population in the leading cities of the world during the decade just preceding and the one just following the introduction of the serum.

	1885–1894 Before use of Antitoxin	1895–1904 Antitoxin Period
Paris	6.41	1.49
Berlin	9.93	2.95
London	4.85	3.88
New York	15.19	6.62
Boston	11.76	6.34
Chicago	14.29	5.13

It might appear that, since the serum is such a perfect cure for the disease, the death rate should be reduced much lower than the preceding table shows. It is a fact, however, that for the best results the serum needs to be used in an early stage of the disease. Since there are so many other types of sore throats which may be confused with an early stage of diphtheria, many people fail to call a physician in time to give the serum a fair chance.

355. Antitoxin As a Preventive of Diphtheria.—Diphtheria antitoxin is not only a specific cure for the disease but it has been found very effective also as a preventive. When a case of diphtheria breaks out in a family, the physician who attends the case, the nurse, and members of the family who are liable to exposure are generally given regular doses of the serum. This treatment is usually effective in preventing further spread of the disease.

4. Other Bacterial Diseases

It will be impossible for us to consider other bacterial diseases as fully as we have considered diphtheria. This study, however, has given us considerable knowledge of the general theory of such diseases and some brief mention of some of the more important ones that remain will be of value.

356. **No Two Diseases Just Alike.**—It might appear to you that, since we have worked out so perfectly methods of cure and prevention for one bacterial disease, it should be easy to work out similar methods for all other diseases. This is far from being true. To understand this, you must remember that these different diseases are caused by different species of bacteria and that these different species vary widely in their characteristics and in their relations to the animal body. For example, not all disease-causing bacteria produce a soluble toxin which can be easily separated from the organism and used in the production of antitoxin as in the case of diphtheria. Again, the antitoxins, when produced, are not always so effective in the neutralization of the toxin or so harmless to the body of the patient as is that of diphtheria. Many other differences exist which can not be explained here because of the technicalities and difficulties they involve. It is enough to say here that almost every bacterial disease presents its own peculiar difficulties and that little headway has been made up to the present time in dealing with some of them.

357. **Prevention and Cure.**—In general, it may be said that the efforts of bacteriologists in seeking to gain control over bacterial diseases are directed along three general lines.

First, they seek to find some method of preventing the disease, by giving the people or animals *artificial immunity from the disease.* As a result of efforts along this line we have the various vaccines, such as Pasteur's vaccine against anthrax which consists of attenuated cultures of the bacteria, and the cow-pox virus as a vaccine against smallpox. When vaccines are used, you will note that the body of the patient is stimulated by the presence of the toxin or the attenuated bacteria to secrete its own antitoxin or to raise its resistance to the disease in some other way.

Second, the bacteriologists seek to find some method of producing an antitoxin and therefore a cure for the disease as in the case of diphtheria.

Third, bacteriologists seek to learn the methods by which the different diseases are ordinarily spread from patient to patient. Knowing this, they are able to devise methods of preventing such spread of the disease.

It is evident that the first two of these lines of effort must be left to the bacteriologists and physicians but it is quite as evident that the value of the known methods of preventing the spread of disease depends very largely on the faithful co-operation of all the people. Therefore, it is quite important that as nearly as possible, every one should come to know how the common diseases are ordinarily spread and how this spreading might be prevented. For this reason, this latter phase of disease should be emphasized.

5. Important Facts about Common Diseases

358. **Pneumonia.**—This is primarily a disease of the lungs and is usually caused by a certain spherical bacterium called PNEUMOCOCCUS. In most serious cases, however, the organism finds its way into the general circulation and is distributed over the body. While pneumococcus is the cause of a majority of the cases of pneumonia, other organisms, such as Bacillus diphtheriæ, and Bacillus influenzæ, and others may cause an inflammation of the lungs which is difficult to distinguish from that resulting from pneumococcus. Often two or more of these organisms are involved in an attack of the disease.

Pneumococci and the several other organisms which may cause this disease are very widespread and are very commonly present in the mouths and throats of healthy persons. As long as the body is in a vigorous state of health, however, it is usually able to ward off an attack but often when weakened by other illness, or by exposure to extreme cold, hunger, fatigue, or lack of fresh air or other similar causes, the resistance of the body seems to break down and the disease gets a start. This fact explains why the disease so often follows other forms of illness and also why it is more prevalent in the winter time than in the summer. Lack of fresh air in the winter time is a fruitful cause of pneumonia. Hence it is evident that the surest means of escaping this disease lies, not in an effort to escape the bacteria for that is practically impossible, but in keeping the body in a vigorous state of health. Fear of this disease should be a strong stimulus to sanitary living. Good food in moderate amounts, warm clothing, plenty of exercise, and plenty of fresh air are the best means of protection against this disease.

A person who has suffered one attack of pneumonia shows little or no increased resistance to a second attack. Therefore, it seems that the organism does not form a soluble toxin nor does it stimulate the body to form an antitoxin. Consequently, we have no serum treatment for it of any kind. It is not definitely known just how the body finally overcomes the organism and recovers.

359. Typhoid Fever.—This is one of the most common and important of all bacterial diseases (Fig. 202) and yet it need not be if every one knew and practised some very simple things concerning it. The disease affects primarily the alimentary tract and is contracted almost wholly by taking the organism into the mouth with food or drink. The organism escapes from the body of the patient suffering from the disease with the wastes from the alimentary tract and in the urine.

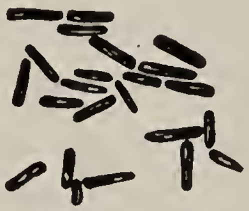

FIG. 202.
Bacillus typhosus.

Since the organism can not multiply or live for any great length of time outside the human body, it is evident that it must be carried more or less directly from the wastes of the sick patient to the alimentary tract of the next victim. This transfer could be cut off if all the wastes from sick patients and convalescents everywhere were treated with disinfectants as soon as removed from the body. If this is not done, however, there are many ways in which the organisms may be spread to other persons. Flies may carry them directly to the food or water used by healthy persons; the nurse and other persons who wait upon the patient may carry them on their hands to the food or dishes used by other members of the family; they may get into water supplies or wells, into the milk distributed by dairies, or on fresh fruits and vegetables distributed by groceries and be widely spread through a community. In many such ways the transfer of the organisms from the wastes of the sick patient to the food or drink of healthy persons is accomplished if they are not destroyed at once by the use of disinfectants.

If the wastes from a typhoid patient are all collected in a suitable vessel and treated with a 5 per cent. solution of carbolic acid for an hour before they are put into the sewer or outdoor vault, and if due care is taken by those who attend the patient, there is little chance for further spread of the disease. This sterilization of the wastes needs to be kept up, however, until the patient is known to be free from the organism. The time when a patient is free from the organism after recovery can be determined by a bacterial examination. Some persons recover from the disease and yet carry myriads of the organism for months or even years and may, all the time, be a source of spread of the disease. Such persons are known as TYPHOID CARRIERS.

We do not have any successful serum treatment for typhoid fever but we do have vaccines which consist of the dead bacteria or materials derived from them that have proved wonderfully successful in rendering persons immune from the disease. Soldiers in the armies are regularly vaccinated against typhoid now and the result is that this disease which was once a principal danger to the soldier has, in many instances, nearly disappeared from the army camps. Vaccination is also widely practised in cases of epidemic outbreaks of the disease among private citizens. The immunity produced either by an attack of the disease or by vaccination is only temporary and so vaccination must be repeated at intervals.

360. Influenza or Grippe.—This very common disease is now known to be caused by a very small rod shaped bacterium known as Bacillus influenzæ. This disease is of common occurrence, especially in the winter time, and at times has swept over the country as severe epidemics. The organism generally invades only the mouth, throat, and air passages, the toxin being absorbed from such local infection. It follows from this that the organism is expelled from the body of the patient mainly through coughing and sneezing and in the sputum. It has been found that very little drying serves to kill the organism and therefore the disease is generally contracted through rather intimate association with a patient or convalescent. Due observance of this fact may enable one to avoid contracting the disease.

361. Common Colds.—What we commonly call "bad colds" are infectious diseases which are due to a variety of organisms. Streptococcus, pneumococcus, and the bacilli of influenza and diphtheria as well as other organisms may each be the cause of what is generally regarded as a bad cold. The first stages of the more virulent diseases caused by these organisms show essentially the same symptoms as a cold. This fact makes a cold deserving of more serious attention than it commonly receives. When one goes about his work, mingling with other people, while suffering from a cold, he is not only running a serious risk himself, but is exposing other people to danger. We should be taking a long stride toward the prevention of several serious diseases, if we could induce everyone to give proper attention to bad colds.

362. Tuberculosis.—This disease is often spoken of as the GREAT WHITE PLAGUE, and it richly deserves that name for it is, each year, responsible for more deaths than any other single cause. It has been estimated that in 1907, 153,000 persons died from tuberculosis in the United States. It has also been estimated that it costs the people of the country annually $200,000,000. Another bad feature of the disease is the fact that it usually results in a comparatively early death. The average age of persons dying from tuberculosis in the U. S. has remained at about 35 years ever since 1860, when statistics first began to be collected. Death at this age is about the saddest, for it usually means broken families and motherless and fatherless children. Another bad feature of the disease is that it usually means a long lingering illness that is more or less hopeless.

It is difficult to paint the picture of this disease too darkly. It is important that everyone come to know how great a scourge it is. If every citizen could realize how great a danger threatens him from this source we might have a more united effort in our endeavor to do away with the disease or lessen its attack.

There is hardly any part of the human body that the TUBERCULAR BACILLUS (Fig. 203) may not attack. The lungs constitute the chief seat of infection but the intestines, the various glands of the body, the skin, the throat, the bones and joints and other parts of the body are frequently attacked.

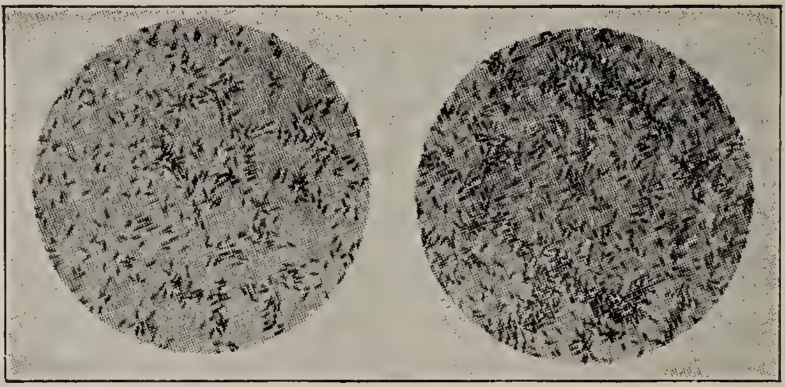

FIG. 203.—Tuberculosis bacilli.

The organism generally finds entrance to the body through the mouth or nose and it also leaves the body to become a source of infection to others through the same openings. The sputum of a consumptive contains myriads of organisms. It has been found that in dried sputum, some of these organisms may retain their vitality for as long as eight months. These facts make it evident that all sputum from tubercular patients should be completely destroyed or sterilized. The droplets of water that are usually thrown violently into the air when a tubercular patient coughs or sneezes usually contain great numbers of the bacteria and are thus a source of danger to others intimately associated with the patient. Spoons, forks, and dishes used by a tubercular person are likely to be infected with the organism and should always be sterilized by boiling water before they are used by others. Strict observance of these and other similar precautions may enable one to live in the same family with a tubercular person and yet avoid infection.

363. **Where Danger Lurks.**—It seems that the average healthy person has a rather high natural resistance against tuberculosis, provided that he is properly conditioned. Many occupations and customs of modern life are highly conducive to the contraction of the disease. People who work indoors, particularly where there is much dust, poor ventilation, and bad sanitary conditions, are much more likely to contract the disease than are those who work in a better environment. This is shown by the following table which shows the number of persons per 100,000 of population in the specified occupations, who died from tuberculosis of the lungs in the year 1900.

Occupation	Number of deaths per 100,000
Marble and stone cutters	540.5
Cigar makers and tobacco workers	476.9
Compositors, printers, and pressmen	435.9
Servants	430.3
Bookkeepers, clerks, and copyists	398.0
Laborers (not agricultural)	370.7
Farmers	111.7

Other sickness such as measles, whooping cough, scarlet fever, and influenza which leave the body in a weakened condition are often a predisposing cause of tubercular infection. During attacks of these and similar diseases and during convalescence, one should be extremely careful to avoid all chance of tubercular infection.

We often hear the statement made that tuberculosis is hereditary and that it tends to run in families. While the former statement is entirely untrue, it is doubtless true that susceptibility to the disease does run in families, or in other words, that the amount of resistance against the disease is a matter of heredity. For this reason, people who have tuberculosis in the family need to be extremely careful to avoid infection and to avoid conditions which are conducive to infection, for they are likely more susceptible than are others who have no tuberculosis in their ancestry.

364. Tuberculosis Curable.—We hear a good deal in these days in newspapers, in popular magazines, and in the advertisements of sanitariums to the effect that tuberculosis is a curable disease. This is no doubt true and the means of cure sound comparatively simple. *They consist of rest, plenty of fresh pure air day and night, and plenty of good wholesome food.* But no one should be deluded by the fact that the disease is curable by these means into being careless about contracting it. One great danger of the disease lies in the fact that one may be affected by it for months or even years before the fact is easily determined and then it is often too late to hope for a cure. If one is once seriously infected with tuberculosis, he is not likely ever to be able to do much else but obtain a cure; if he is ever successful in so doing.

Many people with apparently high resistance have slight attacks of tuberculosis and recover without ever knowing that they had it. One investigator made a comprehensive study of the bodies of 500 persons who had died from various causes and he found evidences of former tubercular infection in 97 per cent. of the bodies. Doubtless most of these people had never known of the attack.

Our chief defenses against this disease are our natural resistance, and vigorous health. As long as the disease is as prevalent as it is, we can hardly hope to escape entirely chances of infection. We should do what we can to escape the organism but we should rely mainly on being able to overcome it when it attacks us. We should all try to live all the time much as a tubercular patient must live. We may not need so much rest but we all need the fresh air and the wholesome nourishing food.

III. PUBLIC HEALTH

365. Our Duty Regarding Public Health.—It is perfectly evident that in matters that have to do with health, no one lives unto himself alone. One may do much for his personal health through proper attention to personal cleanliness, to food and clothing, to fresh air and exercise but in the matter of contagious diseases, no one person by his own efforts can guarantee his own safety. Those who supply us with milk and other foods may bring infection to us, we may get it from those with whom we associate, or we may get it from the strangers with whom we mingle as we travel. The city water supply may give us disease, or flies may carry it to us from garbage or sewage which are not properly disposed of. We may be endangered by the failure of public officials to properly enforce quarantine. In all these ways, we are dependent on others for protection against disease. If these others on whom we depend for protection are ignorant or careless, we are bound to suffer.

If we would seek to better our conditions with reference to contagious diseases, we must rely mainly on our efforts to raise the general level of intelligence and sense of responsibility in regard to these things on the part of the whole people. Every one who has the grand privilege of a high school education and who learns concerning matters of health, even what may be learned in this book, should consider himself or herself eligible for leadership in matters of public health. There are needed in every community many people who will practise good sanitation and observe all the laws of public health and who will insist that others do the same. What we learn in school should be for use in our daily lives and it is to be hoped that what you have learned here concerning health and disease will be made a foundation for your daily practices.

CHAPTER VII

Food—Its Uses and Preparation

I. THE DIET

366. The Essentials of Human Life.—Air, water, food, clothing, and shelter are necessary to maintain human life. Without air, death soon results. Without water death from thirst follows. Without the proper kind and amount of food starvation begins, the body becomes weak and less able to resist disease and death results. Acute starvation from utter lack of food is not commonly met, but slow starvation is all too common. Clothing and shelter are needed to protect the person from the inclement weather of the Temperate Zone.

367. Relative Costs of the Essentials.—Air is the cheapest of the essentials, yet it is not free as is sometimes supposed, as the providing of fresh air in cold climates costs money. The cost of water is not considerable, perhaps $5.00 a year would supply a family of six with the water needed for sanitary and drinking purposes. Food, clothing, and shelter are all costly essentials. Which costs the most depends largely upon the habits of the family or individual, but usually the cost of food exceeds the cost of either of the others.

368. Importance of Studying the Food Problem.—The business of obtaining food is the most important one in which man is engaged. This business includes, not only agriculture, which is the art of obtaining foods indirectly from the soil, but also the carrying of the food from the farm to the market, the milling, the packing, and the other manufacturing processes by means of which the food is prepared for the consumer, and the retailing of the finished product to the consumer. A large portion of our population is engaged in the work of obtaining, transporting, preparing, and retail·

ing food. The food bill of our country amounts to more than any other single bill.

With the early pioneer, the food problem was comparatively simple. He raised his own wheat and corn. He took them to mill and had them ground into flour or meal. His wife made the bread in her own kitchen. The pioneer produced his own meat and slaughtered it himself. He produced his own sugar, maple sugar, or sorghum. He produced, of course, his own milk, butter, and cheese. Very few foods were purchased at the grocery.

Now all is changed. Even the farmer often buys his flour, meat, cheese and butter. The population of cities has largely increased. Food must be produced for city dwellers as well as for those directly engaged in the production of food. We have a greater variety of foods offered for sale in our modern markets than the pioneer ever thought of. Food is brought from all parts of the world. Much of the food offered for sale has passed through one or more manufacturing processes. The problem of getting food in these days is, not only a question of getting enough to eat, but it is also a problem of selecting the best and the cheapest foods from the great varieties offered for sale in the markets.

369. What Foods Do for the Body.—We eat that the body may be kept in health. Health demands that the foods shall keep the body strong and vigorous. The foods must supply the body with the materials of which it is made. They must also supply the body with energy (Art. 81) so that its work may be carried on. In some respects, foods are to the body what coal or gasoline is to the steam or gasoline engine. The fuel must be burned in the engine in order to make the engine go. In a similar way, the foods eaten supply the body with the energy to do its work. But the foods do more for the body than the fuel does for the engine. The foods provide for the growth and the repair of the body. The fuel does no such thing for the engine. The engine is not self-repairing by the fuel supplied to it. If one part wears out it must be replaced by a new part from the machine shop. *It is evident then that the foods must furnish the body with the materials out of which it is made as well as furnish it with energy.*

370. What Substances Must the Foods Furnish to the Body?—While the body is known to be composed of many complex chemical compounds, it is also known that these compounds are composed of but few chemical elements (Fig. 204).

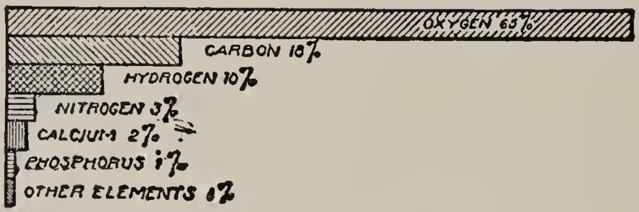

Fig. 204.—The composition of the human body.

Chemical Elements in the Human Body

	Per cent.		Per cent.
Oxygen,	about 65.00	Sodium,	about 0.15
Carbon,	about 18.00	Chlorine,	about 0.15
Hydrogen,	about 10.00	Magnesium,	about 0.05
Nitrogen,	about 3.00	Iron,	about 0.004
Calcium,	about 2.00	Iodine	Very minute traces.
Phosphorus,	about 1.00	Fluorine	
Potassium,	about 0.35	Silicon	
Sulphur,	about 0.25		

The oxygen, carbon, hydrogen, and nitrogen are the elements to which most attention is directed. The carbon and nitrogen come exclusively from the foods eaten. Much of the oxygen in the body comes from the air we breathe and the water we drink. Water also supplies much of the hydrogen found in the body. The other elements are usually present in the food in such abundance that we give very little thought to getting enough of them.

371. Foods Must Supply the Body with Energy.—The gasoline engine transforms the chemical energy (Chap. XI) of the gasoline into heat and power. The body likewise transforms the chemical energy of foods into heat, muscular activity, power to digest foods, power to think, to see, to feel, to hear; in short, into all processes included in "LIFE."

372. How the Energy of Foods is Liberated to the Body.—Just as the fuel for the engine must unite with oxygen in order that its energy may be delivered to the engine, so the materials composing the food must undergo oxidation in the body in order to liberate their energy to the body. However, in the case of the fuel, the oxidation is rapid and takes place at a high temperature. Such oxidation is known as COMBUSTION. In the human body, oxidation is slow and proceeds at the body temperature. The process is called SLOW OXIDATION. Without this slow oxidation there is no liberation of energy to the body. Hence, it is evident that oxygen is just as necessary as food for the maintenance of the body activities. The oxygen comes from the air. As a result of the combination of oxygen with the two most important elements found in foods, viz., carbon and hydrogen, carbon dioxid and water are the common products.

Exercise 69.—To Show That Water and Carbon Dioxid Are Produced in the Human Body

(*a*) Blow the breath against a cold window pane or some other cold surface and observe the film of moisture deposited. Where did the water come from? In what state was it in the breath? In what state is it now on the cold surface? What caused the change? Much of the moisture expelled in the breath comes from the water drunk, but a part also comes from the water formed in the body by the combination of the hydrogen of foods with oxygen.

(*b*) By means of a glass tube blow the exhaled breath through clear lime water contained in a clean bottle. What happens to the limewater? What substance does it show is present in the exhaled breath (Ex. 26 f)? Now take a bottle filled with such air as you are inhaling, place some clear limewater in the bottle, cover the mouth of the bottle, and shake the liquid with the contained air. What happens to the limewater? Can you detect any evidence of carbon dioxid in this fresh air? Was carbon dioxid more abundant in the exhaled breath than in the inhaled breath? Where did the extra amount come from?

373. **Where Do the Foods Obtain Their Energy?**—It is a notable fact that all energy-giving power of the foods of animals and of the higher plants is traceable to the work of green plants. Green plants are the only living things in all the world that have the power to take up the non-nutritious materials like water, carbon dioxid, and mineral matter and build them into the nutritious foods like sugar, fat and protein. If we eat the flesh of an animal, we are still dependent upon the green plant for our food, for the animal either got its food from plants or from some other animal which subsisted on plants. Sunlight is necessary for the growth of the green plant. Sun energy is taken into the plant through the leaves and is stored in the food made by the plant. Thus it is that the green plants are the food factories of the world, gaining their raw materials from the earth and the air, and storing in the finished product the energy derived from the sun.

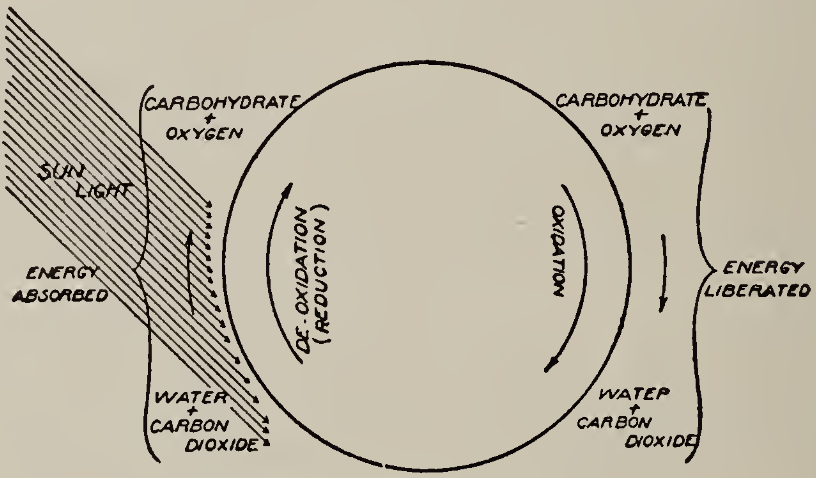

Fig. 205.—The carbon cycle.

374. **The Carbon Cycle.**—Of the raw materials coming to the green plant, water and mineral matter come to it from the earth by way of the roots, while the carbon dioxid is absorbed through the leaves. Out of the raw materials and with the energy derived from the sun, the plant makes a simple sugar in the leaves. Oxygen is liberated at the same time. This escapes into the air. From the simple sugar, the plant, by means of other materials, produces other foods. When the plant or an animal consumes the food the plant

has produced, oxygen is taken from the air, the food is oxidized, its energy is liberated, and carbon dioxid and water are produced. The carbon dioxid is returned to the air, subsequently to be built into a food again by some green plant. This round of changes goes on continually. It is known as the "CARBON CYCLE" (Fig. 205). All of the energy possessed by fuels is traceable to the work of green plants.

375. What Is Food?—

DEFINITION.—*A food is anything from which the body may obtain its substance and energy.*

Many of the substances we eat furnish both of these for the body and are therefore rightly called foods. Some of the other substances we eat and which are sometimes called foods, are without the ability to supply the body with energy. They ought not to be thought of as foods in the same sense as those materials which furnish both for the body. Thus our meats and cereals supply both for the body. They are foods. Salt and water which are taken into the body yield no energy to the body. They are not to be thought of as foods in the same way as we think of meats and cereals.

376. Classes of Foods.—Our foods may be broadly classed as foods derived from animals and foods derived from plants. The animal foods include such foods as beef, pork, mutton, fish, game, poultry, milk and its products, and eggs. The foods derived from plants include a greater variety. The cereals such as corn, wheat, oats, rye, rice, and barley are used. Other plant materials such as the potato, pea, bean, sugar cane, sugar beet, and nuts are used. Still other plant materials commonly called fruits are widely used.

377. Man's Quest of Food.—Seeking food has always been an important task with man. The earliest races obtained their food by gathering edible portions of plants as tender stems, roots, seeds, and fruits. These foods were bulky and large quantities were required to meet the needs of the body. Had it not been for their ability in hunting and fishing, these early men would have found it impossible to live on such vegetable foods as they could gather. In those far off times plants were not cultivated nor animals domesticated. All food was eaten uncooked. (Art. 1 and Art. 65.)

378. The Discovery of Fire and the Invention of Cooking.—With the discovery of fire simple cooking began. This might have consisted of laying the food upon the hot coals or of placing it in rude ovens previously heated by making fires in them. Cooking food in water was out of the question until vessels capable of holding water and withstanding the fire could be produced. The discovery of fire made possible the manufacture of pottery and the extraction of metals from their ores. Thus vessels suitable for use in cooking were made.

379. Cookery and Agriculture.—Dr. Harry Campbell of London has shown that the invention of cookery led to agriculture. He holds that the vegetable foods of early man were bulky and required much labor to secure an adequate supply, while the seeds of plants, although less bulky and more highly nutritious than other parts of the plants, were so hard that it was difficult to eat such parts raw. With the coming of cookery it became possible so to soften the seeds that they became edible. As a consequence man turned his attention to cultivating the seed producing plants, because by that means he could obtain his vegetable diet with less labor than by simple foraging. This marked the beginning of agriculture. Finding it easier to domesticate certain animals than to capture them in the chase, primitive man turned his attention to breeding animals that would furnish his meat, milk, and skins, the last, of course, serving for clothing. Thus animal husbandry arose as a branch of the agricultural industry.

380. The Food Principles.—While there is a great variety of substances used as food, it has been found that they are all made up of a few essential substances called the FOOD PRINCIPLES. These include: (1) FATS, (2) CARBOHYDRATES, and (3) PROTEINS. It is from these *food principles* contained in greater or less amount in our common foods that the body derives its energy and nearly all of its substance. Mineral matter and water are sometimes included in the food principles, but they yield no energy to the body.

381. The Fats.—FATS are composed of carbon, hydrogen, and oxygen. They are found in plants and animals in both the solid and the liquid states. The liquid fats are frequently called oils. But the oils would become solid at a sufficiently low temperature. Petroleum and its products, though commonly called oils, are not fats. They are without food value to the body.

Our common fats come from animals, from the cotton seed, from corn, from the olive, and from certain nuts such as the peanut and the cocoanut.

382. Carbohydrates.—Like the fats, the carbohydrates are compounds of carbon, hydrogen, and oxygen but in different proportions from those in fats. Carbohydrates are found chiefly in plants, no considerable amount of them coming from animal bodies. The following list includes the commoner carbohydrates:

1. Cellulose (cotton is nearly pure cellulose).
2. Starch.
3. Sugars. These include not only common sugar (sucrose) which is derived from the sugar cane, sugar beet, and sugar maple, but also milk sugar (lactose) found in milk, fruit sugar (fructose) found in ripe fruits, glucose (dextrose) the chief sugar of glucose syrup, and malt sugar (maltose) derived from grains.
4. Dextrin (commonly used as an adhesive).

Cellulose is not an important constituent of human foods, although it plays an important part in animal foods. Starch and all of the above sugars are valuable foods, while dextrin is unimportant being found in small amounts in glucose syrup.

383. Simple Tests for Carbohydrates.—

Exercise 70.—Tests for Carbohydrates

1. THE SUGARS MELT.—Place half a teaspoonful of granulated sugar in a large spoon and carefully heat it until it melts.

2. The Carbohydrates Char When Heated Hot Enough.—Continue to heat the melted sugar until a solid black residue, carbon, is left behind. This residue contains most of the carbon that was in the original sugar. Repeat the charring test with starch.

3. The Iodine Test for Starch.—Apply a drop of iodine solution by means of a pipette to a little starch (Fig. 206). What color is produced? Apply the iodine test to the inside of the following grains, corn, wheat, oats; also apply it to the following fruits and the vegetable, apple, banana, potato. In which ones of these do you find starch? If possible compare ripe and green fruits as to the presence of starch.

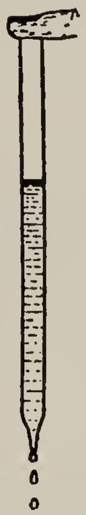

Fig.206. —Using the pipette.

384. Proteins.—These substances contain nitrogen in addition to carbon, hydrogen, and oxygen. Many proteins also contain sulphur and phosphorus. The proteins are found in the cereals, in many vegetables, in meats, in milk and its products, in cheese and butter, and in eggs. The skin, hair, and nails contain protein substances. Wool and leather, glue and gelatin also contain protein substances. The white of egg is nearly pure protein mixed with water. Milk is a mixture of protein, fat, carbohydrate, mineral matter, and water, while cheese is a mixture of the same substances, but with less water.

The proteins are the most expensive of the food principles. Animal bodies are generally rich in proteins and poor in carbohydrates, while the cereals are relatively poorer in proteins but rich in carbohydrates.

Exercise 71.—Tests for Proteins

1. The Burning Test.—Because of the nitrogen they contain, protein substances burn with a characteristic odor, that of burnt hair. Burn a little wool and note the odor. Compare it with the odor arising from burning cotton. Heat a little wheat flour and dried beef in separate evaporating dishes or crucibles. Note the odor of the burning materials.

2. The Ammonia Test.—When protein substances are heated with lime (calcium hydroxid, not the solution, but the dry material) ammonia is produced. The ammonia may be identified either by its odor or by the fact that it turns moist red litmus paper blue. Place small equal amounts of dry gelatin and lime in a test tube

and mix them. Heat the mixture strongly, holding a piece of moist red litmus paper in the gases escaping from the tube (Fig. 207). Be careful that the paper does not touch the side of the tube where it may meet lime which would turn the paper blue just as the ammonia does. When you get a strong test for ammonia, note the odor of the gases escaping from the tube. Disregard the odor of burnt hair and give attention only to the ammonia. Ammonia was formerly made almost entirely by heating animal products with lime. The ammonia was called SPIRITS OF HARTSHORN because the horns of the hart deer were frequently used as the animal substance. (See Art, 440.)

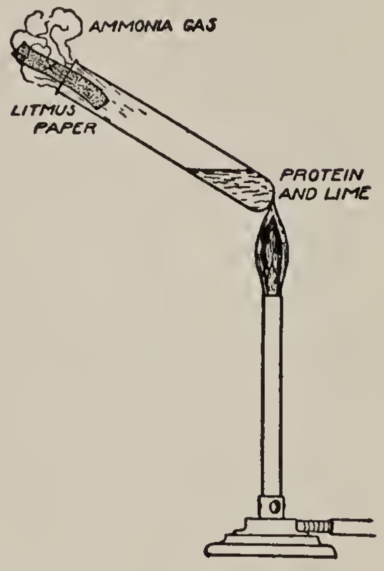

FIG. 207.—Test for proteins.

3. THE NITRIC ACID TEST.—Place a little dry gelatin in a test tube and moisten it with a single drop of concentrated nitric acid. Warm the mixture gently. What color is produced? Now add ammonia solution until the mixture smells of the ammonia. What has happened to the color just observed? Care should be used to prevent any nitric acid from getting on the skin for it produces a disagreeable stain. Why?

385. The Protein Foods Absolutely Necessary.—While the protein foods yield energy equal in amounts to equal weights of carbohydrates, their chief value to the body lies in the fact that they alone contain nitrogen. Proteins must be found in every diet. The body may obtain energy quite as well from fat and carbohydrates as from protein, but neither fats nor carbohydrates can furnish the body with the nitrogen which it needs. Moreover, the protein foods, as a rule, are higher in price than either the carbohydrates or the fats. It would be folly therefore to consume protein foods for the sole purpose of producing energy for the body when this energy can be obtained more cheaply from carbohydrates and fats. Moreover, the waste products from protein are much harder to get rid of than the waste products from carbohydrates and fats. However, enough protein must be supplied the body at all times to keep the body in repair.

386. How Much Protein?—This is a matter which has caused a great deal of discussion. But authorities are now agreed that the body should be supplied with from 3 to 5.3 oz. of protein per day. Dr. Atwater gave the following as the protein requirement of persons engaged in different occupations:

Man with hard muscular work..................	5.3 oz. per day
Man with moderately active muscular work.......	4.4 oz. per day
Man at sedentary or woman with moderately active work	3.5 oz. per day
Man without muscular exercise or woman at light to moderate work..........................	3.17 oz. per day

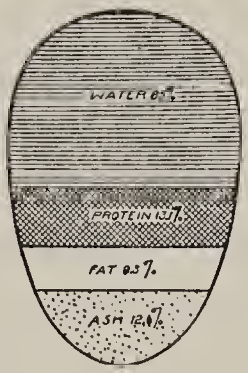

Fig. 208.—Composition of the whole egg.

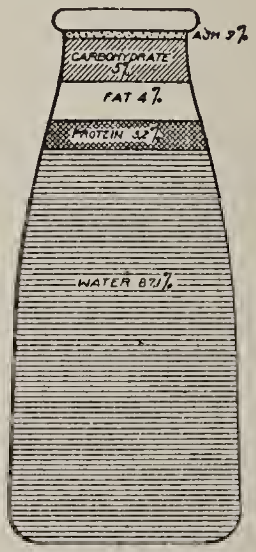

Fig. 209.—Composition of whole milk.

Exercise 72.—Weighing the Amount of Protein Needed by the Body for a Day

Weigh a dozen eggs and calculate the average weight of one egg. By the use of Table VII on page 333 or Fig. 208 which gives the percentage of protein in whole eggs, calculate the weight of egg needed to furnish protein enough for a man of sedentary occupation. How many eggs will be required per day if eggs are to furnish the protein for the body? Weigh a quart of whole milk and by use of Table VII or Fig. 209 calculate the weight of milk a man would have to consume daily to furnish 3.5 oz. of protein. Calculate the weight of round steak needed to furnish 3.5 oz. of protein.

TABLE VII.—COMPOSITION AND CALORIFIC VALUE OF FOODS

(1) CEREALS AND CEREAL PRODUCTS

Kind of Food	Per cent. of water	Per cent. of protein	Per cent. of fat	Per cent. of carbohydrate	Heat value in greater calories per lb.
Bread, average	35.3	9.2	1.3	53.1	1200
Corn meal	12.5	9.2	1.9	75.4	1635
Corn flakes	7.3	10.1	1.8	78.4	1680
Oat meal	7.7	16.7	7.3	66.2	1800
Rice	12.3	8.0	0.3	79.0	1620
Rye flour	12.9	6.8	0.9	78.7	1620
Wheat flour	12.0	11.4	1.0	75.1	1640
Wheat, shredded	9.0	10.5	1.4	77.3	1650
(2) EGGS AND DAIRY PRODUCTS					
Eggs, whole	65.5	13.1	9.3	None	635
Eggs, white	86.3	12.8	0.4	None	250
Eggs, yolk	50.0	16.0	33.0	None	1705
Milk, whole	87.1	3.2	4.0	5.0	325
Milk, skimmed	90.5	3.4	0.3	5.1	165
Butter	12.0	0.5	85.0	None	3600
Cheese, full cream	34.2	25.9	33.7	2.4	1885
(3) MEATS, EDIBLE PORTION					
Beef, chuck ribs	57.3	17.4	24.4	None	1355
Beef, loin	60.5	18.3	20.2	None	1190
Beef, round	65.8	19.7	13.5	None	935
Beef, rump	56.7	16.8	25.6	None	1395
Beef, dried	50.8	31.8	6.8	None	845
Pork, bacon, smoked	18.2	10.0	67.2	None	3020
Pork, ham, smoked	40.7	15.5	39.1	None	1940
Pork, shoulder, fresh	57.5	15.6	26.1	None	1390
Poultry, chicken	74.2	22.8	1.8	None	500
Poultry, turkey	55.5	20.6	22.9	None	1350
Fish, mackerel	73.4	18.2	7.1	None	640
Fish, salmon	69.1	18.2	11.4	None	820
Fish, sardines	56.4	25.3	12.7	None	1010
Fish, trout, brook	77.8	18.9	2.1	None	440
Oysters, solids	88.3	6.1	1.4	None	235
(4) FRUITS AND FRUIT PRODUCTS, EDIBLE PORTION					
Apples	84.9	0.4	0.5	14.2	285
Bananas	76.1	1.3	0.6	22.0	447
Blackberries	86.8	1.3	1.0	10.9	262
Figs, drier	21.2	4.3	0.3	74.2	1437
Dates, dried	16.7	2.1	2.8	78.4	1575
Grapes	77.9	1.3	1.6	19.2	437
Oranges	79.4	0.8	0.2	11.6	233
Peaches, fresh	89.8	0.7	0.1	9.4	188
Raisins	18.0	2.6	3.3	76.1	1562
Raspberries, black	84.7	1.7	1.0	12.6	300
Strawberries	91.0	1.0	0.6	7.4	169
Watermelon	92.7	0.4	0.2	6.7	136
(5) MISCELLANEOUS, EDIBLE PORTION					
Beans, dry lima	14.5	18.1	1.5	65.9	1586
Potatoes, white	79.5	2.2	0.1	18.4	378
Sugar, granulated	None	None	None	100.0	1815
Peanut butter	11.2	25.8	38.6	24.4	2490

387. How Much Food?—The food eaten must not only supply protein to keep the body in repair, but it must also furnish enough energy for the needs of the body. The ability of foods to produce energy in the body is measured by the amount of heat they produce when burned. Now the energy requirements of the body are measured in heat units, usually the greater calorie (Art. 102). Dr. Atwater in Farmer's Bulletin No. 142, U. S. Department of Agriculture, gave the following as the energy requirements per day for persons in different occupations:

Man with hard muscular work	4150 greater calories
Man with moderately active muscular work	3400 greater calories
Man at sedentary or woman with moderately active work	2700 greater calories
Man without muscular exercise or woman at light to moderate work	2450 greater calories

Chemists have analyzed nearly every food, and have determined its heat-producing ability by burning in a calorimeter. The results of these investigations on some of the common foods are given (page 333). By reference to Table VII, it is an easy matter to see just what food principles each food furnishes the body, what proportion of the food principles is furnished, and just how much energy, measured in greater calories, is furnished.

388. Some Observations on the Table.—It is evident to anyone who will study the table that some of our foods contain much water. Their calorific value is, therefore, rather low. Watermelon, for instance, contains over 92 per cent. water and its heat value is but 136 Cal. per lb. while butter contains about 13 per cent. water and its calorific value is 3600 Cal. per lb. This must mean that butter is a much better fuel for the body than watermelon. A man could scarcely eat enough watermelon to supply the energy needs of his body, while a rather small amount of butter would meet the energy demands easily (Fig. 210).

It is also evident that some foods are much richer in certain of the food principles than others. Thus butter contains about 85 per cent. fat and no carbohydrates while sugar contains 100 per cent. carbohydrate and no fat. The cereals are all rich in carbohydrate while their fat and protein percentages are rather low. The meats, on the other hand, contain, as a rule, no carbohydrates while their percentages of fat and protein are rather high. In general fruits contain much water, little protein and fat, and relatively much carbohydrate. In selecting foods, then, a knowledge of their composition is necessary.

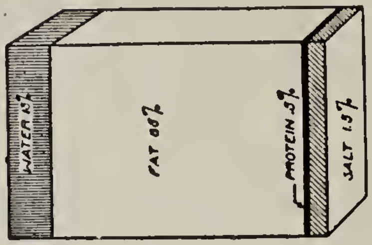

Fig. 210.—Composition of butter.

389. **The Heat Value of the Food Principles.**—When the pure food principles are burned in the calorimeter it is found that they produce the following amounts of heat:

Protein	2562 greater calories per pound
Carbohydrate	1860 greater calories per pound
Fat	4286 greater calories per pound

But the body does not realize the full heat value of the food principles when they are oxidized in the body. This is because of incomplete digestion and incomplete oxidation. The following is the net value in heat units of above to the body:

Protein	1815 greater calories per pound
Carbohydrate	1815 greater calories per pound
Fat	4084 greater calories per pound

It will thus be observed that protein and carbohydrates are of equal value to the body as producers of energy, while fat produces about 2¼ times as much energy. It is a well-known fact that fatty foods are greater heat producers than other kinds. Inhabitants of cold climates consume and relish large quantities of fat. Most of us have a better appetite for fat in the winter than in the summer. Why?

390. **Bread and Butter; Pork and Beans.**—These are well-known combinations of food. Why are these foods thus com-

bined? It will be observed that bread is composed of 9.2 per cent. protein, 1.3 per cent. fat, and 53.1 per cent. carbohydrate. It is therefore rather poor in fat. Butter on the other hand is rich in fat, so that a thin coat of butter on a slice of bread supplies the deficiency of fat in the bread. Explain why the combination of fat pork and beans is better than either one alone. What combination would you suggest with eggs? Why do we relish cheese with bread or crackers? Why do we combine meat and potatoes? Why combine milk, eggs, and sugar in a custard?

TABLE VIII.—ONE HUNDRED CALORIE PORTIONS OF FOODS

Kind of Food	Weight of Food Yielding 100 Calorics	Weight of Protein in 100 Calorie Portion
Bread, wheat	1.33 ounces	.122 ounces
Corn Flakes, toasted	.95 ounces	.095 ounces
Oat meal, uncooked	.88 ounces	.147 ounces
Wheat, shredded	.97 ounces	.102 ounces
Eggs, whole	2.52 ounces	.330 ounces
Milk, whole	4.92 ounces	.157 ounces
Butter	.44 ounces	.002 ounces
Cheese	.85 ounces	.220 ounces
Round steak	1.71 ounces	.337 ounces
Bacon	.53 ounces	.053 ounces
Ham, smoked	.82 ounces	.127 ounces
Chicken, dressed	3.20 ounces	.729 ounces
Fish, trout	3.63 ounces	.686 ounces
Apple	5.61 ounces	.022 ounces
Raisins	1.02 ounces	.026 ounces
Beans, dry lima	1.00 ounces	.181 ounces
Potatoes	1.20 ounces	.092 ounces
Sugar, granulated	.88 ounces	none

391. Food for a Day.—What amount of food should be purchased at the market in order to properly nourish a man engaged in ordinary labor? Bearing in mind that a man engaged in moderately active muscular work should have food enough to furnish about 3400 calories per day (Art. 387) and that he should have about 4.4 ounces of protein per day

(Art. 386) it becomes a simple problem to calculate his food requirements by making use of Table VIII. The figures resulting from such calculations are shown in the following table.

TABLE IX.—FOOD FOR A DAY FOR MAN AT MODERATE LABOR

Kind of Food	Amount in Weight or Volume	Amount in 100-Cal. Portions	Total No. of Cals. Yielded	Protein in Ounces
Bread	13.3 oz.	10 100-Cal.	1,000 Cal.	1.22 oz.
Oat Meal	1.75 oz.	2 100-Cal.	200 Cal.	.30 oz.
Milk	1 pint	3.2 100-Cal.	320 Cal.	.50 oz.
Cheese	2.5 oz.	3 100-Cal.	300 Cal.	.66 oz.
Butter	1.0 oz.	2.25 100-Cal.	225 Cal.	No oz.
Round steak	5.0 oz.	3 100-Cal.	300 Cal.	1.00 oz.
Bacon	2.0 oz.	4 100-Cal.	400 Cal.	.21 oz.
Potatoes	1.75 lb.	5 100-Cal.	500 Cal.	.46 oz.
Sugar	1.75 oz.	2 100-Cal.	200 Cal.	No oz.
Total			3,400 Cal.	4.35 oz.

In making up such a menu one should expect to get nearly one third of the total calories from bread which will furnish nearly one fourth of the total weight of protein. Potatoes and sugar, together, may furnish about one fifth of the calories and one tenth of the protein. The remainder of the calories and protein required may be obtained from such foods as butter, cheese, meat and cereal.

PROBLEMS

1. Make up a breakfast menu for a man engaged in moderate labor so that he may obtain one third of his daily requirement from the meal.

2. Arrange a full meal menu for a man at moderate labor so as to provide one half of his daily requirement.

392. The Results of Eating too Much.—Many people consume more food than the body needs. No good can come from such a practice. The food in excess of 3500 or 4000 Cal. per day is not only unnecessary, but more than this, it interferes with the proper working of the body. The organs of excretion have an added and useless burden placed upon them. Physicians tell us to eat slowly, to chew the food until it becomes creamy in the mouth, and to let the act of swallowing be largely involuntary. By following this plan, the appetite is satisfied with less food and the danger of overeating is diminished. Half an hour should be used in eating a meal. The food should not be washed down, improperly chewed, by use of large draughts of water.

Many people partake too liberally of a protein diet. Having an appetite for meats and similar high protein foods they eat this kind to the exclusion of foods containing more carbohydrate as bread. This is especially likely to happen when one is ordering food from an extensive menu. Unless care is exercised a selection is likely to be made which is too high in protein.

II. PROCESSING FOOD

393. Origin of Processing.—Early races learned arts of processing foods whereby they might be preserved from the season of plenty to a season of scarcity. Thus man learned to dry fruits, to cure meat by salting, drying, and smoking, and in very recent times to preserve fruits and vegetables by canning. He also learned processes whereby the work of concentrating the food stuff with reference to certain constituents might be done. Thus from milk, cheese, rich in fat and protein, is made by processing milk. Similarly butter is extracted from milk; lard and tallow from animal bodies; starch from corn, potatoes, and rice; flour from wheat; sugar from the cane, beet, and maple; and oils from the olive, corn, and cottonseed.

Great industries concerned with the business of processing food have arisen in our country. It seemed at one time that the great meat packing concerns, by extending their activities to other lines than the meat foods would soon come to control the food markets of the country. But late in 1919, under pressure from the Federal government they relinquished their hold on other lines and agreed to confine their activities to meat foods.

THE DAIRY PRODUCTS

394. Milk.—MILK is the food of the infant for the early months of his life. It contains all of the ingredients needed for the child. It is also largely used as food by adults. Milk should not be looked upon as a mere beverage. Its food value should be taken into account in the dietary. Milk is especially liable to become impure through the introduction of filth and germs in the dairy. It is an ideal breeding ground for bacteria and its production and handling should be done under the most sanitary conditions possible. Because milk contains so large a proportion of water (87 per cent.) it is sometimes made a more concentrated food by removal of a part of the water by evaporation. The resulting product, CONDENSED MILK, is sterilized and sealed in air-tight cans when it can be kept for a long time in a usable condition. Condensed milk contains about 27 per cent. of water. Often considerable sugar is added during the condensing process. Sometimes all of the water is evaporated from milk and the resulting MILK POWDER is used in the preparation of self-rising pancake flour. When water is added to the flour, the milk powder dissolves and the result is much the same as that obtained by adding milk to the flour. Condensed milk is used in the preparation of ice cream and candies.

395. The Percentage of Fat in Milk.—Whole milk ordinarily contains from 3 to 5 per cent. fat. Cream contains from 18 to 45 per cent. fat. Much attention is given to the amount of fat in milk, and it is commonly supposed to be a safe guide in judging the quality of the milk. But it must be remembered that there are other food materials in milk besides fat. Milk also contains about 3.2 per cent. protein and 5 per cent. carbohydrate, MILK SUGAR (see Fig. 210). But in general, if the fat percentage is low, the other constituents are likely to be low also. But there is much food value in SKIM MILK. Skim milk contains the valuable protein. One might purchase skim milk and make up for the fat it lacks by purchasing a cheaper fat as oleomargarine. Most states and cities have laws fixing the lowest amount of fat that milk can contain to be sold as whole milk. These laws usually place the lowest limit at 3 per cent. or 3.5 per cent. fat.

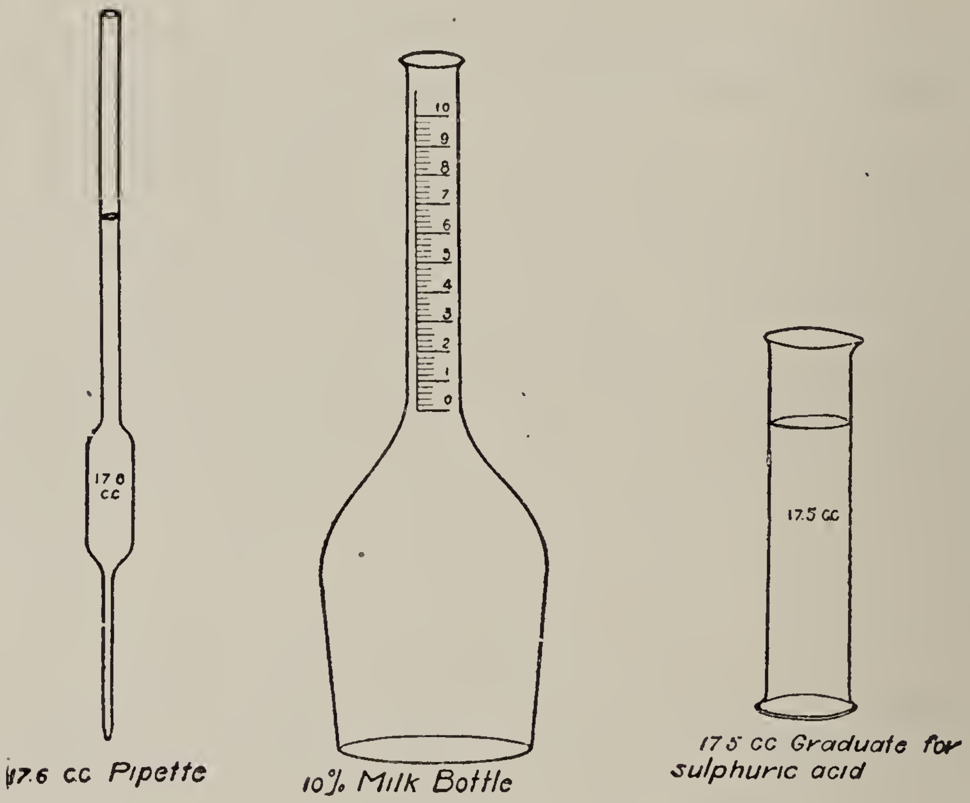

FIG. 211.—Glassware for the Babcock Milk Test.

396. The Babcock Method of Determining Fat in Milk.—The method of the test is as follows: A certain amount of milk is placed in a test bottle having a graduated neck. Concentrated sulphuric acid is then added to the milk and the mixture is well shaken. The sulphuric acid dissolves all of the constituents of the milk except the fat. The bottle and the mixture are then placed in the Babcock machine in which they are whirled at a high rate of speed. The fat, being the lighter, rises to the surface of the mixture in the bottle and by getting the fat into the graduated neck the percentage of fat may be read directly.

Exercise 73.—The Babcock Test

(1) Mix the milk to be tested by pouring it from one bottle to another several times. This mixes the cream with the remainder of the milk. (2) By means of a milk pipette (Fig. 211) draw out 17.6 c.c. of the mixed milk and place it in an 8- or 10-per cent. milk bottle (Fig. 211). Do not insert the tip of the pipette so far into the milk bottle that the milk is spilled as the air escapes from the bottle. Draw out another 17.6 c.c. portion and place it in another bottle. (3) Place 17.5 c.c. of concentrated sulphuric acid in the acid measure (Fig. 211) using care to avoid spilling any of the acid on the hands or clothing. Now carefully pour the concentrated acid into the test bottle of milk containing the 17.6 c.c. of milk allowing the acid to run to the bottom of the bottle. Do not shake the acid and milk until the other bottle is prepared. Measure another 17.5 c.c. portion of the acid and pour it into the second bottle of measured milk. (4) Now carefully shake the bottles containing the milk and acid so as to mix thoroughly. Do not try to mix the liquids by placing the finger over the mouth of the test bottle or the finger will be burned. In shaking, be careful that the curd does not become lodged in the neck of the bottle. The mixture becomes very hot and it is to be kept hot during the entire test from this point on. The acid has now dissolved all of the constituents in the milk except the fat. The fat is now to be separated by use of the machine. (5) Have about a pint of water heating so it will be ready for use later on. (6) Place the test bottles at opposite points in the centrifuge machine (Fig 212) and

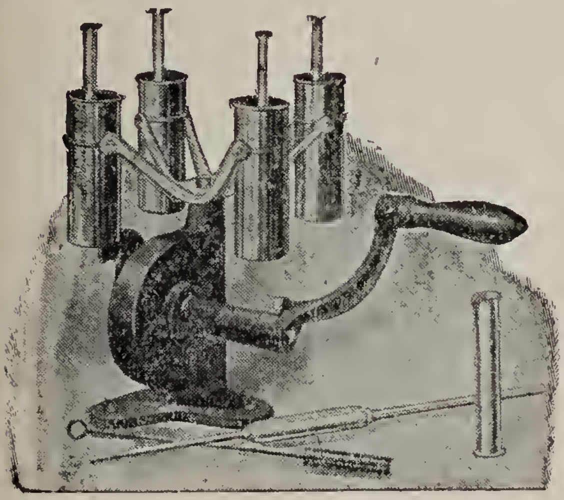

Fig. 212.—The centrifuge machine.

place bottles filled with water in the other holders so as to balance the machine. Turn the handle of the machine at the rate of about 70 revolutions per minute for five minutes. Remove the test bottles and carefully fill them with boiling water until the liquid comes up near the top of the neck of the bottle. Be careful to avoid pouring in so much water that the fat runs out of the bottle. Return the bottles to the machine and whirl them for one minute more at the same rate as indicated above. By this process, the fat is all thrown into the graduated neck of the bottle where its amount may be read. (7) Read the upper and the lower limits of fat column in the neck of the bottles. Subtract the smaller reading from the larger one. The difference is the percentage of fat in the milk. Repeat the operation with the other bottle. Do the two percentages of fat agree?

PROBLEM

How many pounds of butter could be made from 100 lb. of the milk tested, provided the butter is to contain 85 per cent. fat, 13 per cent. water, and 2 per cent. salt?

If possible, test for fat by the Babcock method to see how completely the fat has been removed, milk that has been skimmed by hand. Also test milk that has been separated by means of a cream separator (see Art. 543). For accurate work on the latter kind of milk, a skim-milk bottle should be used.

397. Butter.—When cream is allowed to "ripen" (Art. 544) and is then agitated in a churn the fat gathers together in masses known as BUTTER. These masses of butter are gathered together, washed with water, worked to remove the excess of water, and then salted to impart an agreeable flavor. Churning is most quickly accomplished by having the temperature of the cream about 65 or 70°F., but more solid butter, and butter of better grain or texture is obtained by churning at a lower temperature. The composition of butter is shown in Table VII. According to a standard established by Congress, butter for interstate traffic must not contain more than 16 per cent. of water nor less than 82.5 per cent. of fat (see Fig. 210).

398. Renovated or Process Butter.—Through careless methods of handling milk and cream and carelessness in manufacturing butter, it sometimes happens that the butter is of inferior grade. Moreover, it may be held so long that it has become rancid and unfit for food. Such butter is renovated in specially constructed factories. The butter is melted and air is blown through the melted fat. This removes the disagreeable odors. The salt and many undesirable materials in the butter sink to the bottom of the vessel containing the melted fat. The purified fat is then drawn off and mixed with sweet milk, then it is churned, much as cream is churned. The product is sweet and resembles true butter in many respects. The manufacture and sale of RENOVATED, or PROCESS BUTTER, is regulated by law. The law intends that the purchaser shall know that he is buying such an article and not true butter. All renovated butter must be properly labeled.

FIG. 213.—Ripeners for oleomargarine.

399. Butterine, or Oleomargarine.—Because of the high price of butter fat, various cheaper fats are sometimes used for the manufacture of substitutes for butter. These substitutes are called BUTTERINE, or OLEOMARGERINE. Butterine is a healthful and nutritious food and may be used instead of butter in the diet. Good butterine is better than poor butter. Because unscrupulous manufacturers and dealers in butterine have tried to sell their product as butter, the manufacture and sale of butterine is surrounded by many legal restrictions. Many grades of butterine are manufactured. In the best grades a considerable quantity of butter fat is used to impart a flavor of real butter to the product. In the cheaper grades very little butter fat is used. The fats used as substitutes for butter fat in butterine come from animals and from the cotton seed. One of the substituted fats is called NEUTRAL. Neutral is made from the leaf lard of hogs by RENDERING (trying out) the material at a very low temperature and then EXPRESSING (pressing out) the liquid fat from the tissues. It is without odor and taste. Another substituted fat is called OLEO OIL. This oil is expressed from the fat of cattle. These animal oils are prepared from animals which have been inspected by United States inspectors and

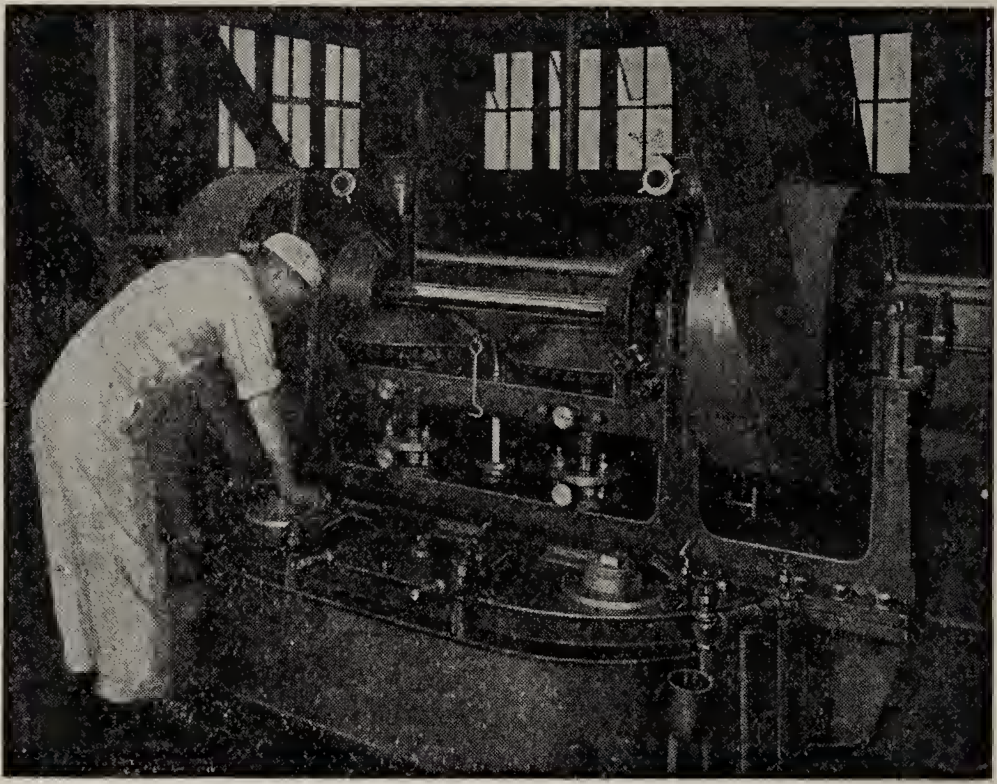

FIG. 214.—Churning oleomargarine.

passed. They are prepared in a sanitary manner and are wholesome articles of food (Art. 405). Cotton seed oil products (Art. 407) are sometimes used in butterine in addition to the fats mentioned. Such amounts of these fats are used as will give with the butter fat a mixture resembling true butter. The cream in the milk is RIPENED (Fig. 213 as for the ordinary methods of churning. The proper amounts of neutral, oleo oil, and cotton seed oil product are then mixed with the ripened cream and the mixture is churned (Fig.

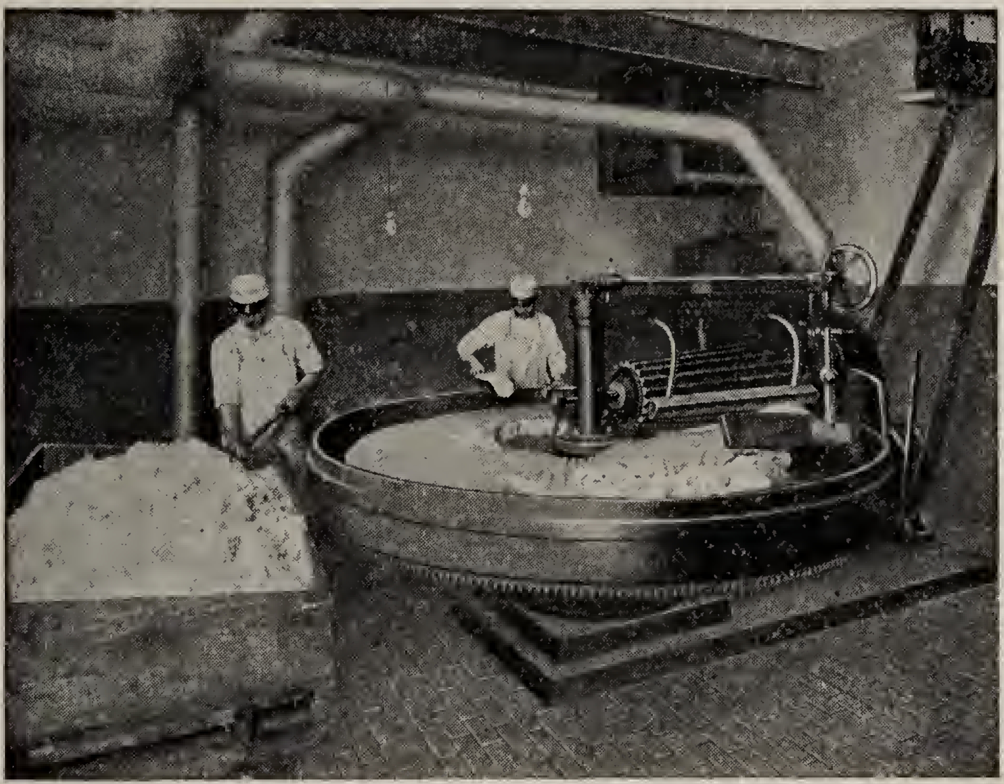

FIG. 215.—Working oleomargarine.

214. The fats gather much as true butter gathers. They are removed from the milk and worked and salted as in the case of butter (Fig. 215). Uncolored butterine is taxed ¼ ct. per lb. If the butterine is colored so that it resembles butter, an additional tax of 10 cts. per lb. is levied by the Federal government.

Exercise 74.—The Foam Test for Butterine and Butter

Place a lump of butterine in a tablespoon and heat it over a flame until it melts (Fig. 216). Continue the heating, noticing the absence of foam and sputtering. Now treat a lump of butter in like manner and notice the foaming and sputtering which accompany the escape of water from the butter. By this test, it is easy to distinguish butterine and butter. If obtainable, test some renovated butter in the same manner. Renovated butter behaves in a manner similar to that of butterine.

400. Cheese.—Both cheese and butter have been used by pastoral people for ages. Abraham set butter and milk before his guests. When a lad, David was sent by his father with cheeses for the captain of the company in which his brothers were serving in the army of Israel. Cheese is the fermented CURD of milk. When milk sours, the CASEIN (curd) of the milk separates from the watery portion called the WHEY. The curd contains nearly all of the food substance in the milk except the sugar. The curd may also be produced by adding RENNET to the milk. Rennet is extracted from the stomachs of calves. The curd is separated from the whey and then pressed to remove as much of the fluid substance as possible. The pressed material is then allowed to ripen in a properly prepared room. During the ripening process the different constituents of the curd undergo certain chemical changes, largely caused by bacteria, producing the flavor and odor of cheese. If the cheese is made from whole milk the product is called FULL CREAM CHEESE. The composition of this kind of cheese is given in Table VII. It will be noticed that

FIG. 216.—Foam test for butterine and butter.

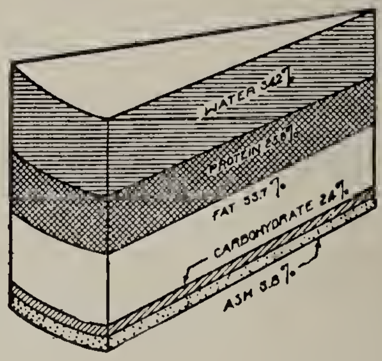

FIG. 217.—Composition of cheese.

cheese still contains a considerable amount of water but much less than whole milk (Fig. 216). In a sense, then, cheese may be looked upon as a kind of condensed-milk product. In some cases, the valuable milk fat is removed from the milk before making cheese. In this case cheaper animal or vegetable fats, as neutral and cotton seed oil products, are put in to compensate for the milk fat removed. Such cheese is known as FILLED CHEESE. Its manufacture is regulated by law as in the case of butterine, and the consumer is supposed to be informed that he is buying filled and not full cream cheese. When good fats are used as substitutes for the milk fat, filled cheese is wholesome and nutritious.

Meat Foods

401. Importance of Meat in the Diet.—Meats are eaten for the protein and fat which they contain. As we have seen, fat is useful to the body as a producer of energy, while protein is needed for its nitrogen. That protein may be obtained from vegetable substances there can be no doubt. Some people eat no meat whatever, obtaining all their protein and fat from vegetable substances. It is a much debated question whether we can get along just as well without meat. But there can be very little question whether, as a nation, we do not eat too much meat. It is doubtless true that most of us could get along quite as well if we were to eat less meat and more vegetable foods, such as grains and vegetables.

402. Meat Rapidly Deteriorates When Stored.—The fat and protein compounds of meat rapidly undergo changes when they are kept. On the other hand, the food substance stored in the grains may be kept for a considerable length of time without damage. For this reason meats must be consumed soon after the animals are slaughtered. In order to prevent decay several methods are used.

403. Preserving Meat by Cold Storage.—When the freshly prepared meat is placed in cold storage the rate of decay is greatly lessened. However, changes do take place in the meat, rendering it less fit for food. Refrigeration during shipment is very useful as a means of transporting meat from the packer to the dealer and to the consumer. Fresh meat should not be exposed for sale in the open air. It should be kept cool and free from dirt until it reaches the consumer. By freezing fresh meat it has been possible to preserve it for months with apparently very little change in the product. But the aim should not be to see how long meat may be kept, but rather to deliver it to the consumer as soon as possible after the animal is killed.

404. Preservation of Meat by Use of Salt and Other Chemicals.—When fresh meat is immersed in a strong brine, the meat is preserved from decay. Such treatment is known as pickling. Often other preservatives than salt are used. Saltpeter is often employed. It is not known that salt and saltpeter injure the meat in any way. But other and poisonous materials are sometimes used. These include borax, boric acid, sulphurous acid, and sulphites. They are powerful preservatives, and when taken in large amounts with the food are injurious to the health. Sulphurous acid and sulphites also impart a red color to the meat, thus causing it to appear fresh. Chopped meats are often treated with sulphites to prevent decay and to keep the meat red. Many states have laws which limit the amount of such preservatives that may be used and also provide that the purchaser shall be informed of the presence of the chemical in the meat. In this latter respect the law is often disobeyed.

405. Meat Inspection.—At all establishments at which animals are slaughtered for food which is to be shipped from one state to another, the United States Government stations officers whose duty it is to inspect all animals that are to be slaughtered and also to inspect the meat produced to see that it is fit for human food. Diseased animals are condemned and destroyed so as not to be used for food purposes. Food that is passed by the inspectors is marked "U. S. INSPECTED

AND PASSED." The United States inspectors work in conjunction with state and city food inspectors and thus largely prevent the coming on the market of meat unfit for human consumption.

406. Lard and Lard Substitutes.—When the fat of the hog is rendered, LARD is obtained. Because of its rather high price lard is frequently adulterated with cheaper fats, beef tallow and cotton seed oil being used for the purpose. Such mixtures are highly nutritious. They must be sold, however, as a COMPOUND LARD.

407. Cotton Seed Oil.—Since COTTON SEED OIL has been mentioned so frequently in the foregoing discussion, it is proper that it should be discussed here, although it is a vegetable and not an animal product. The seed of the cotton plant is rich in fat. For each bale of cotton weighing 500 lbs., about 1000 lb. of seed are produced. About 6,000,000 tons of cotton seed are produced annually in the United States, two-thirds of which is worked to produce oil. This gives an annual production of about 125,000,000 gals. of oil, more than 1 gal. per capita. After the cotton lint has been removed from the seeds, the hulls are taken off and the pulp pressed to liberate the oil. The oil is further refined and finds use in butter and lard substitutes, as a salad oil, in packing sardines, and in soap making. The pulp from which about 85 per cent. of the oil has been expressed is then broken into small pieces and used as stock feed. The use of this vegetable oil takes the place of much animal fat. Its nutritive value is equal to that of the animal fats.

THE CEREAL FOODS

408. The Cereals That are Used for Food.—Wheat, corn, oats, rye, rice, barley, and buckwheat are commonly used as foods. The cereals contain large amounts of starch and smaller amounts of fat and protein. They are the chief sources of the starchy foods, and for great numbers of the human race they furnish the chief source of protein. The use of the cereals as food will doubtless increase in importance as meats become less abundant and higher in price.

409. **Wheat.**—This is the cereal that is most extensively used as human food. It grows in many parts of the world. In North America, wheat is known as WINTER OR SPRING WHEAT according to whether it is sowed in the fall and allowed to lie in the field through the winter or whether it is sowed in the spring of the year in which it is to be harvested. Winter wheat can not be grown in the northern climates because of the cold winters. These regions grow only spring wheat. This cereal is rich in protein, containing about 12 or 13 per cent. It is poor in fat, but rich in carbohydrate.

410. **Wheat Flour.**—The wheat is ground between revolving rollers to extreme fineness. The ground material is then sifted through very fine bolting cloth which grades the ground material into several grades. These grades may be classified as PATENT FLOUR, BAKER'S FLOUR, and LOW-GRADE FLOUR. Besides these different grades of flour the wheat also produces BRAN, SHORTS, and SCREENINGS. To produce a 48-lb. sack of patent flour requires nearly 83 lb. of wheat, or about 1.4 bu. Besides the patent flour, about 9.3 lb. of baker's flour and 5.6 lb. of low-grade flour are produced. The remainder of the 83 lb. of wheat appears as bran, shorts, screenings and waste.

411. **Graham Flour.**—True GRAHAM FLOUR is made by grinding the entire grain without bolting. It, therefore, has the same composition as wheat. Most of the graham flour that is produced at present is bolted, so that much of the bran covering of the grain is removed.

412. **Whole or Entire Wheat Flour.**—This name is applied to a flour produced by removing the bran covering of the grain and grinding. It, therefore, has about the same composition as the so-called graham flour.

413. **Gluten.**—GLUTEN is the name given to two of the important proteins in flour. It is the material which gives to the flour its sticky character when wet. Without the gluten

in the flour, bread, as we know it, could not be made. The gluten is insoluble in water and helps the flour to make a dough when wet. The starch and fat in the flour may be washed away from the gluten.

414. **Shredded Wheat.**—This is a whole wheat preparation, cooked and ready to serve. It is one of the common wheat breakfast foods. The wheat is thoroughly cleaned and is then steam cooked until soft. The excess of water is then dried from the wheat and it is put into machines which crush the grains and form them into shreds which are delivered to an endless belt. The shreds are here cut into lengths to form the biscuits. These biscuits are then placed on trays and baked in electric ovens. Subsequently the crisp biscuits are packed in cartons and sealed. The wheat food is made light entirely by mechanical means, no yeast or other leaven being used in the process. The finished product has nearly the same composition as the wheat from which it is made.

415. **Corn—Its Use as Human Food.**—This cereal is more largely produced in the United States than is wheat. Corn contains the same food principles as wheat does. It contains more fat, however, and somewhat less protein. The proteins of corn do not include very much gluten. For this reason, corn flour has not been used to a very great extent, even in the United States, for bread. Moreover, the high percentage of fat in whole corn meal causes the meal or flour to become rancid in warm weather and hence unfit for food. Besides the corn consumed as flour, there is much of it worked up into breakfast foods, while a still larger part of the grain is carried through various chemical transformations for the making of starch, corn syrup, alcohol, and vinegar. There is every reason for believing that corn food products will be more extensively used in the future. But by far the largest part of the corn crop of this country is now consumed on the farm as stock feed. From it, are produced the various animal products so useful to man, including beef, pork, and dairy products. Food for man thus produced *indirectly* from corn,

is much more expensive than when corn is used directly as food.

416. Corn Flakes.—The well-known corn flakes represent a successful attempt to produce a food from corn which is at once palatable and nutritious. The operation of making corn flakes begins with the hominy, or corn grit, mills which are usually located in the "Corn Belt" of our country. Here the shelled corn is steeped in water until it is soft. It is then put through mills which loosen the germ and the skin which are removed from the remainder of the grain. The germ contains nearly all of the fat of the grain and much of the protein. The germs and skins are made into cattle feed, much being consumed on dairy farms. The remainder of the grain constitutes the hominy. The hominy, or grits, are dried and shipped to the flaking mill. Here the grits are steam cooked until soft; then the cooked material is put through flaking machines which convert the grits into flakes as thin as paper. The flakes are then toasted in great gas-heated ovens and packed in air-tight packages while crisp. In this condition they are delivered to the consumer. Large quantities of corn are thus flaked and find their way to the breakfast tables of American homes.

417. Corn Starch.—Most of the starch used in the United States is prepared from corn, although wheat and potatoes are also used to a limited extent. In Europe the potato is extensively used. Corn contains about 55 per cent. starch, while the potato contains about 18 per cent. However, an acre of land in Europe planted to potatoes can be made to yield a larger amount of starch than an acre of corn. About 50,000,000 bu. of corn are annually converted into starch and allied products in the United States, which represents, however, but one-fiftieth of the annual production.

418. Preparation of Corn Starch.—The shelled corn is steeped for three or four days in great tanks containing water and sulphur dioxid. This serves to loosen the skin and the germ. The soaked corn is then gently ground in mills which crush the grain, loosening the skin and germ from the part of the grain containing most of the starch. The ground material is then placed in tanks containing water in which the germs float because of the oil which they contain while the starch and skins sink. The germs are dried, ground, and pressed in filter presses, thus removing the oil. Corn oil has many uses as human food. The cake remaining after removal of the oil is called OIL CAKE. It is ground and largely used as stock feed. The starch and skins are re-ground and then put through the shakers which separate the starch from the skins. The skins, or bran, are again ground and again treated to remove the remainder of the starch. The starch suspended in water is then run into long troughs, inclined at a gentle slope. As the starch water flows through the troughs, the starch settles, while the gluten and water flow out at the end of the trough. The gluten is removed from the water, dried, ground, and marketed as GLUTEN MEAL which is used for stock feed. The accumulated starch in the troughs is removed, dried, pressed, and made into lump starch. The product still contains from 12 to 15 per cent. moisture.

419. **Glucose.**—Much starch is converted into syrups and sugar known as GLUCOSE SYRUP, or CORN SYRUP, and GRAPE SUGAR. Corn syrup is very extensively used as a food. It is sweet, but less sweet than ordinary sugar. It is without flavor and consequently the table syrups are frequently prepared by blending corn syrup and cane sugar, or REFINER'S SYRUP, the latter imparting a pleasing flavor. A popular brand of corn syrup also contains vanilla flavor.

Commercial glucose is composed of the following carbohydrates: DEXTROSE; MALTOSE; and DEXTRIN. Dextrose is one of the constituents of honey; maltose, or malt sugar is formed when certain grains sprout; while dextrin is the adhesive commonly used on postage stamps. Each of these materials has a nutritive value equal to that of ordinary sugar.

These materials are prepared from starch by the action of dilute acids upon starch.

420. Preparation and Uses of Glucose.—The starch used in the preparation of glucose is obtained as already described except that it is not dried after it has been collected in the troughs. The wet material "green starch" is mixed with water to make a thick, creamy liquid, and then it is mixed with the proper amount of hydrochloric acid for the change; the mixture is then run into a CONVERTER where the transformation of starch into glucose takes place (Fig. 218). In the converter the mixture is subjected to a steam pressure of 50 lbs. Under this pressure the temperature of the steam is about 150°C. or 300°F. Under these conditions the conversion is rapid. When the starch has disappeared, the liquid is blown by the steam pressure into the NEUTRALIZER (Fig. 218) where soda is added to neutralize the acid used in the conversion. The neutralization forms salt as one product of the chemical reaction. The salt remains in solution in the glucose, but there is so little of it that it is not noticed in the final

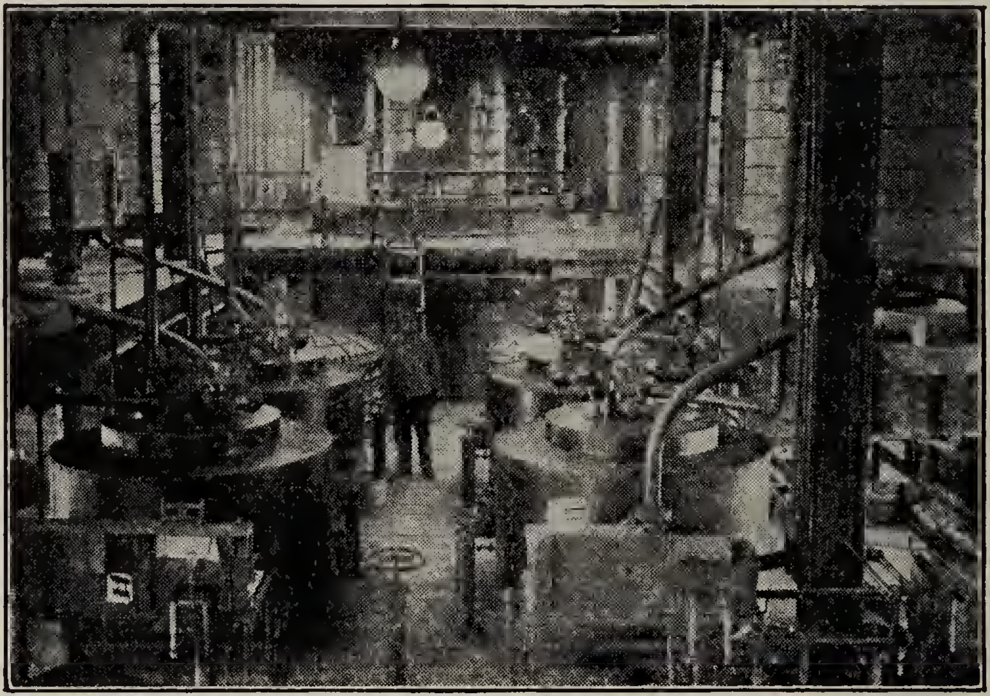

FIG. 218.—Manufacture of glucose. Shows the tops of the copper converters and the working floor around them, also the neutralizers on the balcony just above and surrounding the converter floor.

product. After neutralization the liquid, which is cloudy because of impurities, is filtered, first, through great suspended bags called bag filters, then through BONE CHAR. Bone char, as its name indicates, is made by charring bones. When liquid is filtered through the bone char, the impurities are absorbed into the pores of the char while the clear liquid runs on through. The bone-char filters are great tanks filled with the char, and through the char, the liquid is forced. The glucose liquid comes from the filter, bright and clear, but much thinner than the syrup used on the table. The liquid is next concentrated by evaporating a part of the water in EVAPORATORS. Here evaporation is carried on at a low temperature so as to prevent the darkening of the syrup. Evaporation at a low temperature is accomplished by reducing the pressure of the steam within the evaporator. After the required amount of evaporation, the liquid is placed in barrels and cans for delivery to the consumer. Grape sugar is made by evaporating the syrup still further and subsequently crystallizing the sugar.

Aside from its use as a table syrup, glucose is used in making jellies, preserves, and candy. Large quantities are used for the last-named purpose. Many medicines contain glucose syrup as body.

421. Sugar.—Sugar is one of the most widely used foods. There are but few manufactured foods found in the markets which are as nearly pure as sugar. While the term "sugar" is usually taken to mean the common article of food of the table, it will be remembered that there are several kinds of sugar (Art. 382). SUCROSE is the sugar meant as we commonly use the term. Sucrose is found in nature in the sugar cane, in the sorghum plant, in the sugar beet, in the sugar maple, and in certain kinds of palms. When pure sucrose is obtained from any one of these sources it is found to be like that from any of the other sources. Pure sucrose from the cane is the same as that from the beet. There is a popular prejudice against beet sugar. Many people think it inferior to cane sugar. They are equally nutritious. Maple sugar is prized because of its peculiar flavor. But when maple sugar is entirely purified and its sucrose extracted it is the same as sucrose from the cane or the beet. Nearly all of the sugar of commerce is derived from the cane and the beet. The sugar beet grows in temperate climates while the cane is limited to the tropical or semi-tropical countries.

422. **Preparation of Sugar from Cane.**—The sugar cane contains about 14.5 per cent. sucrose of which less than 90 per cent. is usually extracted. The cane is stripped of its leaves, cut, and carried to the mill where it is run between great rolls in which the cane is crushed and the juice containing the sugar is squeezed out. Water is applied to the crushed cane to remove more of the sugar. The crushed cane is finally burned beneath the boilers of the mill for the generation of steam for power. The juice is strained and then treated with lime. Upon being heated a scum arises on the juice. This scum is removed and the purified juice is then evaporated in vacuum evaporators as in the manufacture of glucose. The sugar solution is evaporated until crystallization of sugar begins when it is run into tanks where it is stirred until the crystallization is complete. The crystals are then separated from the syrup or molasses. The latter finds extensive use in the baking industry and in making stock feed. The sugar, known as RAW SUGAR in commerce, is then shipped to the refinery to be converted into the article which we know.

423. **Preparation of Sugar from Beets.**—Sugar beets contain from 14 to 17 per cent. sucrose. The beets are harvested and the tops removed. After being carried to the factory they are washed and sliced in thin slices. The sliced beets are placed in a series of great tanks called DIFFUSERS, which we shall call, in turn, *A*, *B*, *C*, *D*, and *E*. Fresh water is fed into top of *A* and as it passes down through the slices the sugar is extracted. Emerging from the bottom of *A*, the solution is next fed into the top of *B*. As it passes through the slices in *B*, it dissolves more sugar, but removes relatively less sugar

than was removed in *A*. Thus the solution is led, in the same manner, through *C*, *D*, and *E*, each time becoming a more concentrated solution of sugar, but removing, relatively, less and less sugar from the slices in each diffuser in turn. Finally as it emerges from *E*, the solution is almost as concentrated in sugar as is the natural juice contained in the slices in *E*. The solution is then purified and the sugar extracted.

Meanwhile, the continuous passage of water through *A* has removed as much sugar from the slices as it is profitable to remove. The exhausted slices in *A* are then removed, and *A* is refilled with fresh slices and it is then placed next in series after *E*. Fresh water is then fed into *B*. From *B* the solution passes in turn through *C*, *D*, *E*, and *A*. The solution from *A* is purified and the sugar extracted. Meanwhile the sugar has been quite completely removed from the slices in *B*. Its contents are emptied and it is refilled with fresh slices and placed next after *A* in series. Fresh water is then fed into *C*, passing, in turn, through *D*, *E*, *A*, and *B*. The solution from *B* is then purified and the sugar extracted. So the process is a continuous one. In this manner the maximum quantity of sugar is removed from the sliced beets by means of the minimum quantity of water.

In beet sugar factories the raw sugar is refined in the one establishment, whereas cane sugar is usually refined in other factories than those that produce the raw sugar.

424. Sugar Refining.—In the process of refining sugar, the raw sugar is dissolved in water and the syrup is then purified by means of lime and acid, after which the syrup is filtered through bag filters and then through bone char for clarification. The clarification is similar to that used in glucose. The purified syrup is then evaporated in vacuum evaporators until it crystallizes. The crystals are separated from the syrup and later they are dried in a machine called a granulator in which the crystals are separated from one another. By pressing the moist crystals in a mold the loaf sugar is made. The cubes are later dried.

CHAPTER VIII

REFRIGERATION AND ITS USES

I. THE REFRIGERATOR

425. **Use of the Refrigerator.**—The refrigerator is probably found in as many modern houses as is the furnace. It is probably also true that the health and comfort of the family and economy of living depend upon the use of the refrigerator during the summer months in as large a measure as they do upon modern methods of heating—furnace, steam, or hot water heating—during the winter months. Owing to the difficulty of securing ice, the cellar must still be used in many rural districts as a substitute for the refrigerator, just as the stove is used in the place of the more modern and adequate heating devices. In most town and city houses, the refrigerator is now considered a necessity.

426. **Principle of the Refrigerator.**—Most decay is the result of the action of MICROÖRGANISMS upon vegetable or animal matter. Fermentation, or the action of microörganisms, is hastened by moderately high temperature and plenty of moisture (Arts. 320 to 328). Lowering the temperature of foods or lessening the moisture in the foods delays decay. The function of the refrigerator is to ward off or delay decay as far as possible. It does this by providing a stream of cool, very dry air in which the foods are placed. The effectiveness of the refrigerator depends largely upon the circulation of the air within it. The stronger the circulation, the more effective the refrigerator in preventing decay (see Chap. VI, Microörganisms).

427. **Construction of the Refrigerator.**—The refrigerator is practically a box, the walls of which are usually made of several thicknesses, some of the materials being selected because they are poor conductors of heat. Because air is a poor conductor of heat, most refrigerators are constructed with an

air space in the walls. This air space is usually packed somewhat loosely with some substance such as charcoal or mineral wool or other poor conductors. This packing serves to break up convection currents which otherwise would be produced in this air space (Fig. 219). Air is a poor conductor of heat when not in motion, but, as we saw in the study of furnaces, it is a very effective agent in the transference of heat when it is moving in the form of convection currents.

428. Styles of Refrigerators.—Refrigerators are either TOP-ICING REFRIGERATORS, or SIDE-ICING REFRIGERATORS (Fig. 220). In the top-icing refrigerator the cold, descending column of air may pass downward at the center of the refrigerator while the warmer, lighter air passes upward at the two sides as shown in Fig. 220; or the cold, descending column may pass downward at one side of the refrigerator while the warmer, lighter air passes upward at the other side. In the side-icing refrigerator the air current is evidently always downward on the ice side and upward on the food side. The top-icing refrigerator usually affords a much larger ice capacity compared with the food capacity than does the side-icing refrigerator. On this account, when both ice boxes are filled, we should expect a somewhat lower temperature in the top-icing than in the side-icing refrigerator. On the other hand, since in the side-icing refrigerator the food compartment extends the entire height of the refrigerator, the columns of cold air and of warm air are considerably higher than is possible in the top-icing refrigerator of the same capacity. This insures very perfect circulation, which is an essential feature of a good refrigerator.

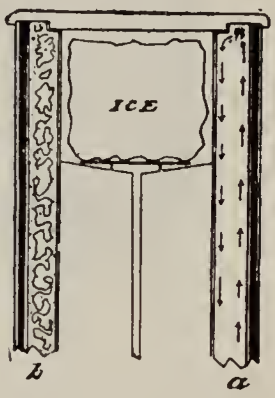

FIG. 219.—Walls of a refrigerator.

429. Temperature Obtained and the Cause of Circulation.—In a good refrigerator well filled with ice, the temperature of the air as it leaves the ice compartment and enters the food compartment is usually from 40° to 45°F. As the air leaves the food compartment and enters the ice compartment, its temperature is often raised to 55° or even 60°F. This difference in temperature is the cause of the circulation, the warmer, moist air being considerably lighter per cubic foot than the cooler, dry air (Arts. 111 and 115).

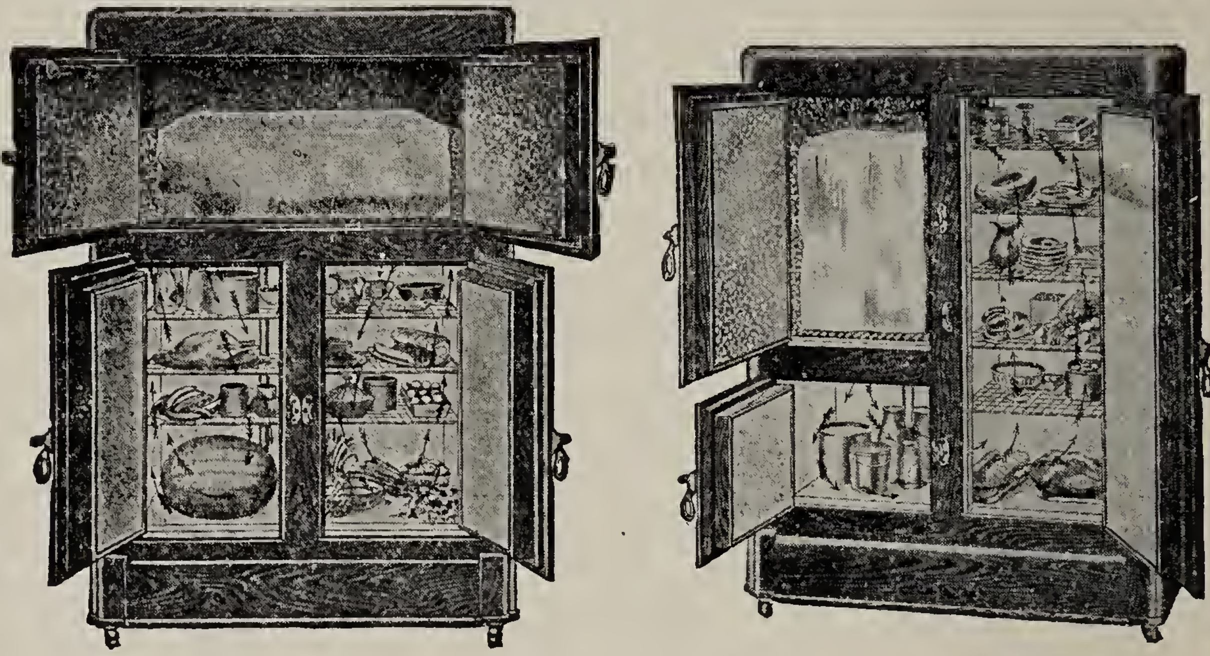

FIG. 220.—Top-icing refrigerator and side-icing refrigerator.

TABLE X.—WEIGHT OF 1 CU. FT. OF AIR SATURATED WITH WATER VAPOR; ALSO, WEIGHT OF THE WATER VAPOR IN EACH CUBIC FOOT OF AIR

Temperature, F.°	Weight of saturated air, grains	Weight of water vapor, grains	Temperature, F.°	Weight of saturated air, grains	Weight of water vapor, grains
—30	650	0.12	40	556	2.85
—20	634	0.21	50	544	4.08
—10	620	0.36	60	533	5.75
0	606	0.56	70	521	7.98
+10	593	0.87	80	509	10.93
20	580	1.32	90	497	14.79
30	568	1.96	+100	487	19.77

The difference in weight of a cubic foot of air at the different temperatures from —30° to 100°F. is more clearly shown by the curve, Fig. 221. If the temperature of the air in a refrigerator varies from 40° on the ice side to 55°F. on the food side, the weight of 1 cu. ft. of air will vary from 556 grains to about 538 grains. This means that the warmer air is only about $^{29}/_{30}$ as heavy as the cooler air. This difference in weight is sufficient to secure a convection current of considerable strength.

Exercise 75.—A Study of the Temperature in a Refrigerator

(*a*) Open the doors of a refrigerator and study carefully its construction. Is it top-icing or side-icing? If it is a top-icing refrigerator, determine whether the cold air drops out of the ice box at the center of the refrigerator or at one side. Also determine whether the warm air enters the ice compartment at one side only or at both sides.

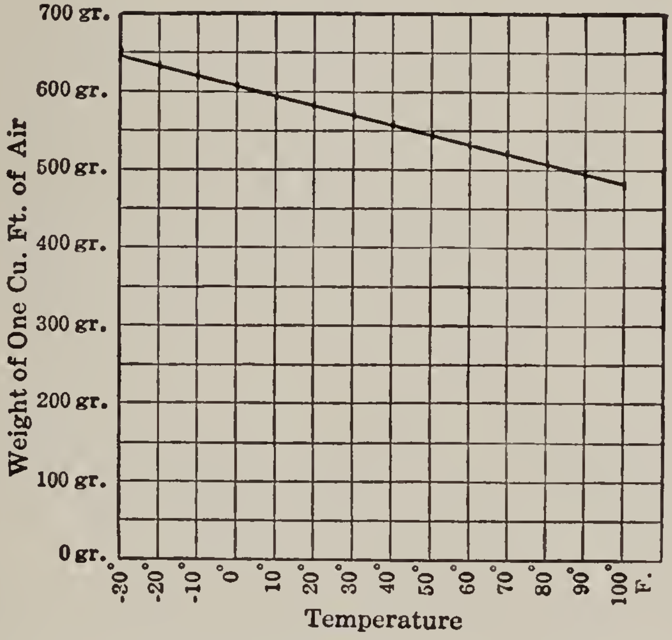

Fig. 221.—Curve showing density of air at different temperatures.

(*b*) Having determined the course of the convection currents in the refrigerator, place the thermometer in this current close up to the opening through which the air passes as it leaves the ice compartment and enters the food compartment.[1] Close all of the doors for about five minutes; then open one door and quickly read the thermometer without removing it from the air current. In like manner determine the temperature of the air as it leaves the food compartment and enters the ice compartment.

If possible, repeat these experiments with a second refrigerator.

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[1] It is well to wrap the bulb of the thermometer with asbestos cloth or paper to prevent the mercury from rising quickly when the thermometer is taken from the refrigerator.

The temperature obtained in this experiment will depend upon several things: (1) Construction of the refrigerator: (2) amount of ice in the ice compartment; (3) temperature of the room; (4) amount and kind of food in the food compartment. Show how each of these factors affected the temperature in the refrigerator you examined.

430. Meaning of Absolute Humidity, Saturation, Relative Humidity, and Dew Point.—In order to understand how the temperature of the air determines the amount of moisture which the air within a refrigerator contains, it is necessary that we learn some new terms and their exact uses.

Definitions.—

Absolute Humidity.—*By* absolute humidity *we mean the weight of moisture or water vapor actually contained in one unit volume of air, usually expressed in grains per cu. ft.*

Saturation.—*We speak of the air as being* saturated *or as having reached the* point of saturation *when it contains all the moisture, or water vapor, it can possibly contain at that temperature.*

In the table given above (Art. 429), the third column gives the absolute humidity of fully saturated air at the various temperatures given in the first column. For example, at 0°F. the absolute humidity of saturated air is 0.56 grain per cu. ft., while at 70°F. it is 7.98 grains, or nearly fifteen times as great.

Relative Humidity.—Relative humidity *is the ratio of the absolute humidity of air at any temperature to the absolute humidity of air were it saturated at the same temperature.*

Suppose the air in a schoolroom is found to contain 4 grains of water vapor per cu. ft. when the temperature is 70°F. The relative humidity of the air is then expressed as the ratio of 4 grains to 7.98 grains, of $^{4.00}/_{7.98}$, or very nearly ½. The relative humidity is usually expressed, however, not as a fraction, but as a per cent. In this case we say the relative humidity is 50 per cent.

Dew Point.—Dew point *is the temperature at which air* *containing a certain amount of moisture per cubic foot, that is, having a certain absolute humidity, becomes saturated, and dew forms.*

Suppose, as before, that the air in a schoolroom is at 70°F. and that it contains 4 grains of moisture per cu. ft. Now, if the temperature in that room were lowered, the air would become more nearly saturated, that is, its relative humidity would become higher, because the actual amount of moisture per cubic foot would remain the same while the amount of moisture it *might* contain would decrease with the fall in temperature. By examining the table above, or still better by examining the curve (Fig. 222), we see that the air will become saturated when the temperature has fallen a trifle below 50°, or about 49°F. Its relative humidity would then be 100 per cent. This temperature at which the air becomes completely saturated is called the dew point. If any object whose temperature is at, or below 49°F., is taken into this room, a portion of the moisture will be condensed upon this object, forming dew. This is exactly what takes place when

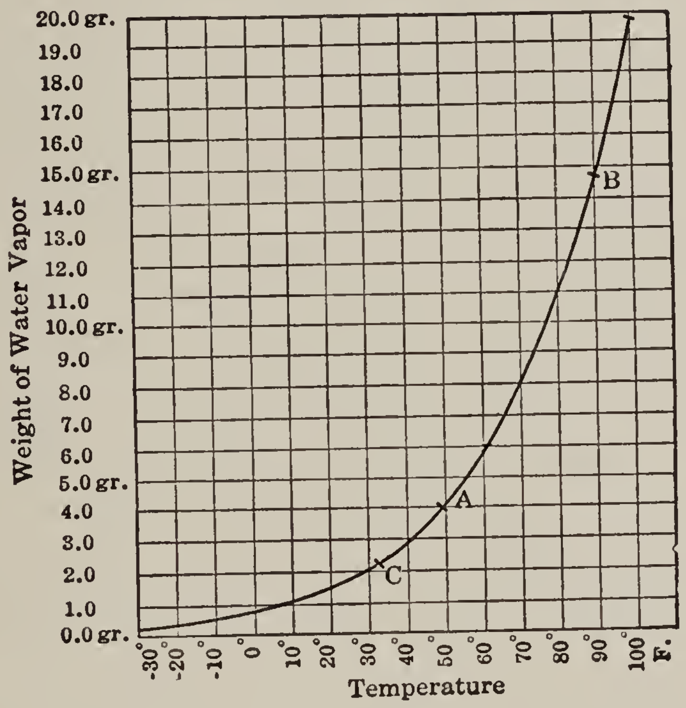

FIG. 222.—Curve showing weight of water vapor in saturated air at different temperatures.

a pitcher or glass of cold water stands for a few minutes on a warm summer day. The pitcher or glass becomes covered with dew. Often dew stands in drops on a pitcher or glass containing ice water.

431. Why the Air within the Refrigerator Is Dry.—In many portions of the United States the air on a summer day frequently reaches a temperature of 90°F., while at the same time the relative humidity is often as high as 80 or 85 per cent. We see, by reference to Table X, Art. 429, or to the curve (Fig. 222, *B*), that this means that the air contains 12 or 12.5 grains of moisture per cu. ft. At the same time, the air within the refrigerator is still more nearly saturated. But, since the temperature of that air is not higher than 50° or 55°F., the largest amount of moisture it can possibly contain is only about 4 or 4.5 grains per cu ft., or about one-third of that contained by the air outside. Again, as the air circulates through the ice compartment, much of it actually comes directly in contact with the ice. This must mean that the air for the moment is cooled nearly to 32°F., the temperature of the ice. All of the moisture in this air in excess of about 2 or 2.5 grains per cu. ft., therefore, is deposited in the form of dew upon the ice. Show this to be true by reference to the curve (Fig. 222, *C*). It is therefore evident that the air, as it flows from the ice compartment into the food compartment, does not contain more than about one-fifth, or at most one-fourth, as much moisture as the air in the room. The air, then, as it flows from the ice compartment into the food compartment, is cold and contains but little moisture, notwithstanding the fact that it is saturated.

432. Effect of the Dry Air within the Refrigerator upon Foods.—When this stream of cold, dry air leaves the ice compartment and enters the food compartment, it takes up heat from all the contents of the food compartment. As this air rises in temperature, its capacity for holding moisture increases rapidly, that is, its relative humidity is lessened; it is not longer saturated. Since most of the provisions usually placed in the refrigerator contain considerable moisture, evaporation takes place and the foods become drier. It is for this reason that fruits, such as apples, oranges and lemons, as well as other kinds of provisions, often dry up and wither instead of suffering ordinary decay when placed in a good refrigerator. Common table salt often absorbs so much moisture in the summer that it can not be shaken from a salt shaker. This can be prevented by placing the shaker in the dry air of the refrigerator.

433. How the Refrigerator Aids in Preserving Food.—We have seen in Chap. VI that the greatest competitors for food that man has are microörganisms, molds, yeasts and bacteria. All foods which man wishes to keep in store for any considerable length of time must be protected from microorganisms. We can protect our foods by adopting one or more of several methods. First, we may so dry our foods that they do not contain sufficient moisture to support microörganisms; second, we may preserve the food stuffs by heating them to such a temperature that all microörganisms and their spores are killed, then sealing the food in cans which prevent other microörganisms from getting into them (canning of foods). Food stuffs thus prepared may be kept almost any length of time.

In actual practice, however, we wish to keep some foods for a shorter time without either canning them or drying them. Nearly every family has a supply of food left over after every meal which should be saved for the next meal. Milk and fresh meats are generally kept in stock for a day or so in advance of use. By placing such food stuffs in a refrigerator where the air is quite dry and the temperature is rather low the action of microörganisms is so retarded that the foods remain almost unaffected by microörganisms for some time. The length of time which foods may thus be preserved depends upon the nature of the food, the temperature maintained within the refrigerator, the dryness of the air within the refrigerator and the circulation of air within the refrigerator. The ordinary refrigerator in the home usually serves to preserve food from the attack of microörganisms for a few days only, but by the modern methods of cold storage (Arts. 323 and 447) foods are regularly kept for long periods of time, from season to the next season.

434. What Keeps the Refrigerator Cool.—It is not possible to construct a refrigerator of such material and in such a manner as entirely to prevent heat from getting into it, even when all doors are closed. If this were possible, very little ice would be needed to operate it. Since heat is certain to penetrate the refrigerator from every side, and at all times, this heat must be taken up or absorbed by the ice. In Art. 127, we learned that heat used in melting ice is called HEAT OF FUSION. *The cooling of the refrigerator is due almost entirely to the absorption by the ice of this heat of fusion; that is, the heat is consumed simply in melting the ice.* Occasionally we hear of someone's wrapping the ice in paper, to prevent melting, before placing it in the refrigerator. This, of course, is an error. Just to the extent that wrapping actually prevents melting as intended, the presence of the ice in the refrigerator is useless. Nevertheless, good judgment on the part of the operator may lessen considerably the amount of ice required to operate the refrigerator. The refrigerator should be placed in the dryest and coolest place possible, consistent with convenience.

435. Rear-icing and Built-in Refrigerators.—Most manufacturers, when requested, now furnish refrigerators with a door to the ice compartment on the back, or rear, of the refrigerator. This device is often of great service, inasmuch as it enables the ice man to fill the refrigerator without coming inside the house. The refrigerator is placed with its back against the outside wall. An opening is made in the wall corresponding to the rear door of the refrigerator. This opening is fitted with a door also. This opening is generally reached from a porch; therefore, the refrigerator can be as easily filled from the outside as it could be from the inside of the house, thereby saving much dirt and inconvenience. In many modern houses the refrigerator is "built-in," that is, it is constructed as a part of the house just as truly as is the staircase (Fig. 223).

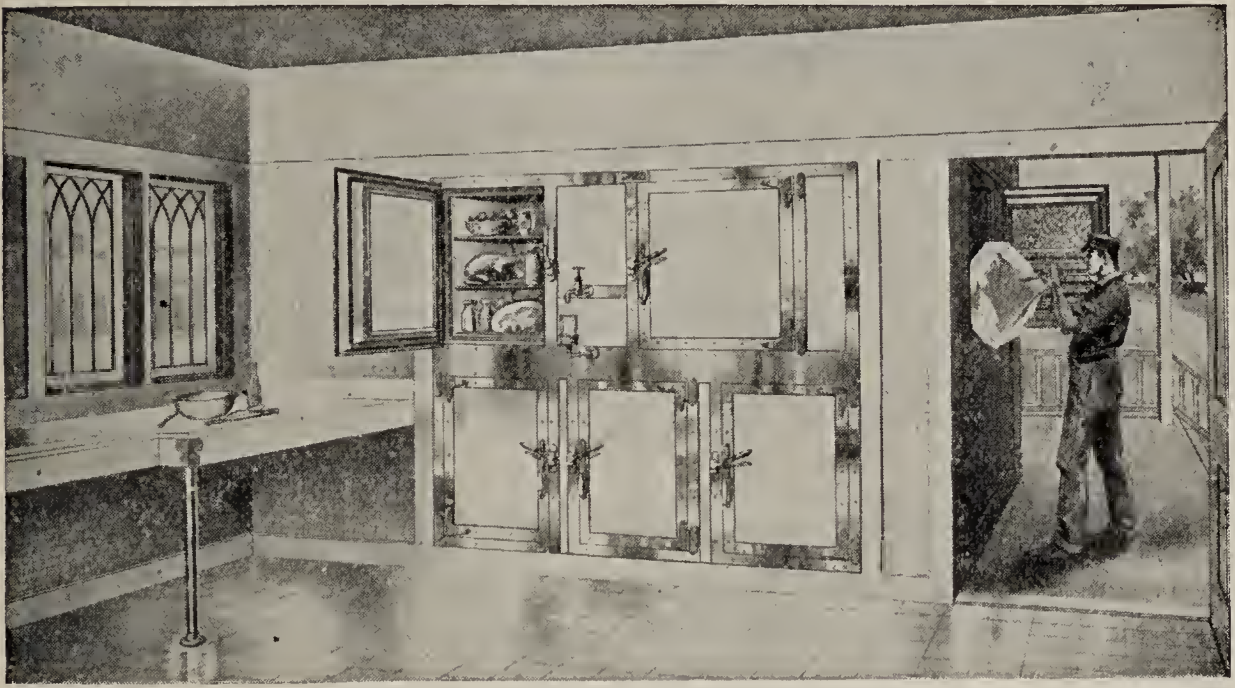

FIG. 223.—A built-in refrigerator.

436. The Refrigerating Machine for Home Use.—During recent years many devices have been constructed to take the place of the refrigerator in the home. They all involve the principles employed in the manufacture of ice and in cold storage plants (see next two sections). Figure 224 shows one such device. It is really a small cold storage plant attached to an ordinary refrigerator. On top of the refrigerator is a com- gas. (Dry ammonia gas, also carbon pressor for compressing sulphur dioxid dioxid are sometimes used instead.) The compressor is run by a small electric motor. The compressed gas passes through cooling coils where it is liquefied. It then passes into the refrigerating

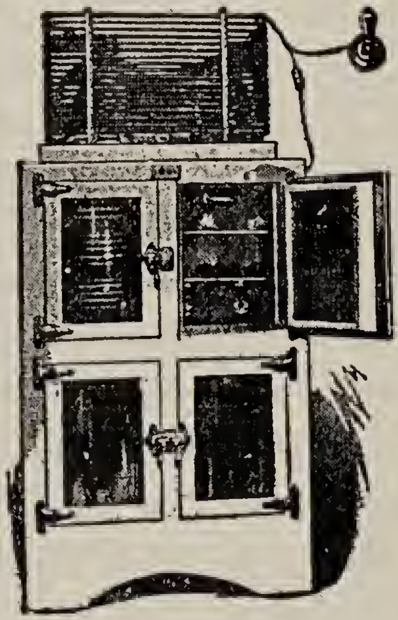

FIG. 224.—A mechanical refrigerator.

coils which are in the ice compartment of the refrigerator. Here the liquid sulphur dioxid is released from pressure and changes into a gas, producing a lower temperature and dryer air than can be secured by the use of ice. (See II, of this chapter).

437. Care of the Refrigerator.—We have seen that the purpose of the refrigerator is to delay or ward off the action of microörganisms upon food stuffs. It is not sufficient that the temperature of the air within the refrigerator and the food be kept at as low a temperature as is possible. In addition to this the interior of the refrigerator must be kept just as clean as possible.

Freshly cooked foods, or fresh fruits and vegetables, are not well seeded with microörganisms or the spores of microörganisms, although they are certain to contain some such organisms and spores. If the conditions within the refrigerator are unfavorable for the rapid growth and multiplying of such organisms, the multiplication will be slow. If, on the other hand, the interior of the refrigerator is dirty, if old food stuffs are allowed to remain scattered about within the refrigerator, or if more or less liquid foods have been spilled within the refrigerator and not thoroughly removed, or if the drain pipe is allowed to go uncleaned,—any one or all of these conditions afford excellent culture beds for all kinds of molds, yeasts and bacteria. In refrigerators not properly cleaned the air is filled with the spores from these microörganisms. These spores settle upon the foods and molding, fermentation and decay takes place rapidly.

Every refrigerator should frequently be thoroughly cleaned and rinsed with hot water, as near boiling hot as possible. The drain pipe should not be omitted.

II. MANUFACTURED ICE AND FREEZING MIXTURES

438. Need of Manufactured or Artificial Ice.—Without manufactured ice it would be impossible to make use of the refrigerator in many portions of the civilized world. Even in climates where natural ice is produced in sufficient quantities, artificial ice is regarded as a necessity for many purposes on account of its greater purity. Most towns and cities of any considerable size have their ice factories. Artificial ice is today in such common use that we should learn something about the principles involved in its manufacture.

439. **The Ice Plant.**—The essential parts of the ordinary plant for the manufacture of ice are: (1) Steam boilers and a steam engine; (2) an ammonia compressor (*B*, Fig. 225);

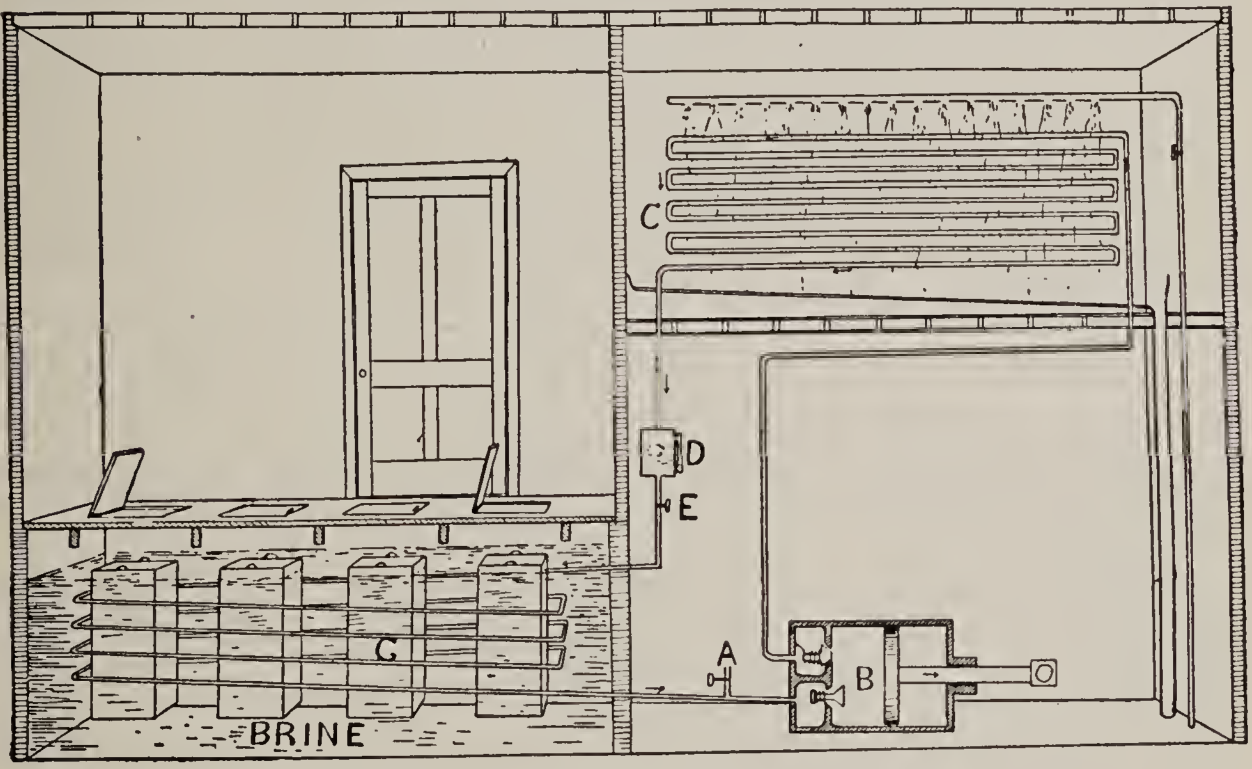

Fig. 225.—Diagram of an ice factory.

(3) cooling coils, through which the ammonia passes and over which flows constantly a stream of cool water (*C*, Fig. 225); (4) a tank of brine through which the ammonia pipes run (Fig. 225); (5) cans containing purified water which is to be frozen (*G*, Fig. 225). There are usually also mechanical devices for handling the blocks of ice, and frequently additional boilers for the distilling of the water which is to be frozen.

Before we can understand the use of these parts of the plant and the process followed, we need to know some of the special properties of ammonia.

440. Some of the Properties of Ammonia.—When studying evaporation (Art. 12, Ex. 10, we learned that when any liquid evaporates much heat is absorbed, or, as we commonly say, cold is produced. This last way of speaking is really not incorrect if we fully realize that cold is simply absence of heat; it is better, however, to speak of the heat's being absorbed. We should also recognize that it is the heat of vaporization (Art. 127) which is absorbed. We also saw that those liquids which evaporate most rapidly absorb heat most rapidly; they feel the coldest on the back of the hand. The substances studied were water, alcohol and gasoline. But each of these substances is a liquid at ordinary temperatures, and each of them boils under the pressure of the atmosphere at a temperature higher than that of the air about us. (Recall the boiling temperature of each of these substances.) Evidently, then, each of these three substances will change from the liquid form to vapor form rapidly, that is, it boils only when raised to a rather high temperature. Further, it is only when a liquid is boiling that it absorbs the heat of vaporization most rapidly.

We see now that if we can obtain some substance in the liquid form which evaporates very rapidly, or even boils, at a temperature below the freezing point of water, we can then allow this liquid to evaporate and absorb heat, taking it from water till the water freezes. This is exactly the principle employed in the manufacture of ice, and AMMONIA is the liquid most commonly used.

Nearly everyone is somewhat familiar with ammonia. It is the gas that escapes from common AQUA AMMONIA, or SPIRITS OF HARTSHORN, which may be purchased at any drug store. This common aqua ammonia is simply water which has absorbed large quantities of ammonia. When aqua ammonia is exposed to the air, the ammonia escapes. Its stinging, biting odor is familiar to all and is easily recognized. The ammonia with which we commonly come in contact, then, is always in the gaseous form. This same ammonia, however, can be changed into liquid form by compressing it. The pressure required to change ammonia gas into liquid form depends upon its temperature; the higher the temperature, the greater is the pressure required. For any given temperature, there is a corresponding pressure which is just sufficient to liquefy the gas. This relation of temperature to pressure is often stated in another way: We often speak of the boiling points corresponding to a given pressure. It must be clearly understood, however, that the boiling point corresponding to a given pressure is exactly the same temperature as the liquefying point corresponding to that pressure. Recall that water boils and steam condenses at the same temperature.

TABLE XI.—PRESSURE AND CORRESPONDING BOILING POINT OF AMMONIA.

Pressure lb. per sq. in.	Atmospheres	Boiling point or liquefying point
15 lb.	1 atmosphere	—29°F.
30 lb.	2 atmospheres	0°F.
34 lb.	2.3 atmospheres	5°F.
63 lb.	4.2 atmospheres	32°F.
107 lb.	7.1 atmospheres	60°F.
130 lb.	8.6 atmospheres	70°F.
155 lb.	10.3 atmospheres	80°F.

From this table we see that to change ammonia from a gas to a liquid at the ordinary temperature of 70°F. requires a pressure of about 130 lb. per sq. in. We also see that at the pressure of 1 atmosphere, or 15 lb. per sq. in., the ammonia will be in the liquid form if the temperature is below —29°F and in the gaseous form if the temperature be above —29°F. (Fig. 227).

NOTE: *It is important that we remember that the ammonia used in refrigerating plants is the pure, dry ammonia; never the water solution of ammonia, or aqua ammonia.*

441. How the Water is Frozen.—The ammonia to be used in the plant is received from the manufacturing chemist in strong metal containers. It is highly compressed, and, therefore, is in the liquid form. This ammonia is fed into the system through the opening, *A,* Fig. 225. As the ammonia escapes from the high pressure, it boils violently and changes to the gaseous form. As the compressor is running, the ammonia is drawn directly through the lower valve into the cylinder of the compressor, *B,* Fig. 225. The piston then forces it through the upper valve into the pipe leading to the cooling coils, *C.* As the ammonia is compressed, it becomes very much heated, and, although the gas is subjected to a pressure of 140 lb. or more per sq. in., it still retains its gaseous form. The cooling coils, *C,* are kept cool, however, by being constantly drenched with cool water. As the heated ammonia gas passes through these coils, it is cooled. Referring again to the table given in the last article, we see that the ammonia will liquefy under a pressure of 140 lb. as soon as the temperature drops to about 75°F. Now the cooling coils can be kept at a temperature as low as 75°F. by drenching them with water from the city mains or pumped from wells.

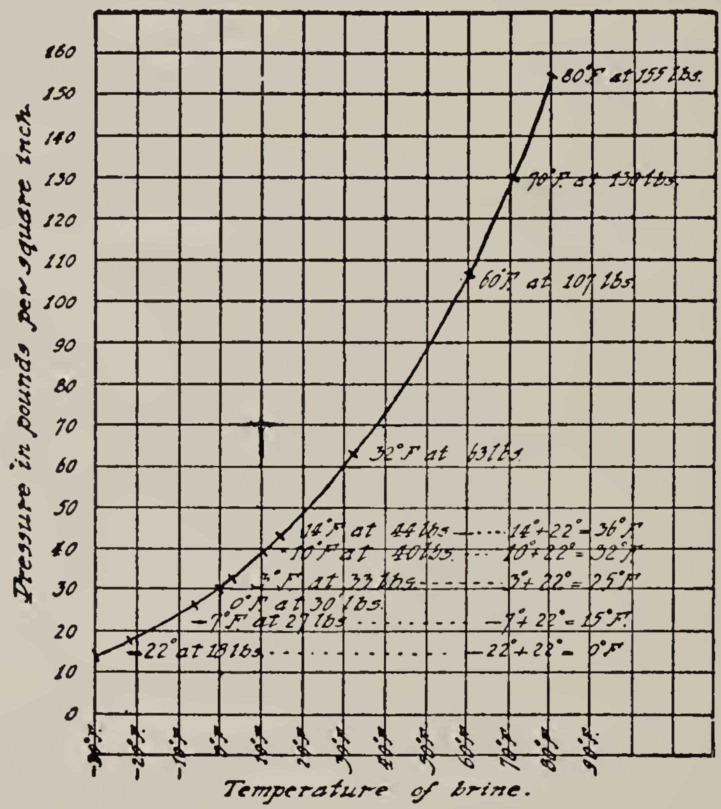

FIG. 226.—Curve showing the properties of ammonia.

It should be carefully noted that the cool water carries away two distinctly different portions of heat from the ammonia. First, the highly heated ammonia gas is cooled down to the temperature of the water, that is, the water carries away the SENSIBLE HEAT (Art. 126). Second, when the ammonia changes from the gaseous form to the liquid form, it gives up exactly as much heat as it absorbs when it changes from the liquid form to the gaseous form. The heat given off when a gas liquefies is called HEAT OF CONDENSATION. *This heat of condensation exactly equals the heat of evaporation.* (Art. 127.)

The liquid ammonia accumulates in the reservoir (*D*, Fig. 225). It is now at about 70°F. and under about 140 lb. of pressure. When the liquid ammonia has accumulated in the reservoir to the desired amount, as shown by the glass gauge, the valve *A* is closed and no more ammonia is fed into the system. The valve, *E*, is now opened and the ammonia is permitted to flow into the coil of pipes submerged in the brine. Being released from pressure, as soon as it escapes through the valve, *E*, the ammonia begins to evaporate rapidly, even boil. This means that it takes up heat of vaporization. It receives this heat from the brine. The brine consequently drops in temperature. When cans of pure water are placed in this brine, as *G*, Fig. 225, the brine absorbs heat from the water and continues to do so till the water is frozen. As long as the compressor is kept running, the circulation of the ammonia continues.

442. Why Brine is Used and How the Temperature of the Brine is Regulated.—When studying the thermometer, we saw that Fahrenheit got the temperature which he called zero on his thermometer by mixing salt and crushed ice (Art. 17). Now if just enough salt is mixed with ice to make a saturated solution[1] when the ice melts, the melting point of the mixture is a little lower than the lowest temperature Fahrenheit

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[1] Note: A saturated solution of salt is one in which no more salt will dissolve in the water. At ordinary temperatures 2½ lb. of water will dissolve about 1 lb. of salt.

obtained. It is about —7°F. But it should be carefully noted that the melting point of such a mixture is also the freezing point of a saturated solution of salt and water, just as the melting point of pure ice is exactly the freezing point of pure water (Art. 16). The saturated solution of salt and water, then, can be frozen only by lowering the temperature to about —7°F., which is 39° below the freezing point of water.

In operating an ice plant it is customary to cool the brine to about 16° or 18°F. The temperature of the brine can easily be governed by opening wider or partly closing the regulating valve. It will be noticed that the compressor not only compresses the ammonia gas on the compression side of the regulating valve *E*, *i.e.*, in the cooling coils, but that at the same time it is reducing the pressure on the other side of the valve, *i.e.*, in the pipes in the brine vat. It also becomes evident that if the regulating valve is nearly closed the pressure becomes great on the compression side while it is reduced on the exhaust side. On the other hand, opening the valve wider permits the pressure to become somewhat nearer equal on the two sides. Hence we speak of the HIGH SIDE and the LOW SIDE of the plant. The high side comprises that portion of the ammonia pipes from the compressor to the valve, *E*. The low side comprises the portion from the valve *E*, to the compressor. Referring to the table (Art. 440), we see that at a pressure of 34 lb. the boiling point of ammonia is 5°F. In operating the ice plant, the regulating valve is usually so set that the pressure on the low side of the valve, *i.e.*, in the pipes in the brine vat, is maintained at about 34 lb. Since the temperature of the brine is usually from 10° to 15° above the temperature of the pipes, the temperature of the brine is about 16° or 18°F.

443. Purity and Cost of Manufactured Ice.—Practically all impurities of every kind are removed from the water by distilling it before it is placed in the cans to be frozen. Even though air be the only impurity present when freezing takes place, the ice will be filled with small bubbles and therefore will be clouded and opaque. It is the presence of a very small amount of air which the water reabsorbs before freezing can take place, which gives the center of the ice cake the whitish, opaque appearance familiar to all users of artificial ice. Even small quantities of dissolved solids generally give the ice a yellowish or brownish tinge. When frozen in cans by the method here described, only pure water can give clean, colorless ice; therefore, only distilled water is used. As far as possible the exhaust from the engine which runs the compressor is used. Since this does not furnish sufficient water, generally, steam from the extra boiler mentioned above (Art. 439) is also condensed and used.

In the southern portion of the United States and in many northern portions which are remote from bodies of fresh water, manufactured ice can be produced at less expense than natural ice can be obtained. The average cost of producing artificial ice is now generally about $2 per ton. The cost to the consumer is, however, much more than this, owing to the expense of handling and the large loss due to melting which necessarily accompanies its distribution during warm weather.

444. Freezing of Ice Cream.—The freezing of ice cream involves some of the principles just described. Finely broken or crushed ice is mixed with common salt and the mixture is then packed in the freezer around the can containing the cream to be frozen. As we saw in Art. 16, such a mixture of ice and salt has a melting point far below the melting point of pure ice. Or, we may express the same truth in another way: We may say that the freezing point of a saturated solution of salt and water is —7°F., or 39° below the freezing point of pure water (Art. 16). If a mixture of one-third salt and two-thirds crushed ice is used in the freezer, the temperature of the mixture will tend to fall to this point as the ice melts.

It is evident that as the first portions of the ice melt, the water formed will dissolve some of the salt, forming a saturated solution of salt water. We also know that as the ice continues to melt it absorbs large quantities of heat. Most of the heat absorbed by the ice, when melting, must be taken from the freezer and from the can of cream. Both will, therefore, fall in temperature. Since the cream freezes at a temperature much higher than the freezing point of the mixture, it is evident that if a sufficient quantity of salt and ice is used the cream can be completely frozen (Fig. 227).

The only puzzling question in the process of freezing cream is this: Why does the ice continue to melt when the temperature falls below 32°F., the ordinary melting point of ice? The answer is: A mixture of salt and ice can exist as salt and ice only at a temperature of —7°F., or lower. If salt is placed upon ice at a higher temperature, the ice melts and the salt dissolves in the ice water. If there is enough salt, a saturated solution of salt is formed. Now a saturated solution of salt will *not* freeze at a temperature above —7° F. In the ice cream freezer we have a mixture of the three substances, salt, ice, and a nearly saturated solution of salt. As long as the supply of salt and ice holds out, the ice continues to melt and absorb heat; the temperature of the

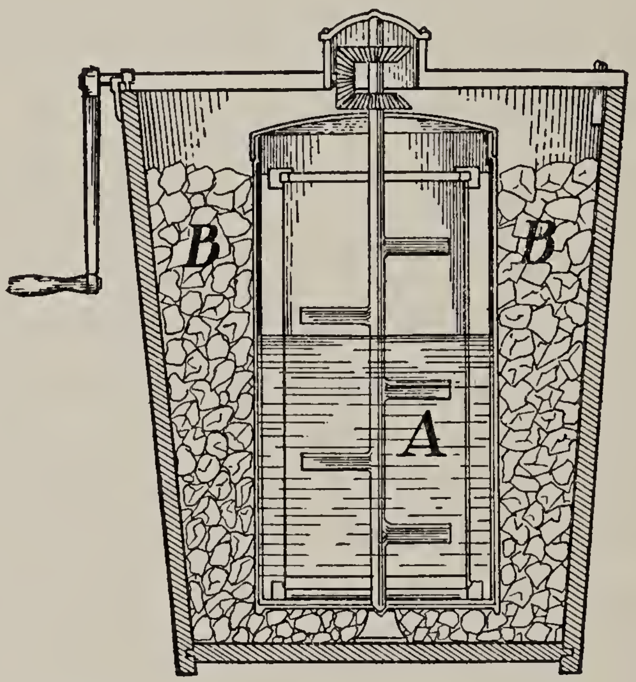


Fig. 227.—An ice cream freezer.

mixture, therefore, tends to fall toward the freezing point of the salt solution, —7°F.

III. COLD STORAGE

445. Effect of Cold Storage on Modern Life.—The development of plants for the production of cold by artificial means has not only given us ice in greater abundance and in greater purity, but it has also made possible the construction of many enormous COLD STORAGE PLANTS. In these cold storage plants, the surplus of perishable produce, such as eggs, butter, poultry, beef, fruits, and vegetables is stored during the seasons of abundance. In cold storage this perishable produce is preserved for weeks, or even months, much of it suffering but little deterioration. Before the establishment of cold storage plants, the markets were often flooded with certain fruits for a short period; in a few weeks, however, the entire year's supply of these fruits was either consumed or had decayed and was lost. Similarly, the production of eggs is much greater during the spring and early summer than at other seasons of the year. Formerly the supply of eggs during the spring was so greatly in excess of the demand that the price fell to a ridiculously low mark, and many eggs even went to waste. During the winter months, on the other hand, eggs were often practically unobtainable at any price. Since the advent of cold storage, however, many kinds of fruit, eggs, and other kinds of perishable produce, are obtainable at any season of the year and at prices which vary but little from season to season. In this and other ways, cold storage has greatly modified modern life.

446. Construction of a Cold Storage Plant.—A modern cold storage plant so closely resembles an ice plant that no extensive explanation is necessary. The plant consists of a compressor, *A*, operated by a steam engine, *B* (Fig. 228). The ammonia is cooled and liquefied in the cooling coils, *C*. It then collects in the reservoir, *D*, and finally is permitted to pass through the regulating valve, *E*. The "high side," then,

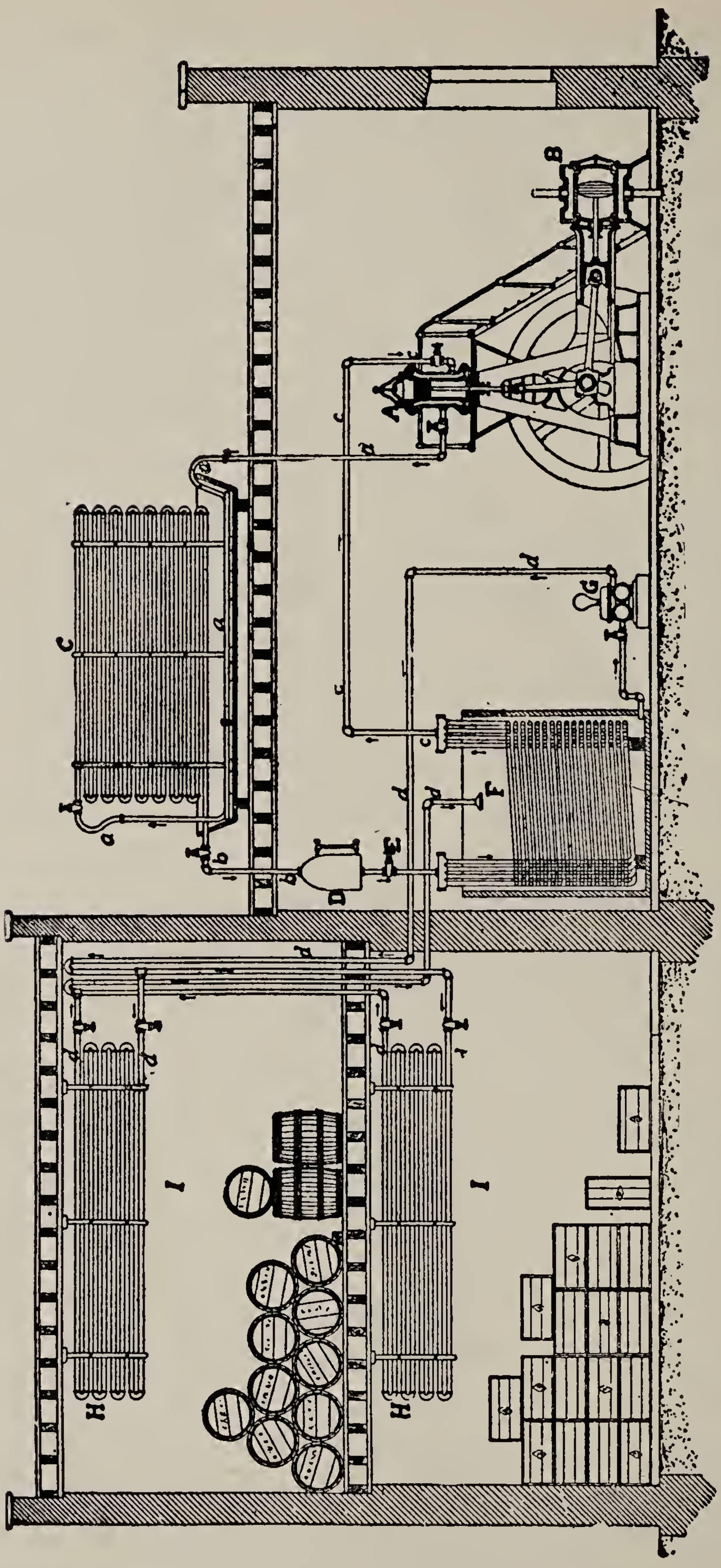


FIG. 228.—Diagram of a cold storage plant.

is exactly like the "high side" of a manufactured ice plant. After passing through the valve, *E*, the ammonia vaporizes in the pipes submerged in the brine in the vat, *F*. After vaporizing, the ammonia returns to the compressor through the pipe, *c-c*. Thus we see that the "low side" is also the same as in the case of the ice plant. The brine vat, however, is not usually within the storage room at all. The chilled brine is forced by the pump, *G*, through the pipe, *d-d*, to the absorbing coils, *H* and *H*, in the storage rooms. After passing through these coils, the brine returns to the vat, *F*.

447. Temperature Required for Cold Storage and How Controlled.—Different kinds of produce keep best when stored at different temperatures. Some fruits are usually stored at about 36°F.; others at about 32°F.; fresh meat at about 25°F.; poultry at about 15°F.; and fish at about 0°F. To obtain a given temperature in the storage room it is necessary that the boiling point of ammonia be controlled.

The coils submerged in the brine vat are evidently cooled about to the boiling point of the ammonia. But it is generally the case that the brine is about 10° higher than this. Moreover, the brine is generally about 6° warmer when it returns from the coils, *H-H*, than when it passes through the pump on its way to the coils. Again, the air in the storage room is usually about 6° warmer than the brine within the coils, *H-H*. Altogether, then, the air in the storage room is about 22° above the boiling point of ammonia.

Now we have already seen how the boiling point of the ammonia is controlled by controlling the pressure on the low side of the refrigerating system. In the storing of fruits where the temperature should be 36°F., the boiling point of the ammonia must be about 22° lower, or about 14°F. By referring to Fig. 225, we see that the boiling point of ammonia is 14°F. when under a pressure of about 44 lb. to the sq. in. Therefore, in storing such fruits, the regulating valve is so set as to maintain a pressure of about 44 lb. on the low side.

Most kinds of fruit keep best when stored slightly above

32°F. If it is found that the temperature of the air in the store room is 22° above the boiling point of the ammonia, we see that the boiling point of the ammonia would need to be kept at about 10°F. Referring to the curve we find that the pressure of the low side should be about 40 lb.

In a similar manner, show that the pressure on the low side must be about 33 lb. for the storing of meat which keeps best at about 25°F.; at about 27 lb. for the storing of poultry at 15°F.; and that the pressure on the low side must be about 18 lb. for the storing of fish which must be kept at zero F., if the air in the store room is 22° above the boiling point of the ammonia in the low side pipes.

448. Refrigeration and Transportation.—A fruit has a life history extending from the formation of the fruit bud to the decay of the ripened fruit. Some fruits have short life histories, others, longer. Fresh fruits, when not overripe, are alive; they do not readily decay. Some fruits, such as strawberries, die very soon after reaching maturity; others, such as winter apples, remain alive for many weeks after being removed from the tree. The purpose of cold storage of fruits is to delay the ripening process so that the life of the matured fruit may be extended over as long a period as possible, in some cases even till the next year's crop matures. In the case of short-lived fruits it is necessary to get them into the hands of the consumer as quickly as possible. But the majority of the consumers live in the larger cities, like New York, Philadelphia, Boston, and Chicago, long distances from the more productive fruit growing sections.

It was formerly practically impossible to transport short-lived fruits from the field to the consumer. Today, however, by using modern refrigerator cars, oranges are shipped from California to New York; strawberries from Mississippi to Chicago; peaches from Florida, Georgia, and Texas to the Boston market with little or no deterioration. Similarly, the markets of the world are supplied with fresh meat and poultry, killed and dressed in the slaughter houses of Kansas City and Chicago.

CHAPTER IX

GROUND-WATER AND GROUND-AIR

I. GROUND-WATER

449. **What Becomes of the Rainfall?**—We have seen that the annual rainfall in the United States varies from a few inches to 70 inches or more. The annual run-off, that is, the water which actually runs off the land through the streams, amounts to about ⅓ of the rainfall, or in different parts of the United States it varies from nothing to about 20 inches. What becomes of the rest of the rainfall? It sinks into the soil and becomes SOIL WATER which is the subject of our present study (Fig. 229).

450. **Visible and Invisible Water Supply.**—The water in streams, lakes and oceans constitutes our VISIBLE WATER SUPPLY. The water which sinks into the earth and disappears from view constitutes our INVISIBLE WATER SUPPLY. We all realize the value of our visible supply. From the earliest times man has used water courses for highways; he has used oceans and seas to carry himself and his goods from continent to continent; he has used the streams and inland lakes to explore the interior of continents and to trade with the native inhabitants. Many times the rapidly flowing stream has turned his mill and done work for him. The visible water supply has furnished him with water to drink and with water to irrigate his growing crops. In olden times all great civilizations were located on or near the banks of bodies of water. Today we are less dependent upon the visible supply and many people live far away from oceans, streams and lakes. Many of their wants are met by using the invisible water supply.

451. **Uses of the Invisible Water Supply.**—Nearly all plant life depends upon the invisible water supply for the

water they must have. Without plant life animal life would quickly perish from the earth. Again, man must have a supply of water for drinking and cleansing purposes. Probably a majority of mankind in civilized countries obtain this supply of water from the earth's invisible supply.

452. The Source of Well Water.—While it is true that upon the frontier of civilization men still get their water supply from streams, and while it is true that most large cities consume so large an amount of water that they, too, are obliged to take their supply from streams or lakes, still it is probable that in the United States a larger number of people are using drinking water from wells. Since wells are such a common source of water supply, we may well ask, *Where does the water come from which we pump from our wells?*

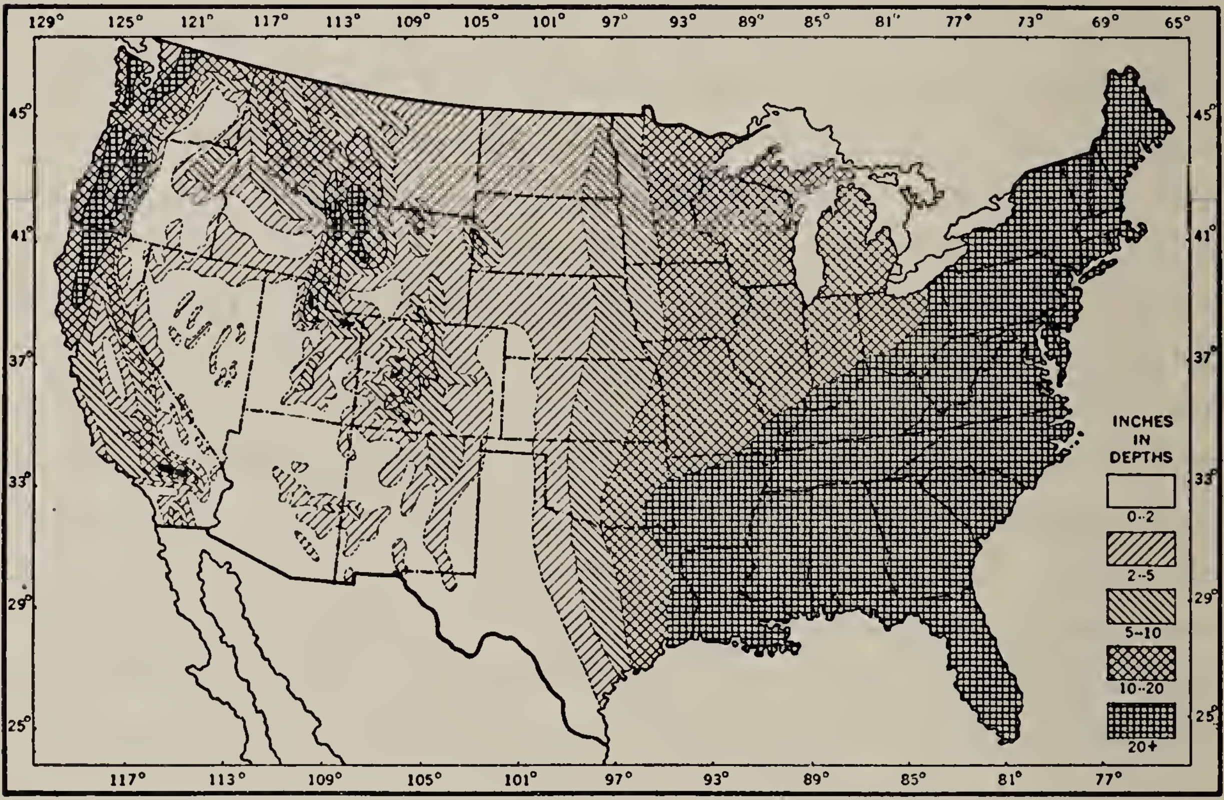


Fig. 229.—Mean annual run-off, United States.

There is no mystery as to where the water comes from in certain seasons of the year. When heavy rains have been frequent and the ground is soaked full of water, it is easy to see that wells, which often are merely holes in the ground, will also be filled. But where does the water come from which fills our wells partly full even after months of hot, dry weather? There are weeks, even months, at a time, in some sections, when but little rain falls and this merely wets the surface of the soil, which is soon dried by evaporation. Evidently *the ground must in some way serve as a great reservoir storing a supply of water* which we are able to draw upon as needed. That this must be so is made more evident by the fact that a good, "never failing" well pumped empty at a certain time is found soon to contain as much water as it did before the pumping took place.

453. **The Earth a Great Sponge.**—The fact is that the earth is not unlike a great sponge. We have all seen a pail of water quickly disappear when poured upon the dry earth. We have all seen several inches of rain fall within a few hours, and still much of it disappeared nearly as fast as it fell if the earth was very dry when it began to rain. Over most of the earth's surface, the earth's crust is composed chiefly of porous soil. This porous soil holds water much as a sponge does.

454. **Ground-water.**—The earth's crust is not composed of the same material at all depths as that at its surface. Through the upper Mississippi valley, for instance, we often find 2 or 3 ft. of black soil at the surface. Beneath this there may lie 6 or 8 ft. of yellow clay. Then, perhaps, is found a 2- or 3-ft. vein of sand and gravel. Next, possibly, lies 10 ft. of blue clay. This may rest upon a foot of gravel. Beneath this gravel may lie a thick bed of less porous clay called hardpan. And so on down through bedrock we find layer upon layer of different substances. Each layer differs from the one above it not only in material of which it is composed, but also, and more important for our present purpose, in the ease with which water can pass through it, or its POROSITY.

No matter how many different layers, or STRATA, of material there may be, or of what material those layers may be composed, in time, water finds its way down through into bedrock. Throughout the millions of years which have passed since the beginning of this earth, the water which has been falling in the form of rain has been soaking down through these layers of soil till the earth's crust in most places is quite saturated. This water is called the GROUND-WATER.

Over much of the earth's surface, then, the rainfall has been, and is, sufficient nearly to saturate the soil with water. This does not mean that the ground is completely filled with water from bed rock quite to the surface all the year around. But it does mean that the GROUND-WATER has sunk deeper into the earth than man has as yet been able to penetrate, and that over much of the earth's area it comes nearly to the surface of the soil. When rains are frequent and heavy, the ground may be completely saturated near the surface. During most of the months of the year, however, the spaces between the soil particles are not filled with water for some distance from the surface downward. If we penetrate the ground deeply enough, however, we come to a place where there is so much water in the soil that it fills the spaces between soil particles completely. This leads us to the point where we must state definitely the meaning of a new term, WATER PLANE, or WATER TABLE.

455. The Water Table, or Water Plane.—While all of the soil is more or less moist, the moisture in the upper portions of the soil usually is not free, unabsorbed water. It is water which adheres closely to the soil particles and cannot be removed by ordinary means. Of this moisture, FILM WATER, we shall learn more, later. At present we are interested in the portion of GROUND-WATER which is *unabsorbed*. This water does not adhere as moisture to the soil particles, but lies as free, unabsorbed water *between* the soil particles. *It is the surface of this free, unabsorbed ground-water which is called the* WATER TABLE, or WATER PLANE.

456. Relation of the Water Table to the General Surface of the Land.—It has been determined by experiment that the water table follows, in the main, the general surface of the land. The water in any shallow well stands at exactly the height of the water table *if no water be used from the well.* The water in the well varies in height just as the water table varies. Numerous wells have been sunk on the rolling ground lying beside a lake. The well at the lake's shore has water standing in it at the lake's level. A well farther up the hill is found to have water standing in it at a level somewhat higher. The next well, still farther up the hill, has water standing at a still higher level. In almost every case the level at which the water stands in the various wells scattered over a considerable area of land bordering upon a lake, indicates that the water table *tends* to follow more or less closely the general level of the land. Where the land rises the highest; there the water table shows the same tendency to stand high in the soil (Fig. 230).

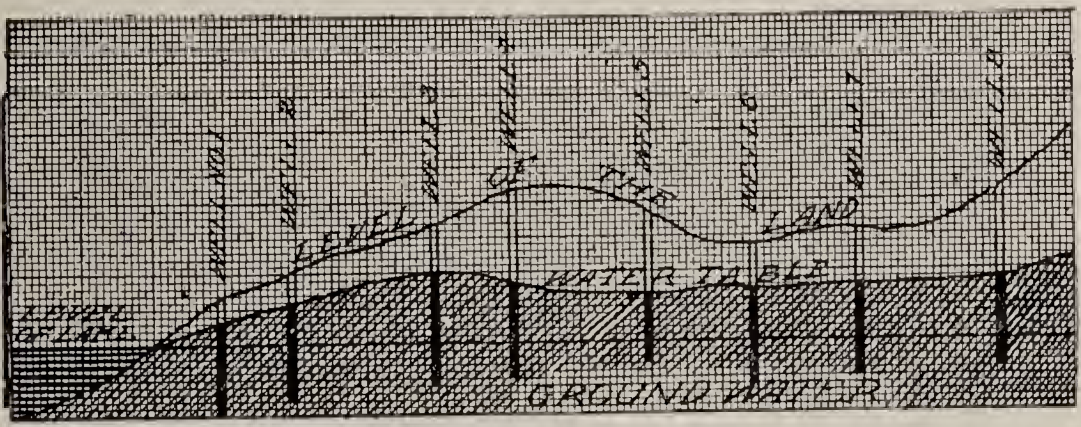


FIG. 230.—Relation of water table to the land surface.

457. The Explanation.—It is easy to see why the water stands higher in the soil back from a river or lake. We must remember that the rain falls equally on the earth's surface near the river or lake. Much of the rainfall soaks into the soil. It then soaks slowly down through the soil to the water table. When the water table gets higher than the surface of the river or lake, it tends to move horizontally into the river or lake. But it has to find its way through the soil, between the soil particles. The soil particles constantly block its passage just as rocks block the free passage of water in the bed of a shallow stream. The ground water, therefore, moves much more slowly down hill through the soil than it does down the more open bed of the river. The water level in the lake or river is, therefore, constantly at a lower level than the surface of the ground water in the soil near its banks. The farther back we go from the lake or river, the higher the level of the ground water stands.

458. Drainage through the Soil.—Since a river's channel is usually considerably lower than the soil on either side, and also lower than the water table, we see that not only does the surface water flow into the river but that the soil-water is also constantly flowing through the soil into the river. This horizontal movement of soil-water, or LATERAL PERCOLATION, is usually very slow but varies with the nature of the soil through which it flows. Different tests show the rate of movement of this soil-water to vary from 5 feet to 100 feet per day.

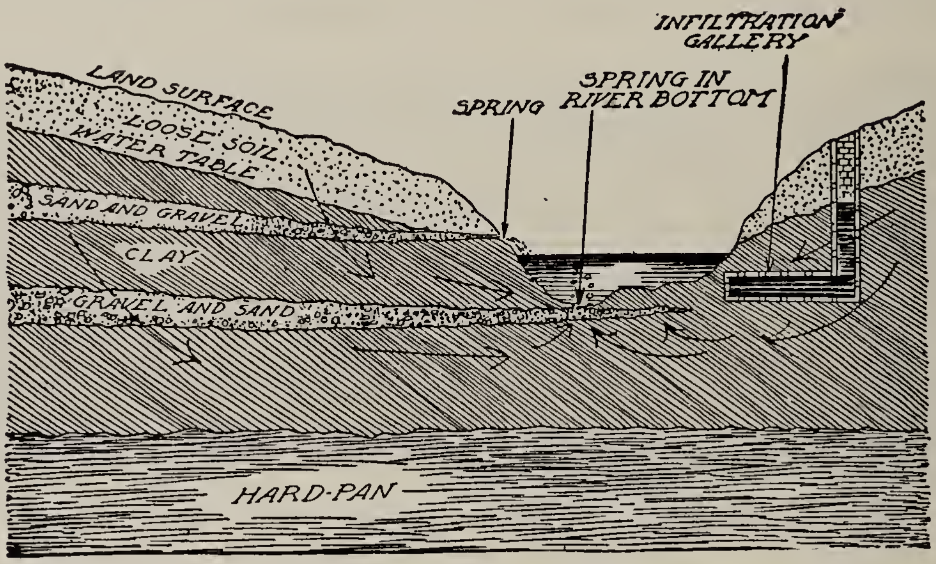


Fig. 231.—Ground-water and river-water.

Roughly speaking, about ⅓ of the rainfall in the United States is carried off by the streams. Fig. 229 shows the amount of this ANNUAL RUN-OFF in the various sections of the country. Compare this map with Fig. 174, the ANNUAL RAINFALL map. The remaining ⅔ of the rainfall evaporates from rivers, lakes, from vegetation and from the soil itself.

459. Relation of the Ground-water to the River-water.—

It is interesting and important to note the relation of the ground-water near a river to the water in the river bed. Anyone who has followed the course of a river far is aware that, in most cases, springs are common along its banks. In many cases where no running water flows down the banks, the banks are very moist, showing the near presence of free ground-water. The cause of springs is easily seen when we know that the conditions shown in Fig. 231 are not uncommon. On the river bank to the left we have the ideal conditions for a SPRING.

Swimmers are aware of the fact that springs of cold water are often located in the very bottom of river beds. The colder ground-water rises into the river at many points. Figure 231 also shows how this may be so.

Many cities, in attempting to secure an adequate water supply, have constructed what are known as INFILTRATION-GALLERIES (Fig. 231). These are merely wells sunk beside the rivers. Sometimes from the bottom of the wells long horizontal galleries extend along beside the river or out beneath it. Each gallery is, of course, bricked up to prevent the ground from caving into it. Other cities have buried FILTER-CRIBS in the bottom of the stream itself. In many cases it was expected that the river-water would find its way into the galleries and cribs. Such has rarely been the case. Repeated and frequent examinations of the water in such cases by chemists have nearly always shown that the gallery or the crib contains ground-water, not river-water. It is evident that the gallery or the crib has intercepted the ground-water on its way into the river. *The general movement, then, of the ground-water along a river bed is nearly always into the river from either side and up into it from beneath.* What forces the water up into the river from beneath?

In some arid regions the flow of water along a river valley is the reverse of that just described. For example, along the Platte River in Colorado and western Nebraska the percolation of water is generally *from* the river off to either side into the soil. The river is fed by the melting of the mountain snows and, as the water runs out on the arid plains, its surface is higher than the general level of the water-plane. The water of the river, therefore, soaks out into the soil and in the dry season completely disappears. In the spring or early summer the river is said "to come down" from the mountains. Explain what is meant.

II. GROUND-AIR

460. Importance of Ground-air.—Closely related to ground-water and, more or less controlling its movements, is the GROUND-AIR. The upper portion of soil, down to the water table, is saturated with air. The spaces between the soil particles are completely filled with this GROUND-AIR, or SOIL-AIR, as it is often called. Each soil particle above the water table is surrounded by a thin film of water, FILM WATER, which can be removed only by the roots of plants and by evaporation (Art. 13). Since this moisture can be removed by evaporation, the soil-air will constantly be nearly saturated with moisture. Plant life is largely dependent upon this moist soil-air and upon the film water for its very existence (see Art. 470). The chief purpose of artificial drainage is so to lower the water table that the soil-air may reach the plant roots.

461. Movements of Soil-air.—The soil-water moves through the soil chiefly through the influence of its own weight; *we say it is moved by gravity.* It is constantly moving down hill toward the sea level or toward the level of some lake or river. The movements of soil-air are strikingly different. Soil-air does not move, to any considerable extent, as a result of its own weight. Its motion is controlled almost entirely by: (1) Changes in the temperature of the soil, (2) changes in atmospheric pressure (see Chap. III, Sec. II), and (3) by diffusion.

462. How Heat Causes Movements of Soil-air.—We know that when air is heated it expands. In fact, we have learned that when air is heated 1°C. it expands 1/273 part of its volume at 0°C. (Art. 111, Ex. 36); if it is heated 15° it will expand $^{15}/_{273}$ of its volume. Now, if the soil temperature should rise 5°C., it is evident that 1 cu. ft. of air out of every 55 cu. ft. would be forced out of the soil, *i.e.*, the earth would exhale, or breathe out, 1 cu. ft. to every 2 cu. yd., of soil-air which it contained. Prove that this is so.

The earth receives its supply of energy from the sun. The sun sends down a greater amount of energy at noon than at any other hour of the day. Why is this so (Chap. IV, Sec. I)? But if we were to take the temperature each hour of the day for a few days with the thermometer hanging on the north side of a tree or a building, we should find that the atmosphere becomes warmest, generally, not at noon, but at about two o'clock. Explain this lagging of the hottest hour of the day behind the time when the sun sends down its greatest heat. (Art. 168.)

463. Soil Temperatures.—The temperature of the soil is most easily taken by means of the SOIL THERMOMETERS. These are mercury thermometers which are usually encased in wooden cases capped with metal tips (Fig. 232). This protecting case makes it possible for the thermometer to be pushed into the soil without danger of its breaking. Repeated experiments show that at the depth of 1 or 2 ft. the soil reaches its *highest* temperature late in the afternoon or in the evening. At a still greater depth, the soil reaches its highest temperature during the early portions of the night. The change in temperature lessens rapidly as greater depth is attained, until at a depth of a few feet, no appreciable daily change is noticeable. It can also easily be shown that the soil at the depth of 1 or 2 ft. reaches its *lowest* temperature during the day time, usually during the forenoon. This is not mysterious; it is simply the application of the principle referred to in the last paragraph. If the changes in

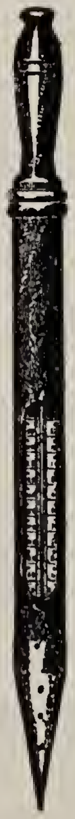


FIG. 232. Soil thermometer.

temperature of the atmosphere lags two hours behind the sun, we can easily see that the changes in temperature of the soil should lag still further behind.

464. Earth's Breathing.—We have seen that the soil becomes warmest during the evening and earlier portion of the night. As long as it is growing warmer, the soil-air is expanding and therefore rushing out. This is the EARTH'S EXHALATION. The soil-air which is expelled is warm, often warmer than the air above ground, and saturated with moisture. The formation of DEW is partly because of this warm, moist air's coming into contact with the colder bodies close to the surface of the ground (see Art. 183, page 167). The EARTH'S INHALATION takes place in the early morning and the forenoon. *Thus we see that the earth takes one long, slow breath each day.*

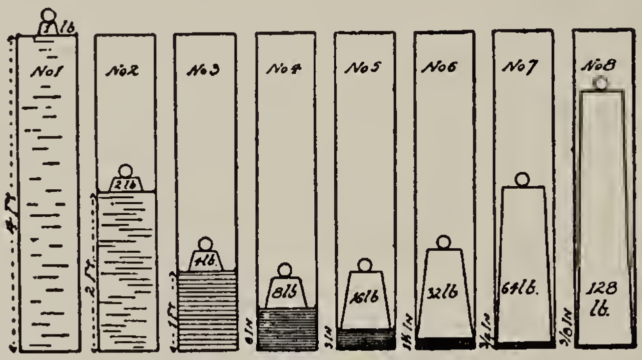


FIG. 233.—Effect of pressure upon volume of air.

465. Effect of Pressure upon the Volume of Air.—But the change in the soil temperature is not the only cause of the earth's breathing. Changes in the pressure of the atmosphere, ATMOSPHERIC PRESSURE (Chap. III, Sec. II), also affect the soil-air.

It is easily proved in every high school laboratory that increasing the pressure upon a certain quantity of air decreases the volume of the air. In fact, it was shown by an English philosopher, Robert Boyle, about 1650, that, if the pressure was doubled, the volume of the gas was reduced one-half; if the pressure was made four times as great, the volume became one-fourth its former value. In general, the volume of a gas *decreases* just as rapidly as the pressure *increases*. Figure 233 makes plain the operation of this law, which is known as BOYLE'S LAW. We shall suppose that No. 1 represents a tube 4 ft. long. At its top, fitting into it air-tight, is a piston. Suppose that all of the atmospheric pressure is removed from the piston and simply a 1-lb. weight is placed upon it. Evidently the 4 ft. of air in the tube is supporting 1 lb. of weight. If the pressure be increased to 2 lb., the volume of gas will be compressed to a volume 2 ft. in length, as in No. 2. If 4 lb. of pressure be placed upon the air as in No. 3, the column will become 1 ft. And so 8 lb., 16 lb., 32 lb., 64 lb., and 128 lb., will compress the air to 6 in., 3 in., 1½ in., ¾ in., and ⅜ in., respectively.

466. Changes in Atmospheric Pressure Cause the Earth to Breathe.—We have seen (Chap. III) that the ATMOSPHERIC PRESSURE varies considerably from day to day, and that it even varies somewhat from hour to hour. At the time of storms the pressure is often considerably less than on the day before or upon the day following. This variation frequently amounts to 1/30 of the entire pressure of the atmosphere. Generally, however, the change is less than this.

Now, if the soil-air is relieved of 1/30 of the pressure which it has been sustaining, it will expand 1/30 in volume, according to Boyle's Law. This means that 1/30 of the soil-air will be expelled from the soil. After the storm has passed and the atmospheric pressure has again increased, *fresh air again enters the soil*. Since on the average, fairly well-marked storms pass over central and eastern United States about once every four or five days, it follows that the earth takes an additional breath, or rather an extra breath, about once in four or five days.

467. Another Cause of Change in Soil-air.—While it is true that both the changes in soil temperature and the changes in atmospheric pressure cause the changes in soil-air as shown, it is also true that they are not the *only*, nor even the *chief* causes of the exchanges of soil-air which take place. Experiments have shown that a still more important cause of this exchange is that OF DIFFUSION.

Exercise 76.—Diffusion of Gases

Close all the windows and doors of the room. Open a bottle of the oil of peppermint or musk (camphor or ammonia will do) in one corner of the room and let a few drops fall upon the floor. Let another person be at the opposite corner of the room. Let him notice carefully to see how long it is before he can detect the odor of the liquid you are using. It will not be very long before he can do so. How does it happen that he can thus detect the presence of the liquid so distant from him?

EXPLANATION.—Evidently the liquid does not reach him. It must be that it first changed to a vapor, or gas, and that the gas by some means reaches him. The truth is that all gases are made up of many rapidly moving particles. The particles of air, for instance, under the usual conditions of temperature and pressure are known to be moving, on the average, at the rate of about ¼ mile per second. But the particles are so very small and so very numerous that even at this rate of motion no particle moves more than a very small portion of an inch before striking another particle and being turned off in some new direction. *Every gas and every vapor is thus made up of millions of particles to each cubic inch and each of these particles is moving with great speed.* When we know this to be true, it is not wonderful that the vapor from the musk or oil of peppermint quickly passes across the room, even though there be no apparent movement of the air in the room. *The mixing of gases and vapors in this manner is known as the* DIFFUSION OF GASES.

468. Diffusion of Soil-air.—It has been shown that this same DIFFUSION OF GASES applies to soil-air. It is known that this diffusion of the soil-air causes a constant exchange to be taking place between the soil-air and the air above the ground. Particles of soil-air are constantly escaping into the atmosphere and particles of fresh air from the atmosphere are constantly entering the soil. This diffusion of the soil-air causes more of an exchange of the impure, moisture-laden air for fresh air from the atmosphere than all other known causes put together. The whole process of change of soil-air is of great interest to agriculturists and is called the AERATION OF THE SOIL, or AIRING OF THE SOIL.

The soil-air removes considerable moisture from the soil above the water table. The soil-air is constantly more or less saturated with moisture which it has taken up from the soil particles. With each exhalation, as well as by the constant process of diffusion, this moist air is being replaced by the dried air from the atmosphere. The effect of soil aeration, then, is to reduce the amount of soil moisture.

Soil aeration and the consequent drying out of the soil is due, then, to three causes:

1. Changes in soil-air temperature,
2. Changes in atmospheric pressure,
3. Diffusion of soil-air.

III. CONSERVATION OF SOIL MOISTURE

469. Plant Life and Moisture.—All plants must be supplied with moisture in order that they may live and grow. The abundance or scarcity of moisture is a large factor determining the character of plant life in any region. Different plants require different amounts of moisture. Certain plants, such as water lilies, reeds, cat-tails, eel grass, bulrushes, wild rice, sedges, and many grasses live and thrive only when growing in shallow ponds or swamps or marshes. Such plants are said to be water plants, or HYDROPHYTES (*hydrophyte* meaning water plant).

At the opposite extreme are plants which live and thrive only when growing in extremely dry soil in regions of scant rainfall. The southwestern portion of the United States, western Texas, New Mexico, Arizona, and southeastern California, is such a region. Here the various forms of the cactus, the yucca, sage brush, and a few other forms of plant life live and thrive although only a scanty amount of moisture is available. Such plants are called XEROPHYTES (pronounced zē′rō-fītes, *xerophyte* meaning dry plant).

Most of the common plant life of the United States, and especially our common cultivated crops require a medium amount of moisture. Our common forest trees, the grasses of our meadows, our corn, oats, wheat, and other grains, potatoes, beans, peas, and all the rest of our common field and garden plants thrive best where a moderate amount of moisture is available. Such plants are called MESOPHYTES (*mesophytes* meaning middle plants).

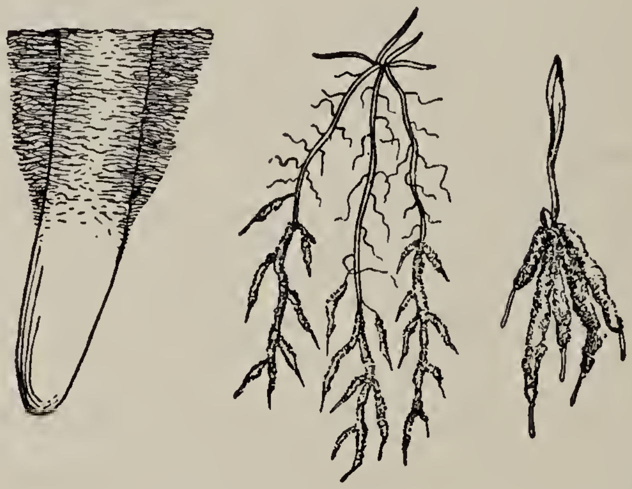


FIG. 234.—Root hairs—on corn roots and on roots of wheat. The soil is still clinging to the wheat root hairs.

470. How Plants Absorb Soil Moisture.—Plants requiring but little moisture, xerophytes, and plants requiring a medium amount of moisture, mesophytes, obtain their supply of moisture principally by absorbing the film moisture from the soil. Their roots are often finely branched or divided and the small rootlets are covered with minute hairs (Fig. 234). These root hairs come into close contact with the film of water surrounding the small particles of soil and absorb the moisture from this film as it is needed for plant growth. As the moisture in the film is thus absorbed, more moisture rises from the deeper portions of the soil to take the place of the absorbed moisture. This moisture rises in the same manner and for the same reason as kerosene rises in the wick of a lamp. It is said to rise on account of CAPILLARITY.

471. Need of Increasing and Conserving Soil Moisture.—In most regions, the soil contains sufficient moisture in the spring and the early part of the growing season. But in many regions the supply of soil moisture becomes too scanty to insure the most rapid growth and full development of plant life later in the season. In most portions of the United States the farmer, gardener, and fruit grower find it desirable so to prepare the soil in the fall or spring as to increase its capacity for moisture and also to conserve the soil moisture as far as possible during the growing season.

472. Increasing the Capacity of Soil for Moisture.—The capacity of soil for holding moisture depends upon several conditions. In regions where the rainfall is likely to be deficient, during the growing season, it is of the greatest importance that the soil be so prepared as to increase as much as possible its capacity for holding moisture. There are several ways in which the capacity of the soil may be increased:

1. Its capacity may be increased by FALL PLOWING. A considerable portion of the annual precipitation in many regions occurs during the winter months. If the surface of the soil is left hard, smooth, and compact in the fall, much of the winter precipitation will run off the surface and never enter the soil. Fall plowing leaves the surface of the soil loose and open, rough and broken, thereby tending to prevent the loss of this moisture.

2. By increasing the amount of HUMUS (Art. 309) in the soil, the capacity of the soil for holding moisture is greatly increased. Scarcely any other kind of soil has equal capacity for holding moisture.

3. The capacity for holding moisture is greatly increased in most soils by providing good UNDER DRAINAGE. Well-drained soils remain porous while soils not well drained be-

come hard and solid. The rainfall readily enters porous soils and passes down through such soils to the water table (Art. 455) below.

473. How Moisture May be Conserved.—As we have seen (Art. 468), at best, considerable soil moisture is evaporated and passes into the atmosphere on account of soil aeration. Moreover, many soils, when dry, tend to become hard and solid, and shrink. The result is, frequently, that cracks open in the surface soil. Sometimes these cracks are numerous, wide, and deep. Such cracks permit freer circulation of air through the soil and consequently more evaporation takes place; worst of all, such evaporation takes place at considerable depth. This evaporation greatly lessens the amount of film water within the reach of the plant roots.

Loss of soil moisture through evaporation may be lessened by covering the soil with mulch. This mulch may be provided by either of two methods:

1. By the application of a coat of manure, straw, dead grass, or any similar material. Mulch of this nature is difficult to obtain in sufficient quantities for use on large cultivated fields.

2. By the preparation of SOIL MULCH. A soil mulch consists simply of a layer of finely pulverized soil. This is produced by thorough tillage after every rain. If the top 1 or 2 in. of soil is kept in a finely pulverized condition, loose and open, during the growing season, the loss through evaporation from the surface is greatly reduced. It does this by breaking the capillary action at the lower surface of the loose soil. The soil moisture rises readily to that point but does not rise farther. It is much the same condition we should have in our kerosene lamp were the wick cut in two a short distance down in the wick tube of the burner. Keeping the surface of the soil covered with this soil mulch is the only practical method of preventing excessive evaporation from large cultivated fields. What effect will such mulch have upon the cracking of the soil? Explain.

IV. RELATION OF GROUND-WATER TO WELLS

474. The Fallacy of Underground Streams.—By many people it has been supposed that to "strike a vein of water" when boring a well means that the drill has tapped an UNDERGROUND STREAM. While it is true that underground streams exist in some places, the supposition that most wells tap something that may properly be called an underground stream is false.

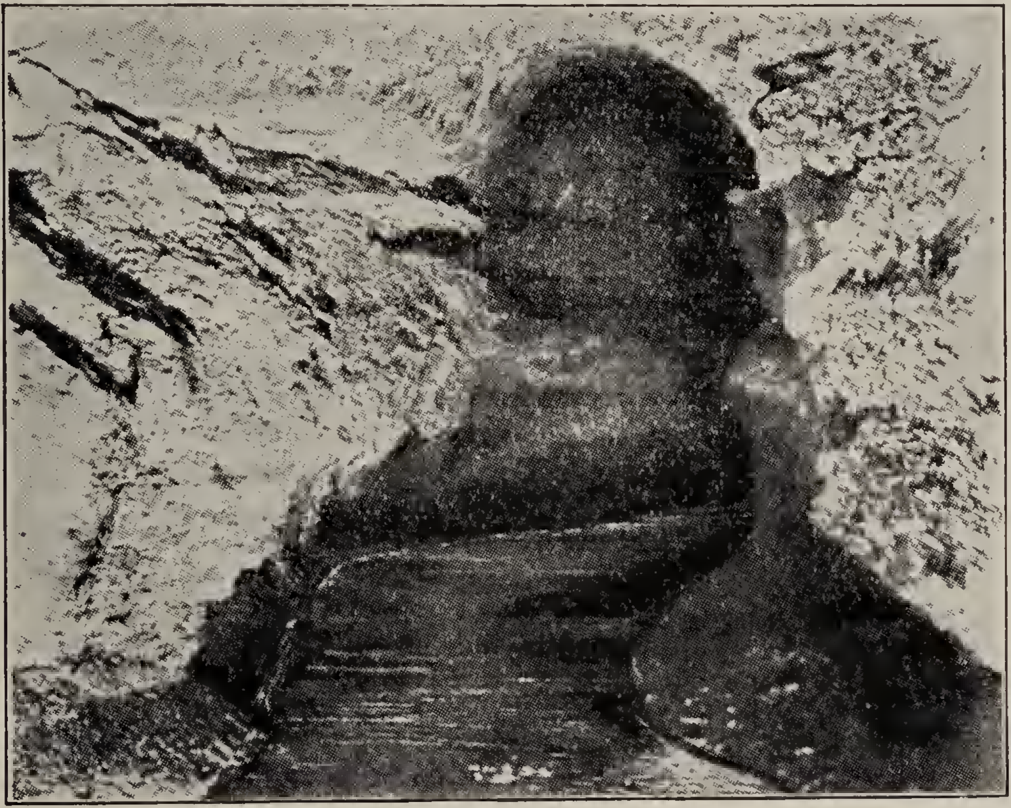


FIG. 235—An underground stream in limestone. The carbonic acid has dissolved the limestone and the ground-water drains away in a true underground stream.

We have already seen that all of the free ground-water moves slowly through the soil down hill, or toward a lower level. In many places the nature of the soil is such that through certain strata, or layers, the water moves more rapidly than through others. If a layer of coarse gravel and sand slopes down hill, the ground-water passes much more rapidly through it than it does through the layers of fine clay above and below the gravel. But this would scarcely be called an underground stream; it certainly is not what most people mean by that term.

The term "underground stream" may properly be applied only to those comparatively rare cases where the water has dissolved portions of the rock, washing the dissolved portion entirely away and leaving an open channel through which the water flows (Fig. 235). But such conditions are so rarely found that *the underground stream is not of any importance when considering the source of water supply for wells.*

475. A Vein of Water.—If to "strike a VEIN OF WATER" does not mean the tapping of an underground stream, what does it mean? In meeting this question we shall also be meeting the question, What is the real difference between a good well with plenty of water and a poor well yielding but little water?

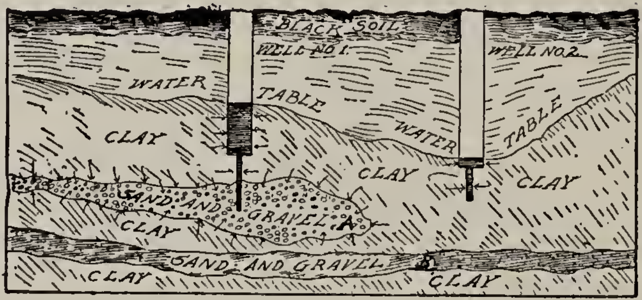


FIG. 236.—A vein of water.

In Art. 456 we saw that the relation of the water table to the land surface has been determined by noting the height of water in wells. We have also seen that the water in a shallow well will stand at exactly the height of the water table, *provided that no water is used from the well.* Why should using water from the well affect the height of the water in the well? If the well is sufficiently deep so that its bottom is below the level of the water table, why should not the well contain a sufficient supply of water at all times? The answer to these questions is this: Although the well does reach below the water table we cannot expect much of a flow till we reach a "vein of water." But what is a vein of water?

It is certain that it is rarely, almost never, an underground stream.

When a vein of water is struck, it is always found in a layer of sand and gravel, or some other open, porous soil; it is always a layer which allows the ground-water to percolate easily through it. Figure 236 represents an ideal case. The soil above and below the bed of gravel, A, is so fine in texture that water passes through it slowly. Therefore neither well No. 1 nor well No. 2 receives water freely from it. But the gravel bed, or GRAVEL POCKET as the geologists call it, increases immensely the exposed surface of the well. This pocket of gravel performs exactly the same function for this well No. 1, as the infiltration-gallery performs for the well in Fig. 231. Well No. 2 would evidently have to be extended till it reached gravel bed, B, before it could be supplied with water from any other source than from the clay. *It is evident, then, that a vein of water is merely a vein of sand or gravel, porous soil, through which the ground-water percolates rapidly.* The trouble with a poor well is that it is sunk in clay or other materials through which water moves but slowly. When water is removed from the well the water nearest in the soil soaks into the well and it too is removed. If the pumping continues long enough the water table about the well is lowered as shown about well No. 2, Fig. 236; in fact, the water table may be lowered to the very bottom of the well. This could not take place if the well were sunk in soil which was sufficiently open and porous so that water flows readily through it.

476. Witching for Water.—It has not been long since it was common to find people who believed that a vein of water could be located by use of a DIVINING ROD. In almost every community some person could be found who honestly believed that he could, by using the divining rod of a favorite wood and shape, actually determine the location of an adequate supply of underground water. If asked to give a good, scientific reason for the fact that the stick turned downward in his hands as he walked over the supposed vein of water, he was invariably unable to do so but insisted that experience proved it. He drew his conclusion from the fact that wells sunk in accordance with the behavior of the divining rod seldom failed to bare water.

We have already seen that every well which extends below the water table is certain to contain some water and that the efficiency of the well depends upon its tapping a bed, or pocket, of loose, porous soil through which water may percolate readily. Unless some reasonable connection can be shown to exist between the divining rod and the bed of gravel buried deep in the soil, "witching for water" must be classed with the outgrown superstitions of the past.

477. Deep Well Water.—Wells are usually divided into two classes, SURFACE WELLS and DEEP WELLS. In speaking of wells as "surface wells" we do not mean that they are necessarily shallow wells. We mean simply that they are fed by the surface water, that is, by the ground-water near the surface of the earth. In speaking of "deep wells" we mean that such wells are fed from deep-seated veins of water. The water which enters the surface wells has not usually passed through much soil. It is water which has fallen as rain or snow near the well; it has sunk into the ground, joined the ground-water, and found its way more or less quickly into the well.

The veins of deep-seated water, on the other hand, are separated from the surface waters by layers of nearly impervious clay or other material. Their source of supply is usually at considerable distance from the well, often even hundreds of miles. They are often ROCK WATERS, that is, water which has collected in porous layers of rock, such as sandstone. It is easily seen, therefore, that local rains can make but little difference in the height of water in deep wells. Most well water contains considerable mineral matter in solution; this mineral matter produces a whitish curdy material when mixed with soap. Such water is called HARD WATER.

478. Artesian Wells.—By ARTESIAN WELLS we mean deep wells. In most cases the water rises above the surface of the ground. Such wells tap veins of water which usually, not only have their source at a great distance from the well, but also at a higher level. The water-bearing material lies between impervious layers of clay or shale, or at least has such a layer overlying it. This overlying layer of clay or shale tends to prevent the water from rising, no matter how great the pressure upon it. Figure 237 illustrates the layers of rock, which underlie South Dakota.

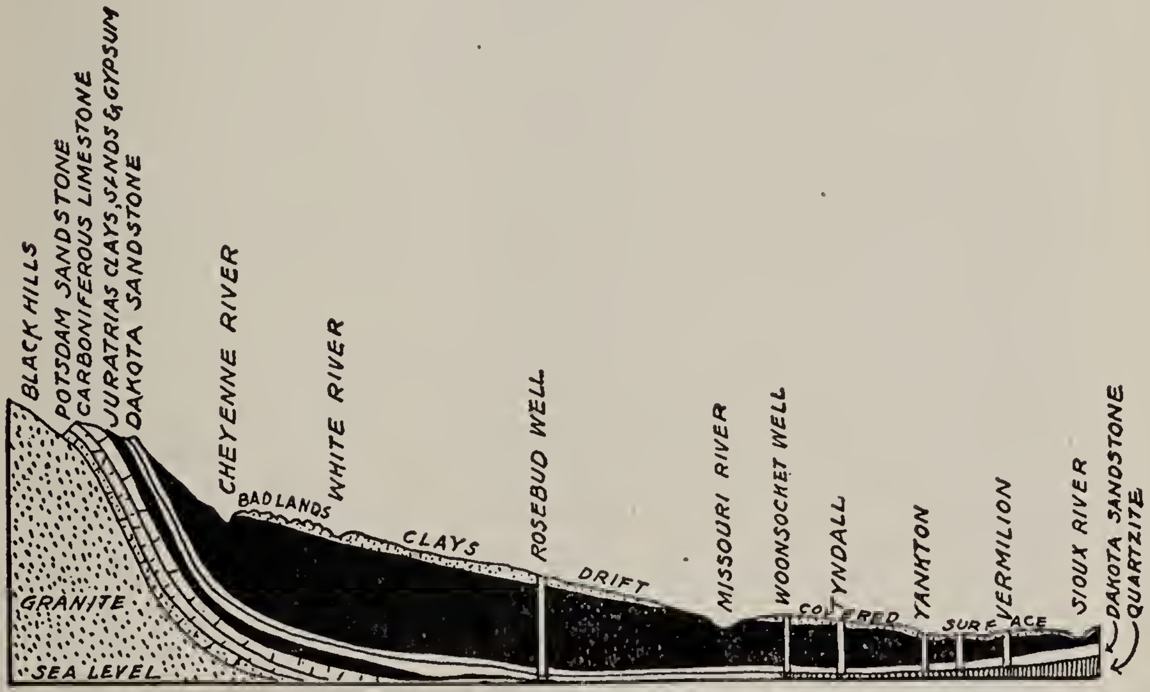


FIG. 237.—Geologic section from the Black Hills eastward across South Dakota. The illustration immensely exaggerates the vertical distance as compared with horizontal distance.

Throughout the eastern half of South Dakota there are numerous artesian wells. These wells receive their supply of water from a layer of sandstone, known to geologists as "Dakota sandstone." This sandstone comes to the surface at the eastern edge of the Black Hills. Much of the water which falls upon these hills soaks into this sandstone and then passes through this porous sandstone down the slope toward the east. Since the sandstone comes to the surface at about 3000 ft. above the sea level and since the surface of the land in the eastern portion of the state where the artesian wells are so numerous is less than 2000 ft. above the sea level, we

FIG. 238.—Artesian well at Woonsocket, South Dakota.

should expect the water to rise above the surface of the land. From many of these wells the water issues with great force, sometimes with a pressure of nearly 200 lb. to the sq. in. Figure 238 is a reproduction of a photograph of a well at Woonsocket, South Dakota, showing a 3-in. stream which rises to a height of nearly 100 ft. The water exerts a pressure of about 135 lb. to the sq. in. when the pipe is closed so as to prevent the escape of the water.

CHAPTER X

WATER SUPPLY AND SEWAGE DISPOSAL

I. THE VALUE OF WATER

479. Man's Dependence upon Water.—When we read nowadays that "a house has modern conveniences" it means that it is not only provided with modern appliances for lighting and heating, but also that the house is supplied with water and suitable plumbing for the disposal of sewage. This is especially true of city houses and is becoming more and more true of country and farm houses. While we may be quite comfortable without having the water piped into the house, *we must have a sufficient supply of wholesome drinking water close at hand.*

A supply of wholesome water is much more important to man than is artificial light. It is also true that in all but severe winter weather and in the colder portions of the country, man can live much longer without food or artificial heat than he can without water to drink.

480. Man Has Always Recognized His Dependence upon Water.—From the earliest antiquity, man has recognized the importance of securing an ample supply of wholesome water. Most of the great cities and nations of the past have been located upon rivers or lakes containing fresh and wholesome water. If the natural water supply was not sufficient, great AQUEDUCTS were built to bring a supply from a distance and huge RESERVOIRS were constructed to store a supply in times of plenty. Some of the greatest structures erected by ancient man were these great stone aqueducts and reservoirs (Fig. 239).

Recognizing their dependence upon water, campers and hunters always make camp, when possible, near some spring or stream. For a similar reason the earliest settlers of the

Mississippi valley and of the great plains to the west settled first upon the lands bordering the streams. When all of the land bordering the streams was taken and the settler was obliged to take land farther back, the first improvement he made was to dig a well, for he must have water.

481. Water Valuable for Purposes Other Than Drinking.—Streams and other bodies of water have always been the highways for commerce. Until the invention of the locomotive and the perfection of the modern railroad, which have taken place within the last century, the means of transportation by land were very poor and costly; in fact, there had been scarcely any improvement in modes of travel since the dawn of history. The ox and the horse were but little improvement over the equally rapid-moving camel, which was the beast of burden in the earliest Biblical times. For this reason practically all of the world's commerce up to about a half-century ago was carried on by water.

FIG. 239.—Aqueduct of Segovia, Spain. Nearly one-half mile in length. Over 1800 years old. From *History of Sanitation*, Cosgrove.

For centuries, man has used the power of running water to help him perform his labor. It has ground his corn and wheat; it has sawed his lumber and run his looms when no other force was available.

Plant life as well as animal life is largely dependent upon water for its very existence. From prehistoric times man has used water from near-by streams to IRRIGATE his crops. Some of the greatest nations of the past have lived on soil where the natural rainfall was insufficient, and artificial watering or irrigation was necessary.

In each of these cases to which we have been referring, man has made use of the *visible* supply of water, *i.e.,* the water which stands or flows above the surface of the land. We have seen, however, that the ground itself is a great reservoir of water and that to this vast supply of *hidden* water man owes as much, possibly, as he does to the visible supply.

II. WATER SUPPLY FOR FARMHOUSE AND COUNTRY HOME

482. New England Well-sweep and the Oaken Bucket.— The earliest settlers of New England had little difficulty in securing a sufficient supply of good water. Springs are numerous throughout New England. In many localities most farmhouses are supplied with water brought in pipes from nearby springs. Many villages and towns also receive their supply from springs or hillside brooks fed by springs. Where the water does not come to the surface, it is nearly always easily obtained by digging shallow wells. These wells are often not more than 10 or 15 ft. deep.

In the days of the colonies the usual method of raising the water from these shallow wells was by means of the WELL-SWEEP and the OAKEN BUCKET. A heavy weight was fastened to the short end of the long sweep to balance the long arm of the sweep. The lifting of the bucket full of water thus became an easy task. This method of raising water from a well has been immortalized in the familiar song "The Old Oaken Bucket."

483. The Suction-Pump.—Water for household and farm use is usually lifted out of moderately deep wells by SUCTION-PUMPS. A common suction-pump consists of two parts, the PUMP-HEAD, and the PUMP-RUN. When made of wood, the head is usually from 6 to 8 in. square and about 7 or 8 ft. in length. This head is hollow, that is, a hole 3 or 4 in. in diameter is bored throughout its length (Fig. 240). Into the lower end of the head a metal tube, the CYLINDER, is fitted. The cylinder is made smooth and true on its inner surface; when of iron it is often lined with enamel. Fitting closely into this cylinder is the PLUNGER or BUCKET. This plunger or bucket, carries the PLUNGER-VALVE which opens easily upward but which prevents any water above it from passing downward. The plunger is raised and lowered by means of the PLUNGER-ROD, attached to the PUMP-HANDLE.

Fitting closely into the lower end of the HEAD is the PUMP-RUN, or the SUCTION-PIPE. In the common wooden pump this run is about 4 in. square and has a hole about $1\frac{1}{2}$ or 2 in. in diameter bored throughout its length. At the lower end of the cylinder, below the plunger, is a second valve, the INLET-VALVE. This valve also permits the water to pass upward but prevents a downward flow.

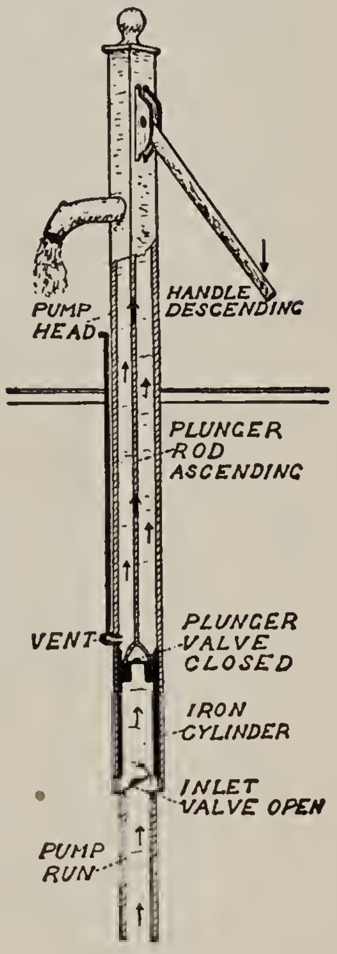


FIG. 240.—The suction pump.

484. How the Suction-pump Works.—The way in which the suction-pump works is made clearer by studying the sketches of the common cistern pump (Fig. 241). As the handle is forced downward, the plunger rod and plunger are raised. The water which is already above the plunger, or bucket, is lifted till it stands higher than the spout, out of which it runs. But what raises or lifts the water in the run and cylinder below the plunger? We say it is raised by suction, or that it is sucked up (see Art. 284).

In the suction-pump, as the plunger is raised there is a *tendency* to produce a vacuum just beneath it. The atmosphere pressing down upon the surface of water in the well forces the water up the run and through the inlet-valve to fill the vacuum. The work we do, then, in pumping with the suction-pump is really expended in lifting the small amount of water in the pump-head already above the plunger and in lifting the atmospheric pressure which is pressing downward upon the surface of that water, and *not in pulling or drawing the water up the pump-run.* Define suction and sucking (Art. 284). Explain the process of "sucking" soda water up a straw.

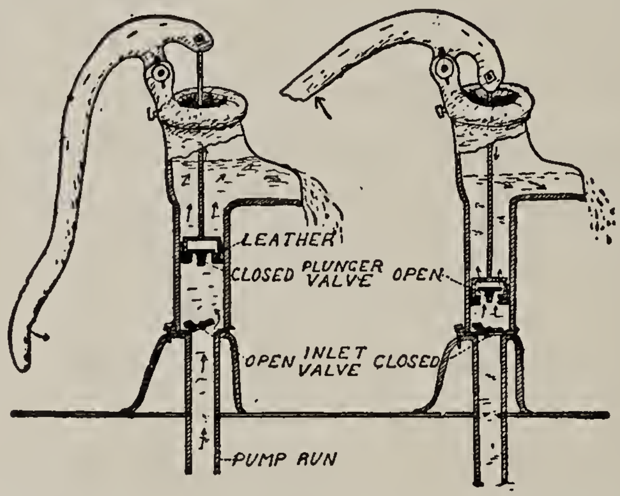


Fig. 241.—Common iron cistern pump.

485. **Lift-pump.**—A lift pump is constructed exactly like the head of a suction-pump. Were the head of a suction-pump long enough to reach to the bottom of the well, it would become a lift-pump. The inlet valve, then, is at the bottom of the well and the cylinder and plunger are at all times below the surface of the water in the well. The water is therefore lifted and not sucked up.

486. **The Force-pump.**—It is often necessary to raise water to a level above that of the pump spout. In farmhouses and

in dwellings in small towns, where there are no city water works, it is often desirable that water be pumped into a tank in the attic so that sink faucets may be supplied with water under pressure at all times. Unless some such plan is adopted, modern plumbing conveniences can not be installed in such dwellings; with such a tank, common farmhouses may be equipped with most of the conveniences of city dwellings. Any pump so constructed that it may be used to force water to a height above the pump is called a FORCE-PUMP.

As far as the lower portion of a force-pump is concerned, it may be either a suction-pump or a lift-pump. Figure 242 shows the construction of an iron force-pump. It differs from the ordinary iron suction-pump only in having a portion of the head somewhat enlarged so as to enclose a considerable quantity of air, forming an AIR CUSHION, and in having the opening at the top through which the plunger rod passes packed air-tight. Explain the use of the three valves, *A*, *B*, *C*.

The air cushion is necessary on all force-pumps if we are to secure a fairly steady stream from the pump. With each upward stroke of the plunger, the air in the air cushion is compressed. While the plunger is descending, this compressed air, pressing downward upon the water in the pump, keeps forcing a steady stream of water through the delivery pipe into the tank.

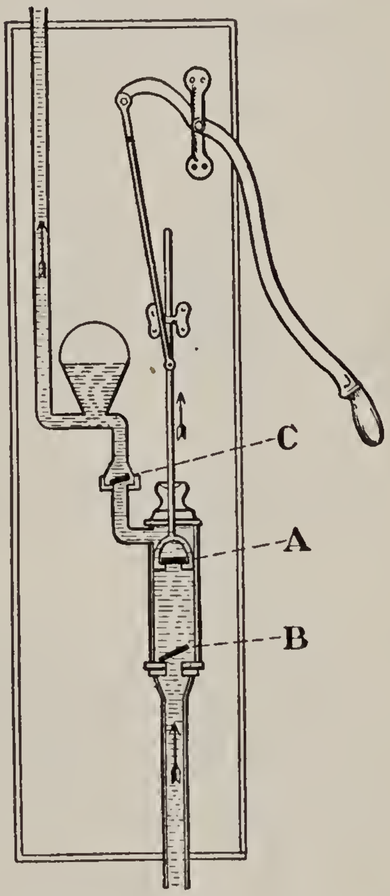


FIG. 242.—The force-pump.

487. The Pneumatic Tank System.—The convenience and comfort derived from having an ample supply of water under pressure in a dwelling can be appreciated only by those who have lived with, and again without, such conveniences. Not only can all of the conveniences of modern plumbing be obtained, but a reasonable protection against fire is thus secured.

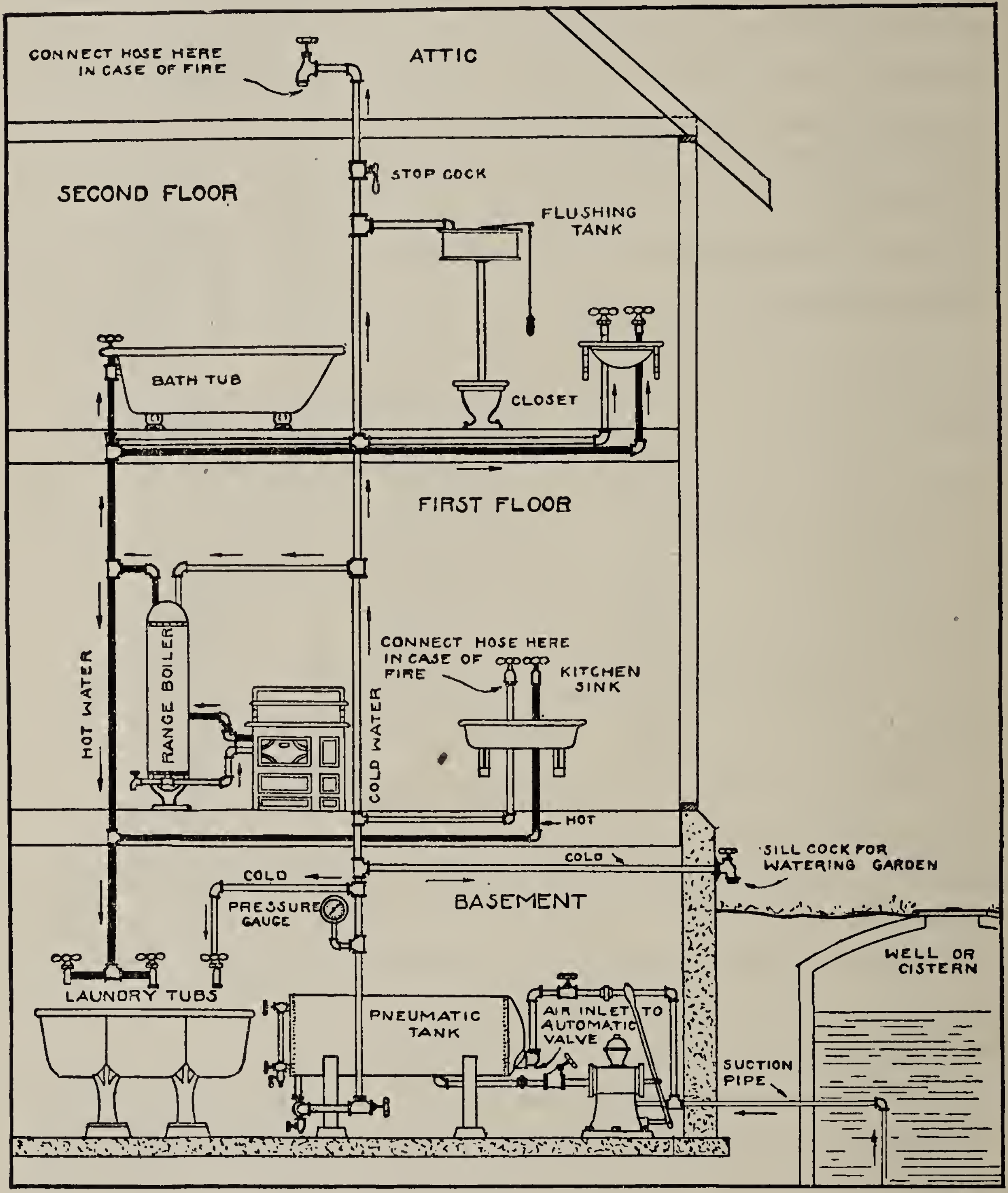


Fig. 243.—Pneumatic tank system.

Figure 243 shows how such a system may be installed and the conveniences which it makes possible. In such a system the tank is placed in the basement of the house, safe from frost and easy of access.

The water is raised from the well or cistern and forced into the tank by means of a force-pump. The lower portion of the tank contains water and the upper portion compressed air. This compressed air constantly presses downward upon the water in the tank, forcing it into the pipes. Special provision must be made to pump more air into the tank occasionally. If this is not done the tank will in a short time become ''water-logged,'' that is, all of the air will be removed from the tank by the water which passes through it. How this may be so is more clearly seen after performing the following exercise.

Exercise 77.—Removing the Air from Water

Place a tumbler or flask filled with water under the receiver of the air pump, first noting the temperature of the water. Begin pumping the air from the receiver. While taking the first few strokes watch carefully to see if any bubbles are rising through the water. Pump out most of the air, watching constantly for bubbles of rising air.

EXPLANATION.—We all know that sugar or salt may be dissolved in water; in much the same way air readily dissolves in water. Since the atmosphere is always resting upon the surface of water standing in an open vessel, it is always possible for air to be dissolved in the water. But is there a limit to the amount of air which will be thus dissolved by a given quantity of water? We know from experience that there is a limit to the amount of sugar or salt which will dissolve in a given quantity of water. After the water is ''saturated'' with the salt or sugar, adding more of the solid simply means that it will settle to the bottom of the liquid and remain there undissolved. In the same way, a vessel of water standing open to the air is soon ''saturated'' with dissolved air; it contains all the air it is possible for it to contain *under the given conditions.* From Ex. 77 what do you conclude is the effect of reducing the pressure of the air upon the surface of the water?

Henry's Law.—*The amount of gas dissolved in water is directly proportional to the pressure, that is, doubling the pressure doubles the amount of gas which dissolves in a given quantity of water.* This law holds true only when there is no chemical union between the gas and water, as is the case when air is dissolved in water.

One cu. ft., or 1728 cu. in., of water at 0°C. and at the pressure of 15 lb. per sq. in., that which the atmosphere exerts at the sea level, dissolves about 45 cu. in. of air. By Henry's Law we see that doubling this pressure would cause about 90 cu. in. of air to be dissolved in each cubic foot of water, or reducing the pressure to 5 lb. to the sq. in. reduces the amount of dissolved air to 15 cu. in. per cu. ft.

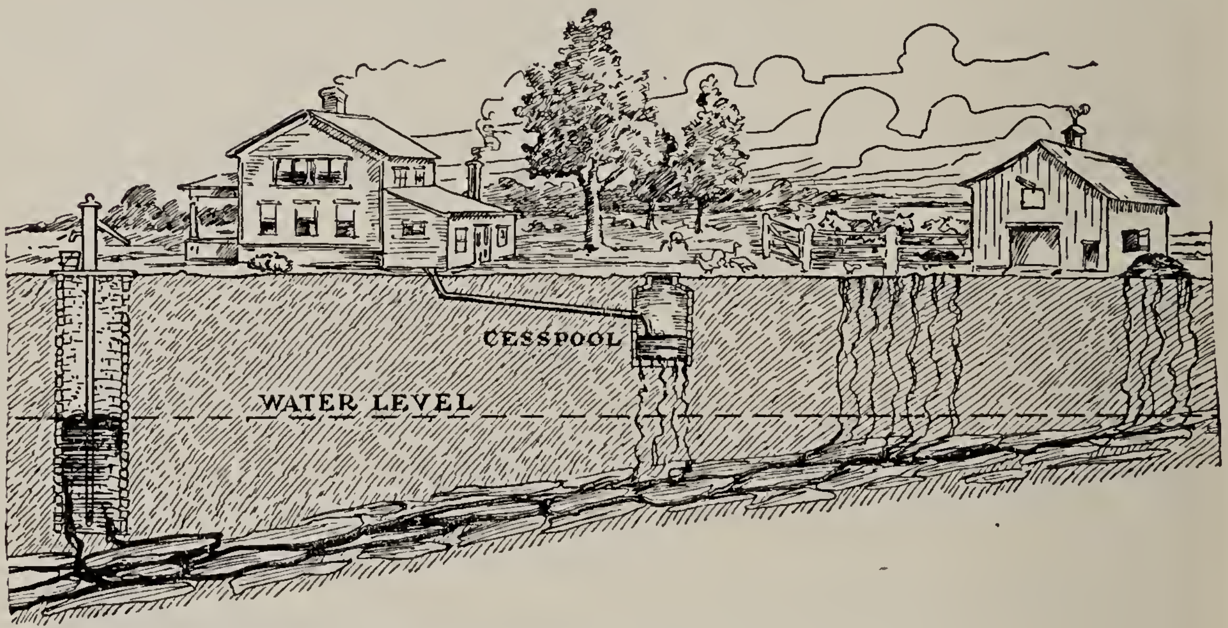


Fig. 244.—Why shallow wells are dangerous.

The need of pumping more air into the tank occasionally to prevent it from becoming "water-logged" is now evident. The water in the well or cistern is under 1 atmosphere of pressure; therefore there are about 45 cu. in. of air in solution to each cubic foot of water as it *enters* the tank. The water in the tank is kept constantly under a pressure of, at least, 2 atmospheres; the water, therefore, as it *escapes* from the tank through the pipes and faucets, contains at least twice as much air as it did in the well. Evidently, if no additional air were pumped into the tank, the tank would soon become "water-logged." What would be the result?

488. Shallow Well Water Often Dangerous.—We have seen that wells are supplied by the ground-water. It is evident that, if the walls of the well are merely bricked up to prevent the walls from caving in, they will not be water tight. In such cases surface water, at times of frequent and heavy rains, will readily enter the well very near its top. If such a well be located near a barnyard on a farm or in a somewhat thickly settled portion of a town or city, especially one not provided with sanitary sewers, the surface soil about the well will be contaminated with manure and other decaying animal and vegetable matter. The surface water, at times of heavy rains, may enter at the surface or, at best, merely soak a few feet into the soil before finding its way into the well (Fig. 244).

Such surface water will necessarily carry with it much undecayed or but partially decayed vegetable and animal matter. Such matter later decays (Arts. 304 and 305, Chap. VII) rendering the water unwholesome for use and not infrequently causing sickness and sometimes death. The danger is greatest when the waste matter is from the human body. This is so because the waste matter thrown off from the human body is very likely to contain microörganisms which cause human diseases. Typhoid fever is often caused by drinking water containing typhoid bacilli (Art. 359).

489. Protecting a Shallow Well against Surface Water.—All shallow wells should be protected against surface water. Some protection is provided by constructing the walls and cover of the well water-tight. When the walls and cover of a shallow well are water-tight, there is no opportunity for the contaminated surface water to get into the well until it has percolated through the soil to the bottom of the well. In passing thus through the soil, the water is fairly well filtered, and the danger of contamination is lessened.

III. CITY WATER SYSTEMS

490. Privately Owned and City Owned Water Systems.—In communities where the families live in homes separated by considerable distances, each family must provide its own water supply. But as soon as a region becomes thickly settled, it becomes somewhat less expensive and in every way better for the whole community to be served by a common water system. City governments generally maintain such water systems to supply all who live within the city limits. Sometimes a private corporation is granted a FRANCHISE by the terms of which the corporation may lay pipes in the public streets and may sell the water to customers under certain conditions and regulations stated in the franchise. In a similar manner, private corporations very frequently are granted franchises to furnish customers with electric current and gas for lighting, cooking, and for power purposes, and occasionally to furnish heat for heating homes and places of business (Arts. 48 and 64). Inasmuch, however, as public health is so largely dependent upon a safe, uncontaminated water supply, the water system of a city is more commonly controlled by the city government.

491. Amount of Water Used.—It has been estimated that the amount of water used for household purposes in homes not supplied with running water or water under pressure is from 2 to 4 gal. daily per person. The amount of water required per person in any city depends upon the occupation of the inhabitants. A manufacturing city requires generally a much larger supply of water than does a residence city. It is common practice to construct water plants capable of furnishing from 50 to 80 gal. daily per capita in the ordinary city where the demand is not great for manufacturing purposes. In some American cities containing many factories and other industries requiring large amounts of water, as much as 100 or even 200 gal. per capita are required. To furnish such immense amounts of water, elaborate pumping and distributing systems are necessary. Figure 245 shows a modern pumping station for a small city. The pump used is a CENTRIFUGAL PUMP; it is driven by a gas engine (Art. 603, et seq.) which uses gas made from coal as fuel.

492. Sources of City Supply.—It is often a serious undertaking for a city to secure an adequate supply of water of such a degree of purity that it may be used safely for drinking purposes, that is, in its unboiled, or "raw," state. Many of our larger cities are located on rivers or lakes where an abundance of water is obtainable. But the purity of such water is frequently not such as to warrant its use without purification. Sometimes sufficient purification is secured by pumping the water into a SETTLING TANK where most of the sediment is removed and then passing it through sand filters where most of the finer suspended matter and bacteria are removed. Sometimes it is found necessary to treat the water chemically in addition to filtering it. This is most frequently

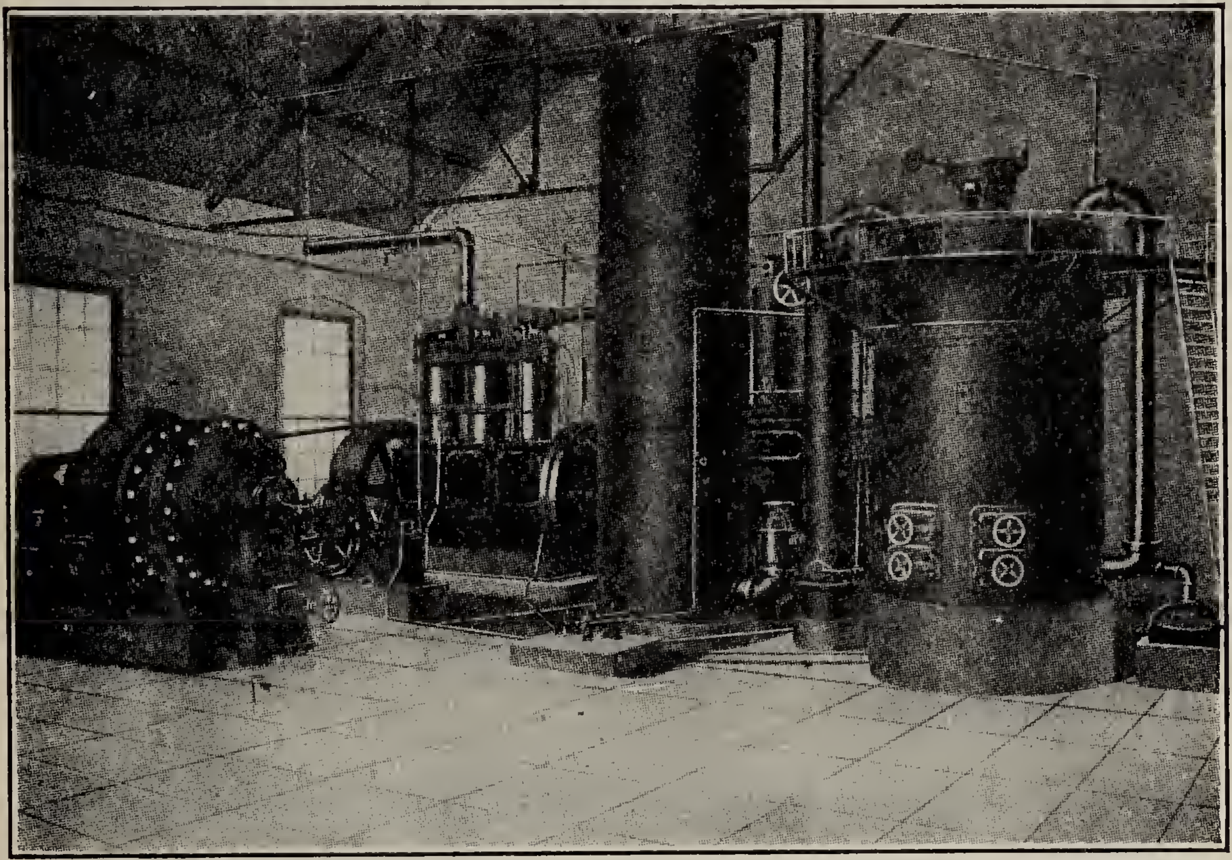


FIG. 245.—A modern city pumping station. Three-stage centrifugal pump, belt-driven by 150 h.p., three-cylinder gas engine, with suction gas producer.

the case when a city gets its water supply from a river into which other cities nearer its source have emptied their sewage.

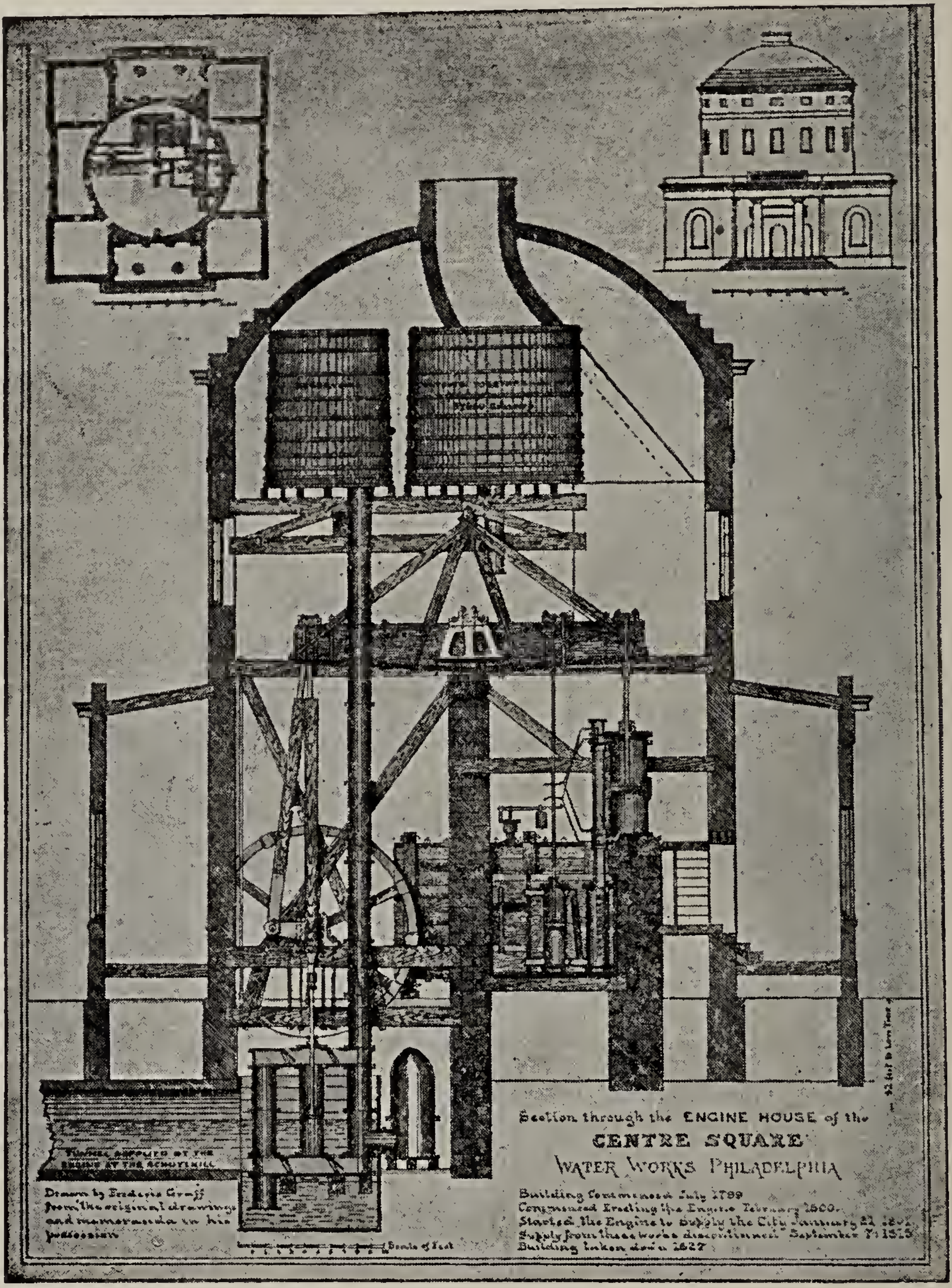


FIG. 246.—Central Square Water Works, 1800. From *History of Sanitation*, Cosgrove.

493. Development of City Water Systems.—The modern city water system has been developed within the last century. We shall see in Chap. XI, p. 502, that the steam engine was still a very crude machine at the beginning of the 19th century. City water systems were still less well developed. Philadelphia was one of the first of American cities to construct a city water system. Fig. 246 is a section through the Central Square water works of that city constructed in the year 1800. Its crudeness is evident when compared with a modern city water plant. The boiler was constructed of 5-in. pine plank with iron firebox and flues. The distributing pipes were also of wood, being logs with the center bored out. The system was never very satisfactory; the boiler leaked steam and the pipes leaked water. In 1804, Philadelphia began laying iron pipes and is believed to have been the first city in the world to do so. New York City's water system, as well as modern plumbing in America, really dates from the completion of the Croton Aqueduct about 1850.

(Copyright, Underwood & Underwood.)

FIG. 247.—The Miraflores Water Purification Plant, capacity, 15,000,000 gallons per day. A large factor in making the Panama Canal zone habitable.

494. **Water System of New York City.**—Many of our larger cities have spent immense sums of money in obtaining an adequate water supply. In 1842, New York City first began using water from the Croton Reservoir. An immense dam had been constructed across the Croton River forming

the reservoir. An aqueduct, the Croton Aqueduct, conveyed the water to the city. In 1890 this water system was enlarged. The cost of the Croton Aqueduct and Reservoir

FIG. 248.—Philadelphia high-pressure fire service. Vertical stream made in underwriters' test.

is said to have been $160,000,000 and the labor required in their construction was equal to that of 600 men working for 10 years. In spite of the immensity of the Croton supply, about 500,000,000 gal. daily, the city is outgrowing its water system. At the present time a second source of supply is nearing completion. The city acquired possession of an area of 900 sq. miles of mountainous land in the Catskill Mountains and is constructing an aqueduct to bring the rainfall of

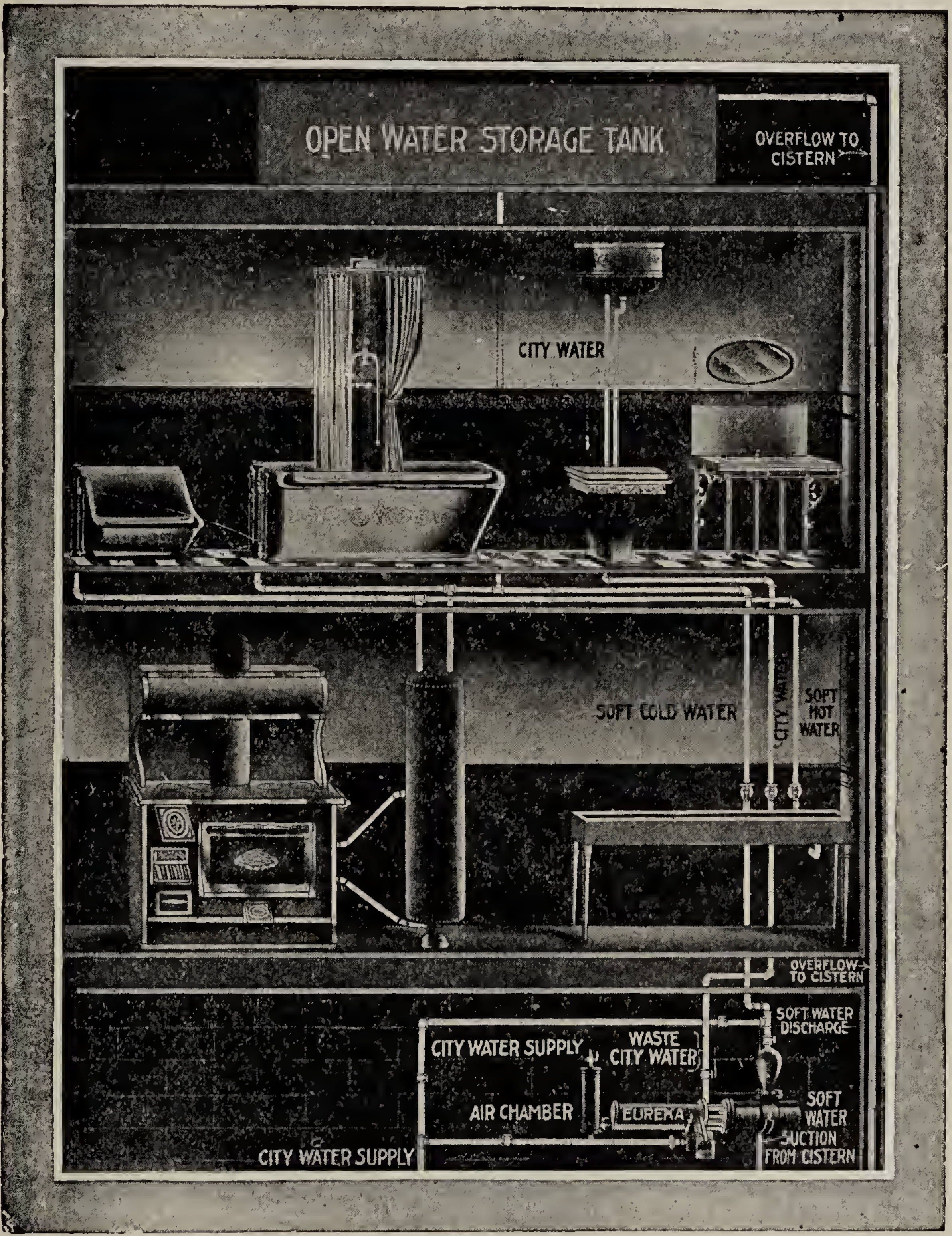


Fig. 249.—Plumbing in a modern city dwelling.

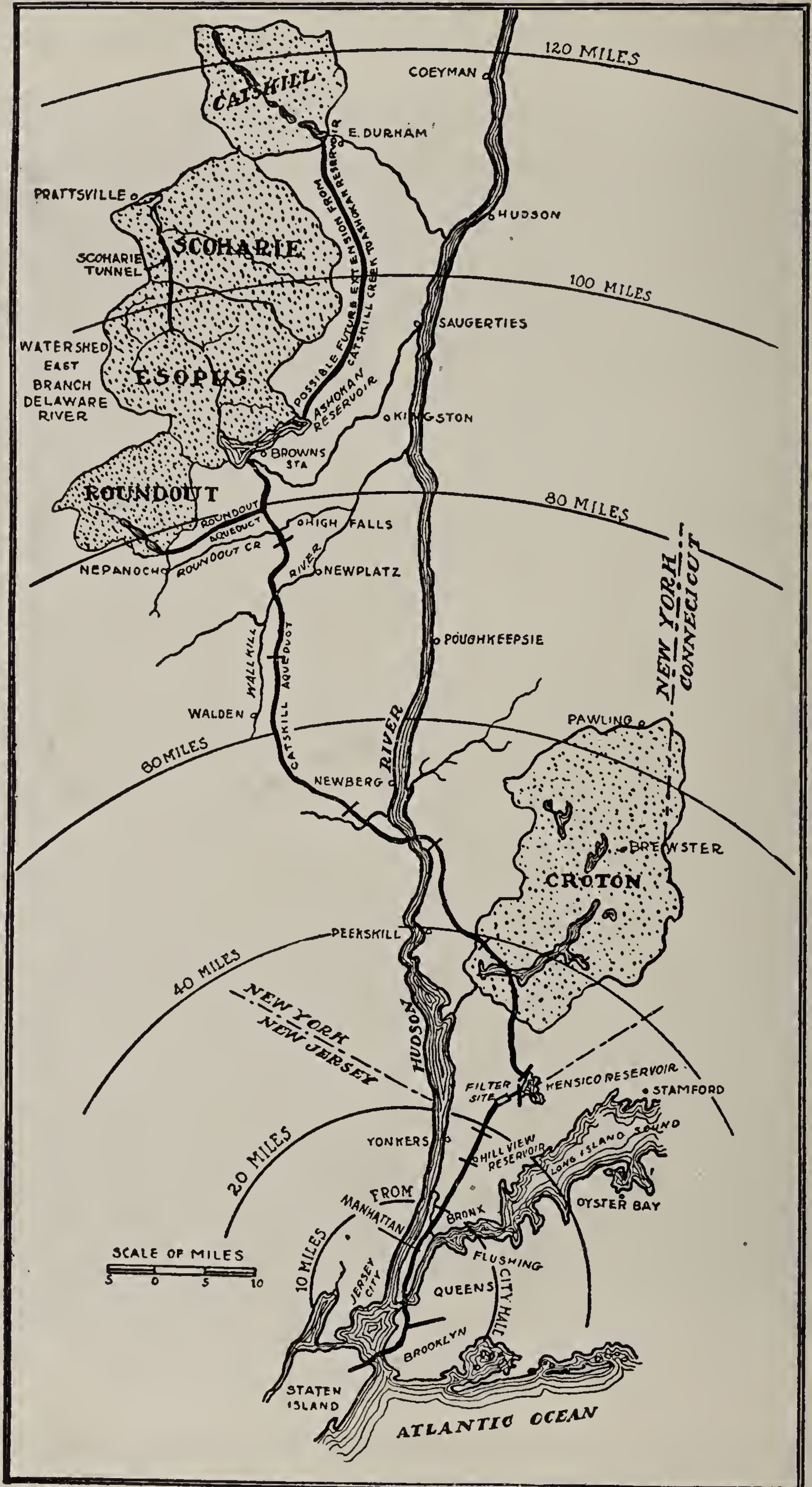


Fig. 250.—The water supply of New York City.

that region to the city (Fig. 250). The new aqueduct is 127 miles in length. The water is carried through a tunnel over 4 miles in length and at a depth of 1100 ft. beneath the Hudson River and later through another tunnel at the depth of 700 ft. beneath the East River. It is estimated that the new system will cost $200,000,000 and that it will double the city's water supply, making the supply 1,000,000,000 gal. per day. This will be an ample supply for a city of 8,000,000 population, allowing 125 gal. a day per capita. Every effort is being made to safeguard the purity of the water from the new source. To do this, seven villages in the Catskills have been abandoned. At the completion of the Catskill development the city will have expended nearly $100 per capita for its water supply.

495. City Supply from Deep Wells.—Many of our smaller cities are able to obtain a sufficient supply of water from deep wells. Many of the cities of southern Wisconsin and northern Illinois, for example, obtain their water from a layer of sandstone which comes to the surface in northern Wisconsin but which is generally reached at a depth of 1000 ft. or more in Illinois. The source of this water supply is at a somewhat higher elevation; therefore, many of these wells are flowing wells. London, Eng., and Brooklyn, N. Y., have in the past secured a considerable portion of their water supply from wells.

496. City Water Must be under Pressure.—The city is fortunate which has its source of supply at a considerable elevation above the level of the city. It is necessary that the city supply shall be under pressure, not only in order that the water may be used on the upper floors of tall buildings, but also to aid in the fighting of fires. It is also of great service that the water be under pressure in a city, for it may then be used for power purposes (Fig. 248). Water motors are frequently used where small amounts of power are occasionally used as in running the family washing machine. All modern plumbing is constructed to be used in connection with a water system where the water is under considerable pressure.

Figure 249 shows the arrangement of the plumbing in a modern city dwelling. It will be seen that both city water and soft, or cistern water, are provided. The city water being under pressure is made to pump the soft water into the storage tank in the attic. The hydraulic pump by which this is accomplished is generally called a WATER-LIFT. One-half of the water-lift, the left half in the figure, is really a water motor operated by the city water; the other half

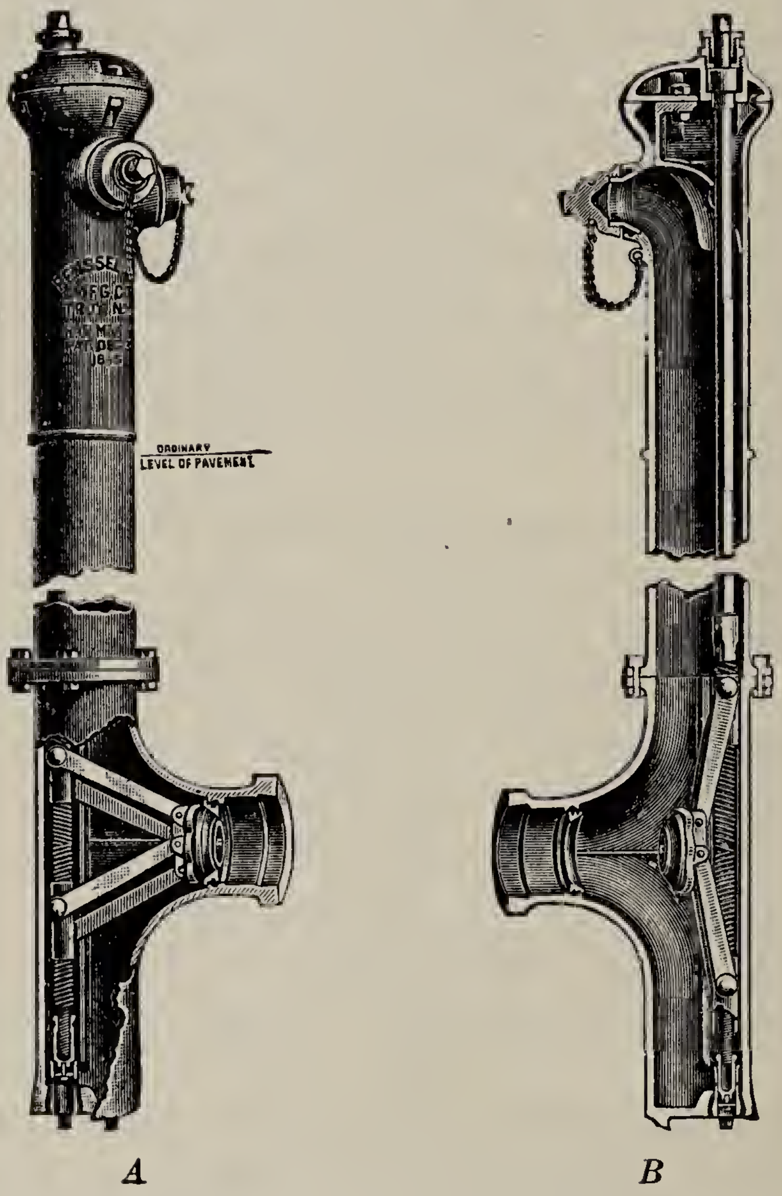


Fig. 251.—City fire hydrant.

is a pump operated by the motor and it pumps the cistern water.

497. The Fire Hydrant.—In cities, fire hydrants are attached to the city main at frequent intervals. Fire hose can be attached quickly to the fire hydrant at the connection near the top of the hydrant (Fig. 251). By opening the cutoff valve the full pressure on the city main may then be utilized in fighting fire. *A*, Fig. 251, shows the position of the valve when the city pressure is cut off the hydrant; *B*, Fig. 251, shows the position of the valve when it is open and the city pressure is on the hydrant. The valve is controlled by a rod extending from the top of the hydrant to its bottom. A screw thread is cut on the rod opposite the point where connection is made to the city main. The upper half of the thread is left-handed, the lower half is right-handed. The upper, left-handed thread carries a left-handed burr; the lower, right-handed thread carries a right-handed burr. To these burrs are attached short rods or levers which control the valve. When the valve is to be opened, a wrench applied to the projecting portion of the rod at the top of the hydrant is turned counter-clockwise. This revolving of the rod forces the upper burr upward and the lower burr downward. The levers spread as the burrs separate and the valve is drawn back away from its seat, thus permitting the water from the main to rush into the hydrant.

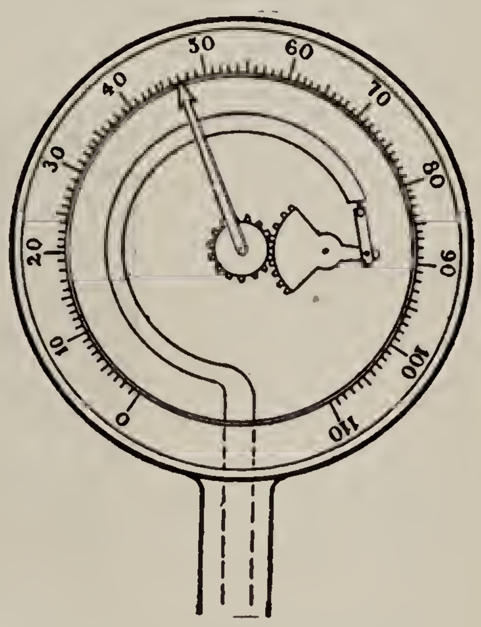


Fig. 252.—Pressure-gage.

498. The Water Pressure-gage.—Water pressure is usually indicated by PRESSURE-GAGE. The pressure-gage consists essentially of an elliptically shaped, thin-walled tube bent into a nearly circular form (Fig. 252). When the pressure within the tube increases, the tubes tend to straighten out. This motion is transmitted to the pointer which moves over the face of the dial. The mechanism is so adjusted that the instrument shows directly the pressure per square inch.

499. The Water Meter.—While the pressure-gage is a necessity at the pumping station indicating to the engineer the exact pressure on the city mains, the majority of consumers are more concerned with the water meter. The pressure-gage merely indicates the pressure under which the water is kept; the water meter indicates the number of gallons or cubic feet of water which flow through the pipes. Generally, the consumer pays for the amount of water consumed, no account being taken of the pressure maintained. This is so, notwithstanding the fact that it requires more work (see Art. 555, and Chap. XI) and costs much more to pump the same number of gallons of water into the city mains when a high pressure is maintained than it does when a low pressure is maintained.

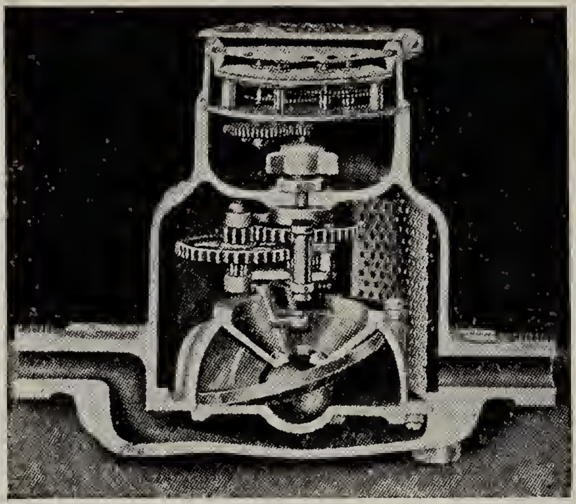


Fig. 253.—Interior view of a Water Meter.

500. Construction of the Water Meter.—There are water meters of many different forms, but most small meters are of the form known as the DISK TYPE. The only moving part in the measuring chamber is a hard rubber disk. This disk is borne, at its center, on a small sphere of the same material.

The case of the meter is usually constructed of bronze so that it will not rust or corrode. The measuring chamber is of the shape of the central portion of a sphere (Fig. 253). As the water passes through the meter, it causes the disk to move with what is known as NUTATION MOTION (*nutation* from a Latin word meaning nodding). The center of the rubber sphere is the point about which the disk moves. If we were to place a common wagon wheel upon the ground so that it rests upon its hub and we were then to walk around the wheel stepping upon its tire, we should be giving the wheel a nutation motion. The upper end of the hub would move with a nodding motion as seen from one side. The water flowing through the meter produces just this sort of motion in the disk. The disk at all times divides the measuring chamber into two separate and equal-sized chambers. A certain amount of water passes through the meter for each complete nutation of the disk. Projecting above the disk at its center is a pin which rests against a short horizontal lever. As the disk rotates, or rather nutates, this lever is carried around and around. A train of gears transmits this motion to the dials, thus recording the amount of water which flows through the meter.

501. Water Meters Generally Reliable.—A good meter is long lived and usually records the amount of water used fairly accurately. If in error it is generally owing to wear. In that case the meter will likely register too small an amount of water because some slips past the disk without causing it to rotate. Water users sometimes complain of the meter's reading too high. If a meter reads correctly when first installed, it is almost certain later to read too low on account of wear. Excessively high reading is generally on account of some undiscovered leak in the piping or too lavish use of water. Leakage is easily discovered, however, by means of the TEST-DIAL, a pointer which indicates the consumption of a cubic foot and fractions of a cubic foot (Fig. 254). To test for leakage, close all taps in the building and watch the test pointer for a few minutes. If any serious leakage is taking place, the test pointer will be seen to keep moving.

502. How Water is Sold to the Consumer.—Although water is generally sold by the 1000 gal., meters often record the amount used in cubic feet. There are 231 cu. in. in 1 gal., while there are 1728 cu. in. in 1 cu. ft. There are, then, nearly 7.5 gal. in a cubic foot.

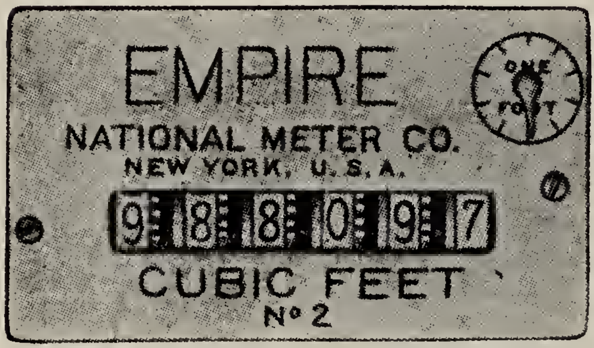


FIG. 254.—The straight reading register. It reads 988,097 cu. ft.

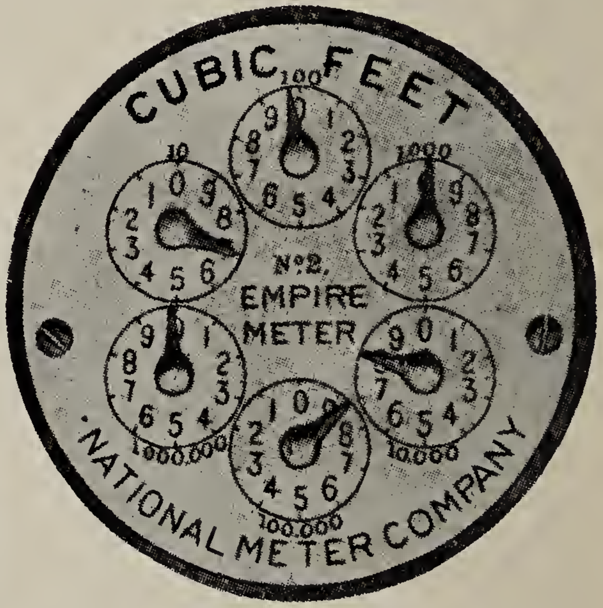


FIG. 255.—The dial register. It reads 987,997 cu. ft.

PROBLEM

If water costs 25 cts. for 1000 gal. and the daily consumption for a city school building is 350 cu. ft., what is the cost of water per day? *Ans.* 65 + cts.

503. Reading the Water Meter.—A water meter may have either a STRAIGHT-READING REGISTER or a DIAL-READING REGISTER. The straight-reading register needs no explanation (Fig. 254). The dial-reading register is so constructed that it requires a complete revolution of the pointer on any circle to indicate the whole number of cubic feet indicated above or below that circle. The circumference of each circle is divided into tenths. In the illustration (Fig. 255) the highest reading pointer stands between 9 and 0. The circle is labeled 1,000,000 cu. ft. The pointer, therefore, indicates a reading of something more than 900,000 cu. ft. The next pointer indicates a reading of 80,000 cu. ft.; the third pointer 7,000; the fourth pointer 900; the fifth pointer 90 and the sixth pointer 7 cu. ft. If desired, the number of tenths of cu. ft. may be *estimated* by estimating the position of the pointer when it stands between any two figures on the 10-ft. dial.

Exercise 78.—Reading a Water Meter and Computing the Cost of Water

Read the water meter at home or at the school on several successive days recording carefully the reading each day. Ascertain the price charged for water and compute the cost of each day's supply.

IV. SANITARY PLUMBING

504. Development of the Art of Plumbing.—The art of modern plumbing has been developed within the past half-century. The word plumbing is derived from the Latin word *plumbum,* meaning lead. From the early days of plumbing, lead pipes have been used to convey water, hence the name plumbing has come to be applied to the entire art of supplying water to buildings and to the disposal of the sewage.

The Greeks and Romans, especially the Romans, made much progress in developing the art of plumbing, although many of their efforts would be considered very crude today. During the 600 years from 300 B. C. to 300 A. D., the Romans built no less than 20 aqueducts, with a total length of 400 miles, to supply the city of Rome with water. It has been estimated that while Rome's population was about 1,000,000, still the city was supplied with sufficient water from these aqueducts, and from other sources, to permit the use of from 30 to 100 gal. a day by each inhabitant. To dispose of this large amount of water after it had been used, immense sewers were constructed, many of which are still in use.

Rome developed the most extensive and luxurious system of public baths the world has ever known. The public baths of Diocletian alone accommodated 3200 bathers at a time; the baths of Caracalla, still more famous and luxurious, accommodated 1600 at once. These baths were not free, the usual fee being one quadran, the smallest of Roman coins, about the equivalent of one-fourth of a cent in our money. The bath was not taken by the Roman merely for the sake of health or cleanliness; it was regarded as a luxury and was often repeated many times each day. The bath was always taken by the Romans after exercising and before the principal meal, and it has been said that it was frequently taken also after the meal in order to stimulate an appetite whereby they might eat in a more gluttonous manner. Emperor Nero, who reigned during the 1st century, is said to have indulged in this practice. Historians often declare that the downfall of Rome was partly due to these indulgences which tended to

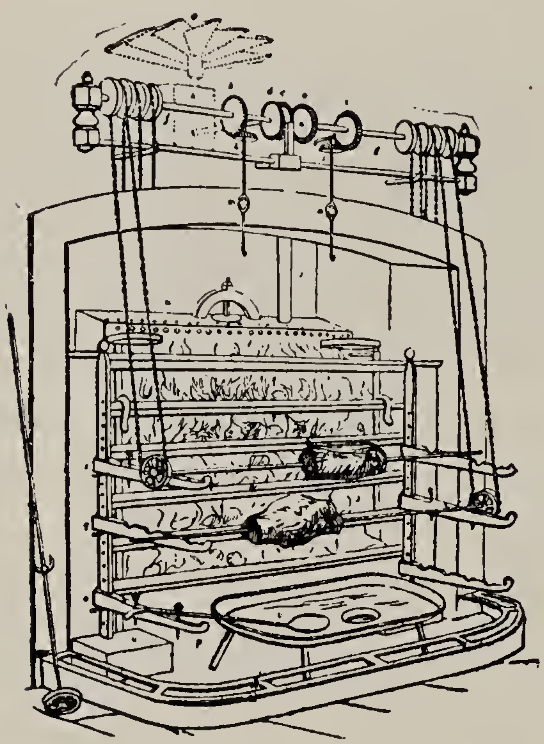


Fig. 256.—The 18th century hot water system.

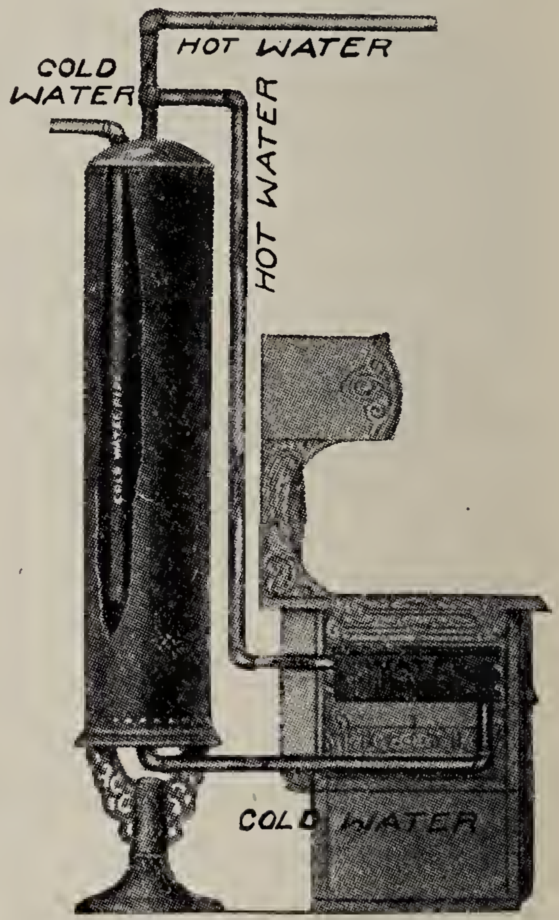


Fig. 257.—The water front and its connections with the boiler.

weaken the physical strength and vitality of the people. Rome was repeatedly invaded and plundered by the fierce barbarians from the north and east for two centuries till the empire finally came to an end in 476 A. D. During this period nearly all the works of art, the bronzes, precious marbles, and nearly every other evidence of civilization which had been accumulated during centuries were destroyed. The famous aqueducts and baths were largely destroyed along with the rest.

505. Hot Water Systems of the 18th Century.—After the destruction of Rome, many centuries passed before man again paid much attention to the development of the art of plumbing. In time, however, man again began to think of improving his conditions for comfortable living. The reproduction of an old woodcut (Fig. 256), shows the method of heating water in the most fashionable hotels of London in the 18th century. The water was pumped by hand into an attic tank. By means of an iron pipe it was conveyed down again into the bottom of the wrought-iron, riveted boiler at the fireplace. Here it became heated. A second iron pipe, shown in the illustration, extended from the top of the boiler to the guests' rooms. The weight of the column of cold water forced the heated water up to the guests' room whenever needed. Thus to be able to have hot water in one's room was considered to be a great luxury (Art. 138).

506. Hot Water System in the Modern Residence.—Today no modern residence is complete without a supply of hot water. In Fig. 256 it will be seen that one side of the boiler was heated directly by the fire. In the modern residence, however, the water is heated by circulating through a WATER-BACK or WATER-FRONT in the kitchen range, or a HEATING-COIL in the furnace, or by circulating through a special heater supplied for this particular purpose.

When the heater forms the front plate of the firebox it is called a WATER-FRONT; when it forms the back plate of the firebox it is called a WATER-BACK. Figures 243 and 249 also illustrate the usual manner of connecting the boiler with the heater. The arrows in Figs. 243 and 257 show the direction of flow of water. Explain why the water circulates as it does. What effect does heating water have upon its volume? What is the effect upon its density (Ex. 11)? What is the cause of convection currents (Art. 115)? The circulation of water through the heater is just as truly due to convection as the circulation of air through a furnace and the furnace pipes. Why is it best that the cold water supply pipe should extend nearly to the bottom of the boiler? In which portion of the boiler is the water the hotter, the bottom or the top? Why?

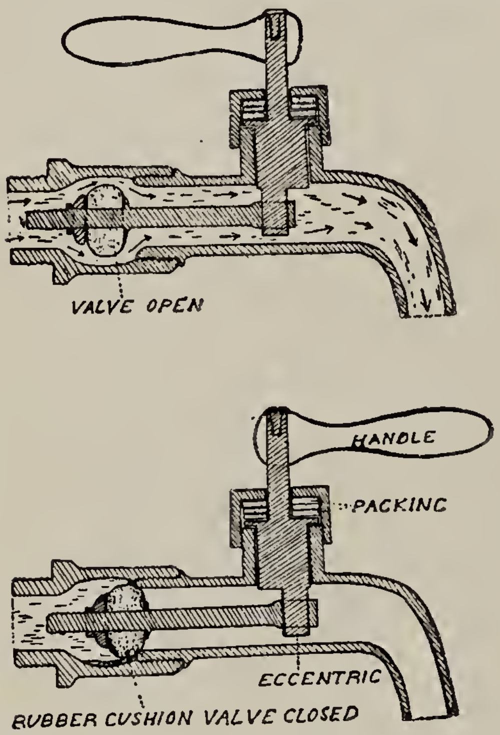


Fig. 258.—The Fuller bibb.

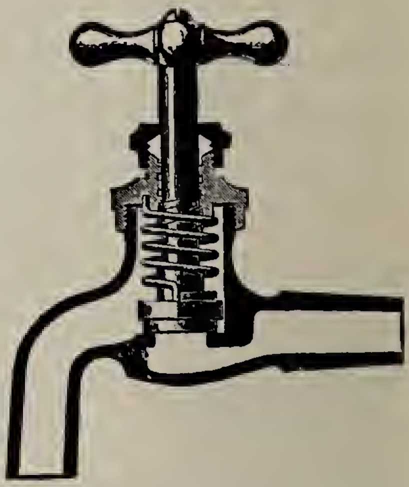


Fig. 259.—The self-closing compression bibb.

507. The Faucet or Bibb.—There are many different styles of FAUCETS, or BIBBS, as the plumber calls them. The FULLER FAUCET is a common type (Fig. 258). The figures show its construction and how it works. After being used for some time, especially if used on a hot water system, the rubber ball is likely to become softened and expanded, thus interfering with the flow of the water. New balls are easily inserted by anyone handy with tools. Most types of faucets occasionally need slight repair.

Faucets used in hotels, public places, and especially in schoolhouses, are often of the SELF-CLOSING type (Fig. 259). This is a modified form of the common COMPRESSION FAUCET. As is the case with any compression faucet, a right-handed tread on the post lifts the valve from its seat when the handle it turned counter-clockwise. But in this faucet a stiff spiral spring surrounding the post is thereby compressed. As soon as the pressure upon the handle is removed, the spring forces the valve down again upon its seat. What is the advantage of a self-closing faucet?

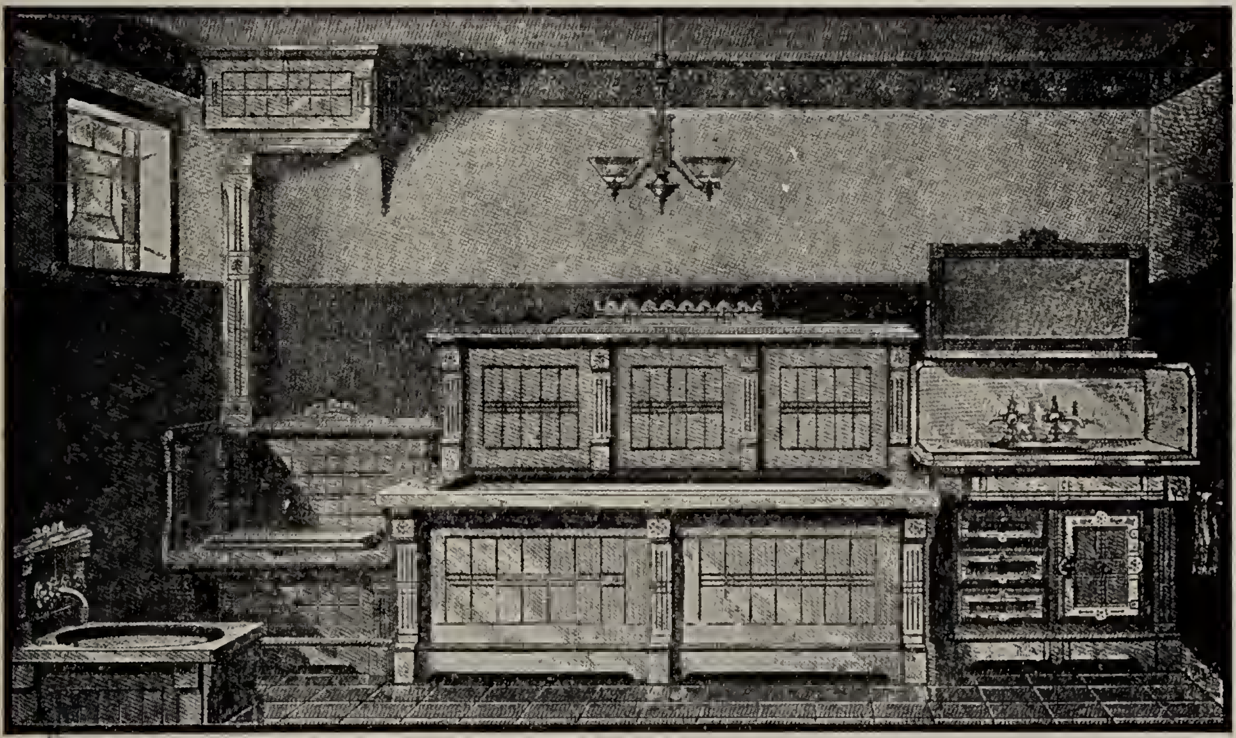


FIG. 260.—An expensively furnished bathroom in 1875.

Exercise 79.—A Study of Faucets

Secure from a plumbing house as many types of faucets as possible and study each carefully, noting its construction and how it is operated. Make a sketch of each and write a brief description of it telling how it works.

508. Importance of Good and Sanitary Plumbing.—No portion of a modern residence needs to receive more careful attention than the plumbing. Faulty or cheaply constructed plumbing is likely to prove both dangerous to health and, in the end, very expensive because no other kind of repair work is more expensive than repair of plumbing. In fact, good, safe plumbing is considered so important that the laws of most states and cities require that all plumbing work be done by licensed plumbers who have passed examinations intended to test their knowledge of sanitary plumbing. These laws require that all plumbing shall be constructed in a sanitary manner; in many cases they state exactly the way in which the plumbing shall be constructed.

Fig. 261.—A modern sanitary bathroom.

509. Sanitary Fixtures.—Such fixtures as bath tubs, sinks, lavatories, wash tubs or laundry trays, and closets have been greatly improved within very recent years. Only 30 or 40 years ago the fixtures used in the most expensively furnished residences were very unsanitary as well as very expensive as compared with those used today. Figure 260 shows an expensively furnished bathroom of about 1875. It was thought desirable in those days to conceal all piping and other metal work within elaborately carved woodwork. In those days such fixtures were not made of single, water-tight pieces as they are today. The result was that more or less moisture was certain to collect within the wooden cabinetwork surrounding the fixtures. Such spaces were dark and moist, ideal places for the growth and development of microörganisms. A glance at the cut shows the utter impossibility of keeping such a bathroom clean and in a sanitary condition.

The fixtures used in modern plumbing are strikingly different from those used a few years ago. Figure 261 shows the equipment of a modern bathroom. Notice (1) that all these fixtures are of one-piece construction, (2) that they are of solid porcelain or enameled iron, (3) that they are so raised from the floor that the space beneath is light, airy, and easily cleaned, (4) that all piping is exposed so that possible leaks are easily discovered. Carefully compare the fixtures and plumbing of this room with those shown in Fig. 260. What advantages do you see in their use?

510. The Drains.—The drains in any building are of the greatest importance, so far as sanitation is concerned. They must be so constructed as quickly to dispose of all waste matter. They must also be air-tight within the building. We have seen that all organic matter is decomposed by microörganisms (Art. 305). These microörganisms attack and decompose the waste matter in the drains. During the process of decomposition this waste matter often gives off large amounts of gases. Many of these gases have offensive odors and they are generally regarded as being very unhealthful. Some of these gases while nearly without odor are just as unhealthful. The drains must be so constructed as to prevent the escape of these gases into the building.

To insure air-tight construction all drains within the building must be of metal. The larger and straighter pipes are generally of iron with all joints closed by means of calking with oakum and lead; the smaller and bent pipes are often of lead with all joints wiped, *i.e.*, soldered.

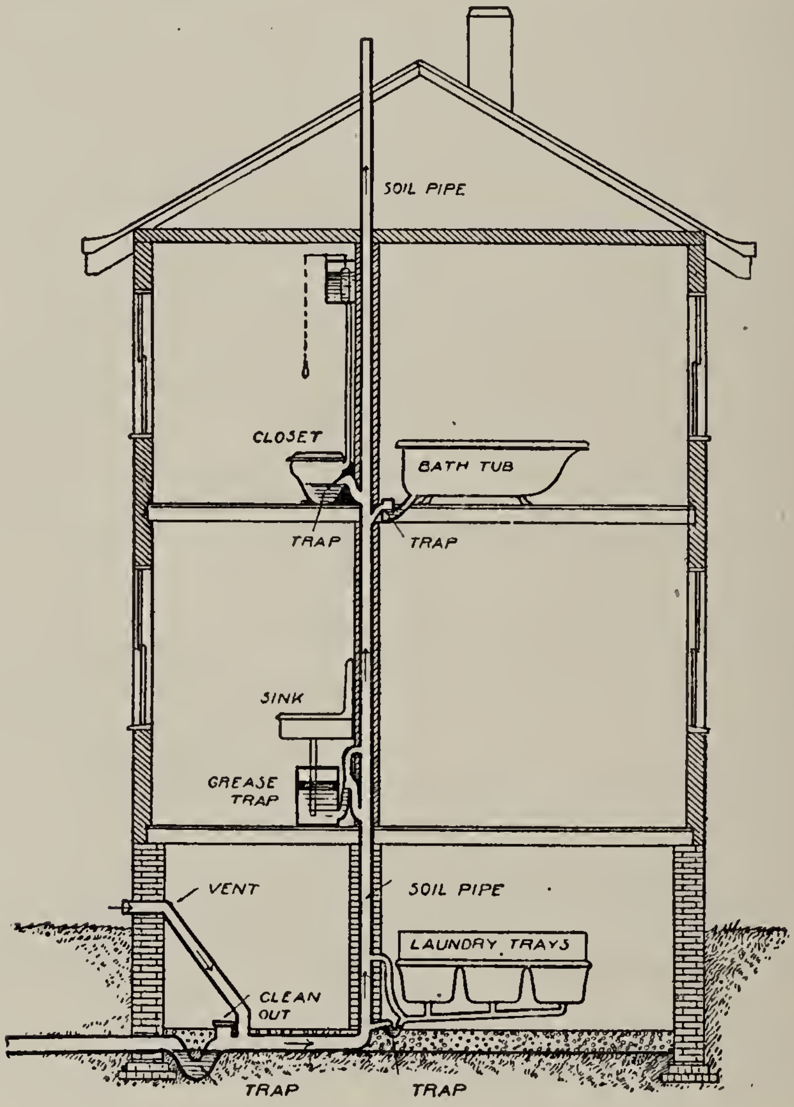


FIG. 262.—Plumbing in a residence.

511. Venting the Drains.—The main drain pipe should be thoroughly ventilated, *i.e.*, provision should be made whereby a current of fresh air passes constantly through the drain pipe and out through the SOIL PIPE (Fig. 262). The air and gases within the drain and soil pipe are nearly certain to be warmer and less dense than outside air. Explain clearly the circulation of air through the drain pipe, and its cause.

512. The Trap.—Every opening into the drain, whether it be from sink, lavatory, bath, or closet should be sealed by means of a trap. Most traps consist of a sharp upward bend in the drain pipe just after it leaves the fixture. The water settles into this bend and seals the outlet. Point out the traps in the illustrations.

Exercise 80.—A Study of Traps

Examine several fixtures in the schoolhouse or residence and study carefully the traps. Notice the provision which is made for removing obstacles from the bottom of the trap. Such openings are called CLEANOUTS.

513. Siphoning of Traps.—When a large flow of water passes though the trap, it sometimes happens that the water completely fills the drain pipe beyond the trap and causes all the water to pass over the upward bend, thus leaving the trap unsealed. When this happens, the trap is said to have been SIPHONED OUT. To prevent siphoning, an air vent is usually connected at the highest point of the trap, the other end of the vent pipe opening either into the soil pipe some distance above or opening into the air above the roof (see Fig. 262).

Exercise 81.—A Study of the Siphon

Place one end of a small clean rubber tube into a vessel of water and hold beneath the surface of the water. Place the other end between the lips and suck out the air (see Art. 284). When the tube is filled with water, close the end of the tube near your lips by pressing between the thumb and finger. Now lower this end to a point lower than the level of the water in the vessel. Remove the pressure from the tube. Does the water flow through the tube? If not, try refilling the tube. Now carefully raise the open end of the tube, noting the effect upon the rate of flow of water. Does the water continue to flow after the free end of the tube has been raised above the level of the surface of water? Such a piece of apparatus is called a SIPHON; the water is said to have been removed from the vessel by SIPHONING.

514. Explanation of the Siphon.—In the experiment, the water in the long arm of the siphon fell through the tube. In so doing it tended to produce a vacuum in the upper portion, the bend, of the tube. Air pressure upon the surface of the water in the vessel forced the water up into the vacuum. This water then fell and more water was forced up into the bend. Thus the action continues till the level of the water falls below the open end of the tube in the vessel. How does the air vent provided in plumbing, then, prevent siphoning?

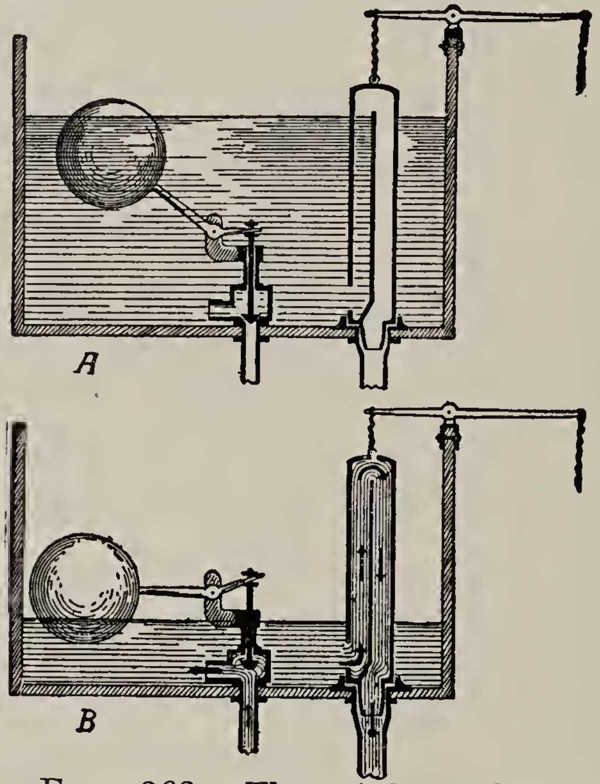


Fig. 263.—The siphon flushing tank. *A*. When not flowing; *B*. When flowing.

If a hole were made in the rubber tubing used in Ex. 81 at the top of the bend, would it destroy its siphoning action?

515. The Siphon Flushing Tank.—The principle of the siphon is utilized in the ordinary flushing tank used in connection with water closets. Figure 263 shows the construction of such a flushing tank. The trap consists of a hollow cast-iron cylinder about 3 in. in diameter and 12 in. in length. A vertical partition extending nearly the entire length of the trap divides its interior into two chambers, or rather into two passages. One side of the trap, near its base, is so cut away as to produce an opening into one of the two passages at that point; the other passage opens downward directly into the discharge pipe. The lower end of the trap fits tightly upon a cushion so as to seal the passage into the discharge pipe when the trap is properly seated. When raised an inch or two, the trap permits the water to rush directly into the discharge pipe. If the trap be again dropped upon its seat, the discharge pipe, now filled with water, together with the two arms, or passages of the trap, becomes a perfect siphon. The discharge pipe and the right-hand passage in the trap form the long arm of the siphon and the left-hand passage forms the short arm. From our study of the siphon, it is evident that the water will continue to flow through the siphon thus formed till the water level sinks to the level of the opening in the side of the trap, air there enters and destroys the siphoning action. The tank then again fills to the height permitted by the AUTOMATIC FLOAT VALVE.

516. The Float Valve or Automatic Cut-off.—In many cases other than the flushing tank it is desirable to have the height of water in tanks automatically controlled. In such cases a float, as shown in Fig. 263, is frequently used to operate the cut-off valve. The float is a light, hollow, brass or copper sphere. When the water is lowered, the float falls, thus permitting the valve to open; as the water rises again. the float is forced upward until it closes the valve.

V. DISPOSAL OF SEWAGE

517. Disposal of City Sewage.—In cities having sewer systems the *final* disposal of sewage gives the individual citizen little or no worry. He merely connects his drain in proper manner with the city sewer; the city is responsible for the final disposal of the sewage. In many cases, city sewage is merely conveyed to, and emptied into, the nearest stream, always polluting it more or less, depending upon the amount and kind of sewage and the size of the stream. Our little friends, the ever-present bacteria, however, at once begin their work of decomposing the organic matter in the sewage and, under favorable conditions and with sufficient dilution, most of the polluting matter is soon destroyed and the stream again becomes reasonably clean and pure before its waters have proceeded far down stream. Sanitarians regard this as a primitive and unscientific method of disposing of sewage. This method of disposing of city sewage is now generally being abandoned and more scientific methods adopted. Most states in the east and central west now con-

Fig. 264.—Pollution of ground water: sewage discharging into sinkholes.

trol stream pollution, through Boards of Health, proper disposal of sewage being required to suit conditions.

518. Disposal of Sewage from Isolated Residences.—In the case of isolated buildings, such as farmhouses, country residences, and institutions, out of reach of city sewer systems, provision must be made for the *final* disposition of sewage. In solving this problem, the laws and principles of science, as far as they are understood, must be observed at every step. Before this problem had been carefully studied many serious mistakes were made.

519. The Leaching Cesspool.—Formerly the sewage from an isolated residence was often conveyed into a cesspool (see Fig. 244). Such a cesspool was merely a small, brick-walled, well-like receptacle a few feet in depth dug in the ground. No attempt was made to construct the cesspool water-tight. It was intended that the liquid portions of the sewage should soak, or LEACH, out into the surrounding soil. This, of course, polluted the soil, and, since the water table frequently rises to a point near the surface of the soil, the ground-water became contaminated. In fact, in cases where much water was sent into the cesspool, the sewage constantly found its way down into the ground-water, thus endangering all nearby wells (Fig. 264). If this same sewage had been spread thinly over the surface of the soil, or better still had been covered by a few inches of soil, it would quickly have been decomposed by bacteria and rendered harmless. Such bacteria are abundant only near the surface of the soil; at the depth of the bottom of a cesspool they are not numerous, nor can they become numerous, therefore, the sewage which leached from the old-style cesspool into the ground-water was practically unaffected by the decomposing and purifying action of bacteria. Sanitary engineers, and students of sanitation generally, now agree that the cesspool is an unsanitary method of disposing of sewage. They are also agreed that one of the most feasible and sanitary methods of disposing of sewage in case of isolated residences

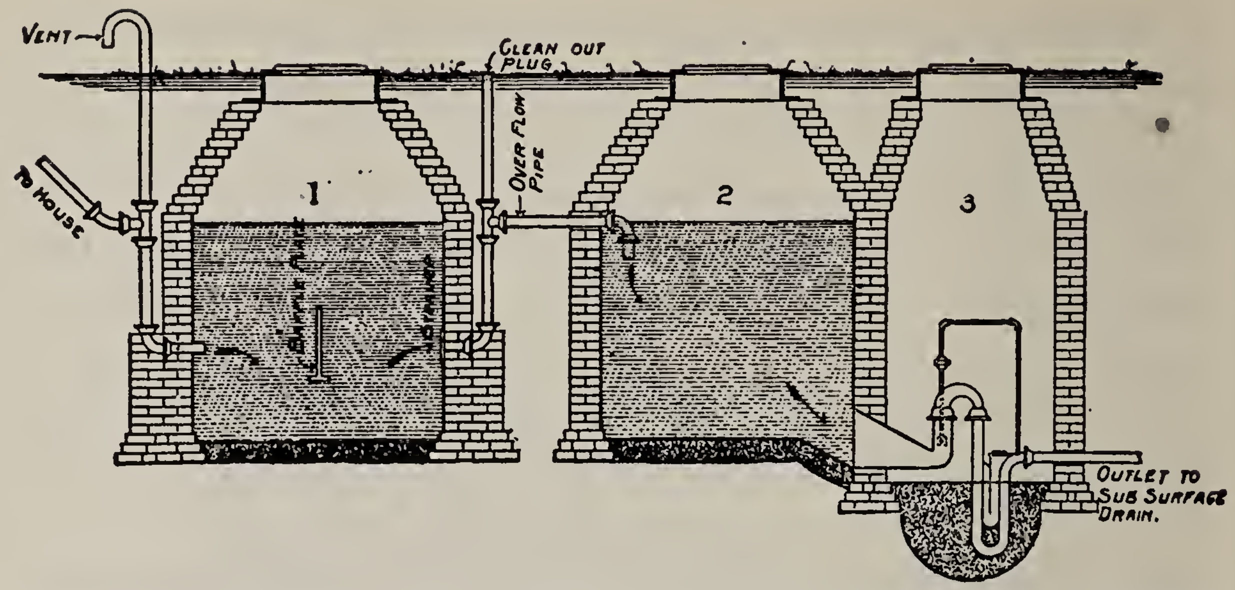


FIG. 265.—A septic tank. (From *Practical Up-To-Date Plumbing*, Clow.)

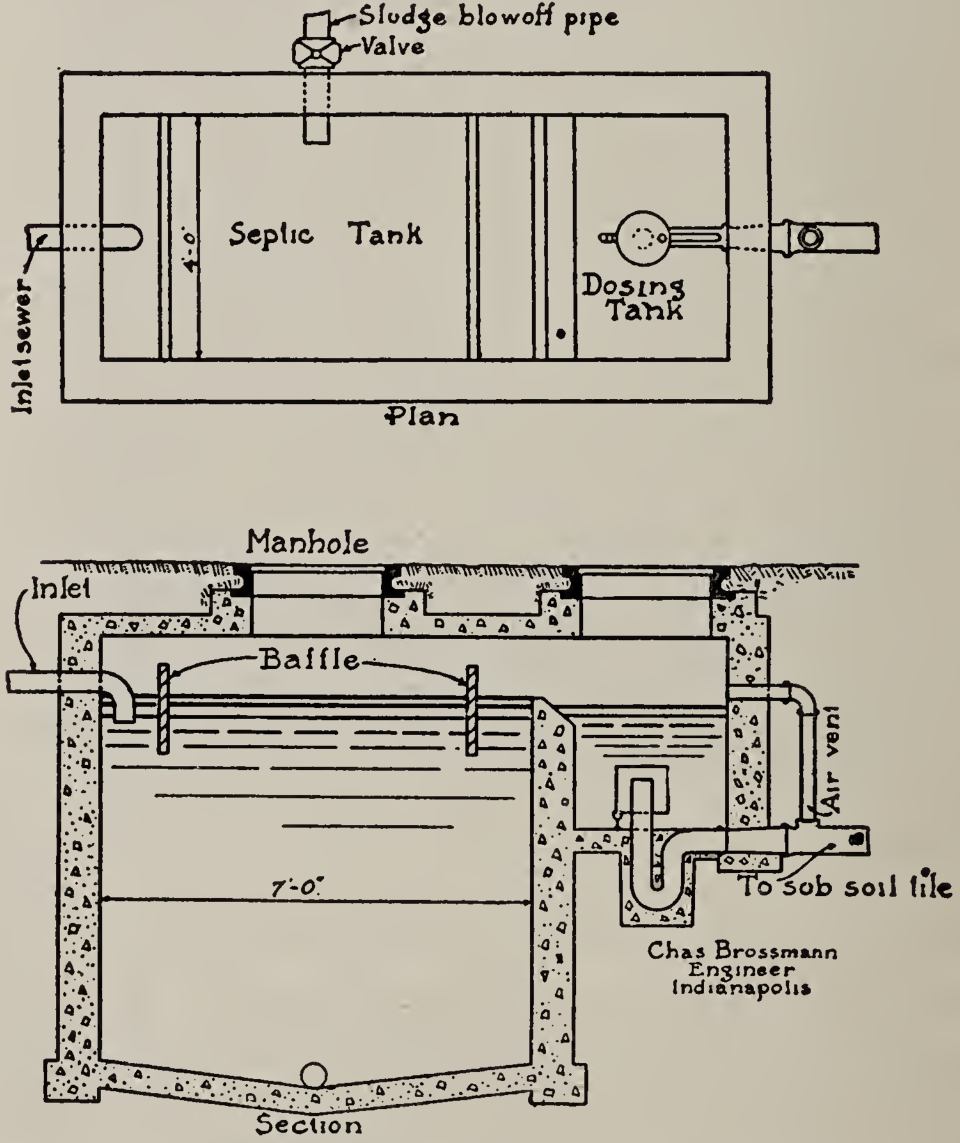


FIG. 266.—Plan and section of septic tank suitable for medium sized residences, two compartments. (Courtesy of Chas. Brossman.)

is by using some type of SEPTIC TANK or DISPOSAL TANK and SUBSURFACE DRAINS.

520. The Septic Tank.—The modern SEPTIC TANK consists of two, and often three, compartments (Figs. 265 and 266). Each of these compartments is cemented so as to be water-tight. The sewage from the house enters compartment No. 1. In this compartment ANAEROBIC BACTERIA (Art. 318, page 287) attack the sewage and by decomposing it soon cause the solid material to dissolve, or, as we say, to LIQUEFY. When working properly, this process requires but a short time to liquefy most solid material in sewage. Even paper and cloth are liquefied within a few weeks or months. The liquefying action of these bacteria sets free considerable quantities of carbon dioxid, ammonia, and other gases which escape around the cover of the tank; it also breaks all fats into small particles, which rise to the surface of the liquid and there form a tough, leathery scum which completely excludes the air, thus producing ideal conditions for the existence of anaerobic bacteria. To prevent the still undissolved solids from being stirred up by the in-rush of fresh sewage a partition, or BAFFLE PLATE, is placed across the tank in front of the opening of the house drain.

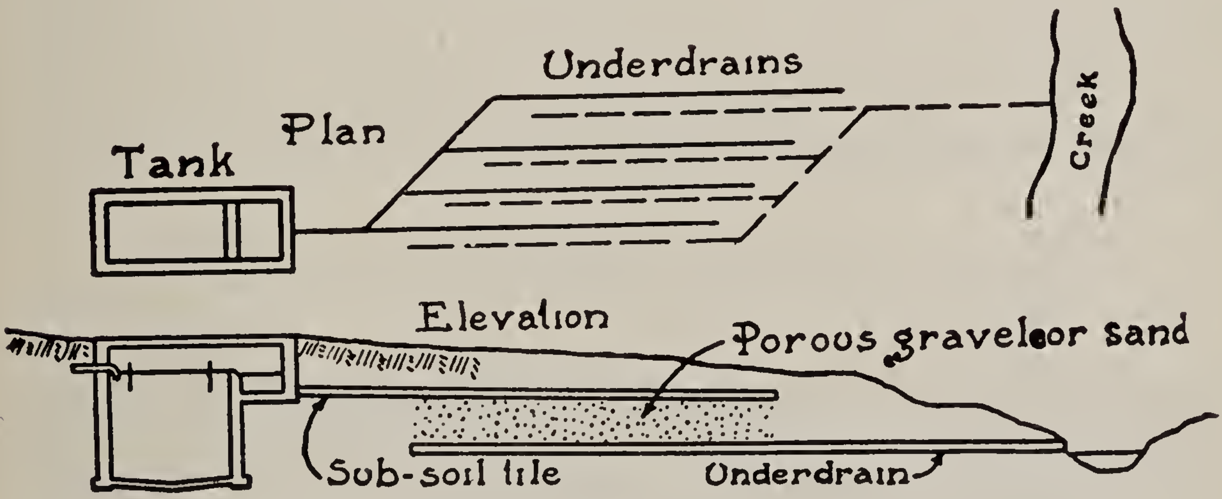
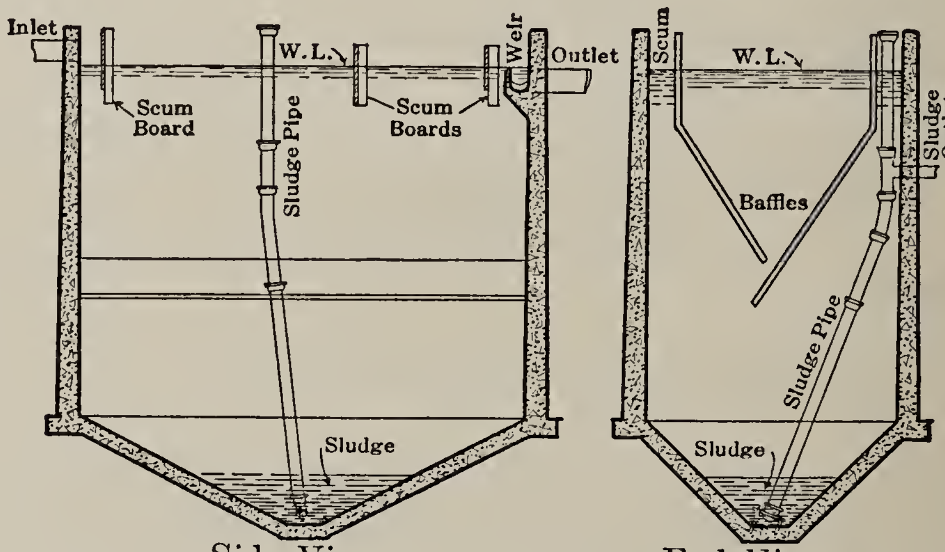


FIG. 267.—Plan and section showing septic tank and subsoil filter. (Courtesy of Chas. Brossman.)

From compartment 1 (Fig. 265) the liquid sewage passes into compartment 2. In this compartment the bacterial action still continues, but the chief purpose of the compartment is to serve as a storage tank. It is called the DOSING TANK. The sewage in this compartment should be fairly clear and nearly free from sediment, but still contains large amounts of undecomposed organic matter. The sewage accumulates in this compartment till it is nearly full and is then drawn off through the INTERMITTENT SIPHON in compartment 3 into the SUBSURFACE DRAINS (Fig 267). Compartment 3 is sometimes omitted and the siphon is placed in compartment 2, the dosing tank, where it is submerged by the liquid (Fig. 266). It is more convenient, however, to set the siphon in a separate compartment, since it is necessary occasionally to examine the siphon to see that it is working properly.

521. The Imhoff Septic Tank.—A septic tank of somewhat more expensive construction is now generally used in disposing of sewage from cities and institutions where considerable quantities must be taken care of. In the IMHOFF TYPE, the septic tank is really composed of two compartments, one suspended within the other (Figs. 268-9-270). The inner, suspended compartment is the SETTLING CHAMBER; the lower compartment is the SLUDGE CHAMBER. The two sides of the settling chamber do not quite meet at the bottom (Sec.



Side View. End View.

FIG. 268.—Imhoff Tank.

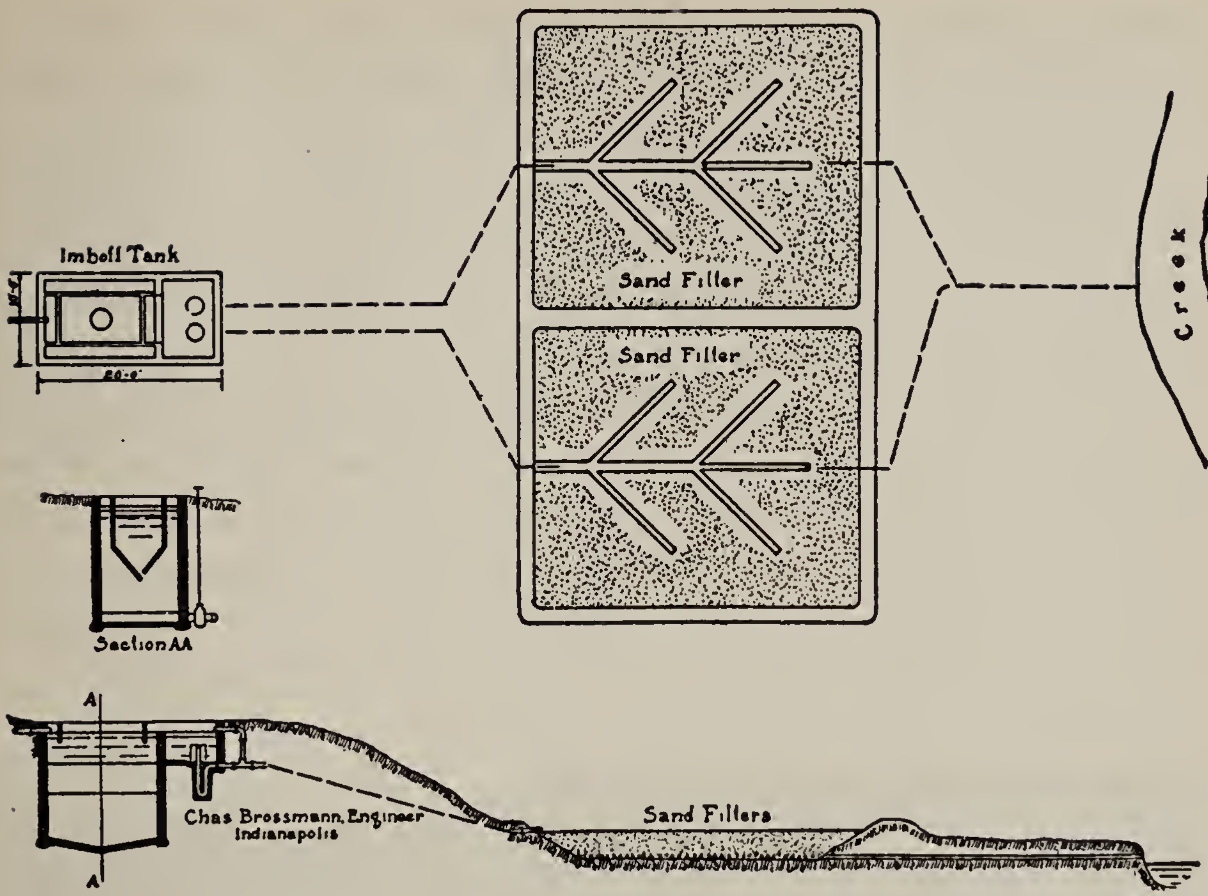


FIG. 269.—Imhoff type of tank and sand filter for small institutions. (Indianapolis Country Club.) (Courtesy of Chas. Brossman.)

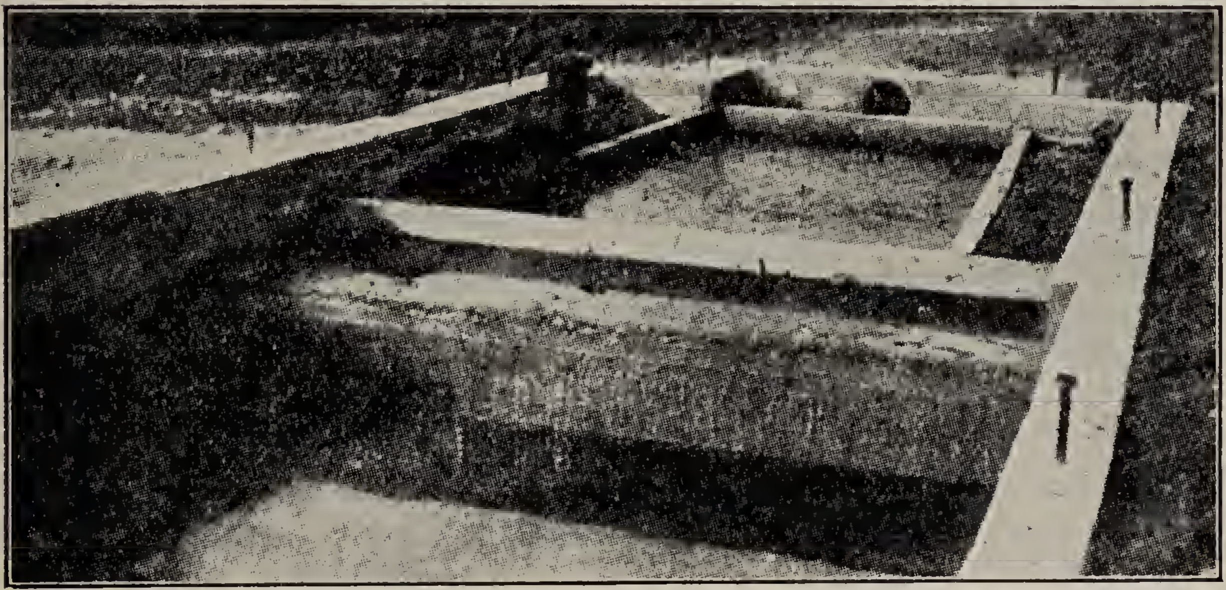


FIG. 270.—Imhoff tank showing sludge formation at sides. Settling chamber in center. Dosing chamber in foreground. Sewer inlet shown at far end. (Julietta, Ind) (Courtesy of Chas. Brossman.)

AA, Fig. 269). As the sewage passes through this settling chamber, the solid matter settles through this opening into the sludge chamber below. It is chiefly in the sludge chamber that LIQUEFACTION or DIGESTION takes place as a result of the action of the anaerobic bacteria. This type of septic tank is considered superior because the contents of the sludge chamber are but slightly disturbed by, or mixed with, the constant in-flow of fresh sewage. The bacterial action is, therefore, more certain and perfect.

522. Sludge and Its Disposal.—Even when operating at its best, considerable insoluble material accumulates in the bottom of a septic tank. This accumulation is known as SLUDGE. Occasionally the sludge must be removed from a septic tank. It is claimed that the Imhoff type of septic tank produces a sludge more solid and more readily handled than that produced by tanks of the type shown in Figs. 265 and 266. Sludge from septic tanks is valuable as fertilizer.

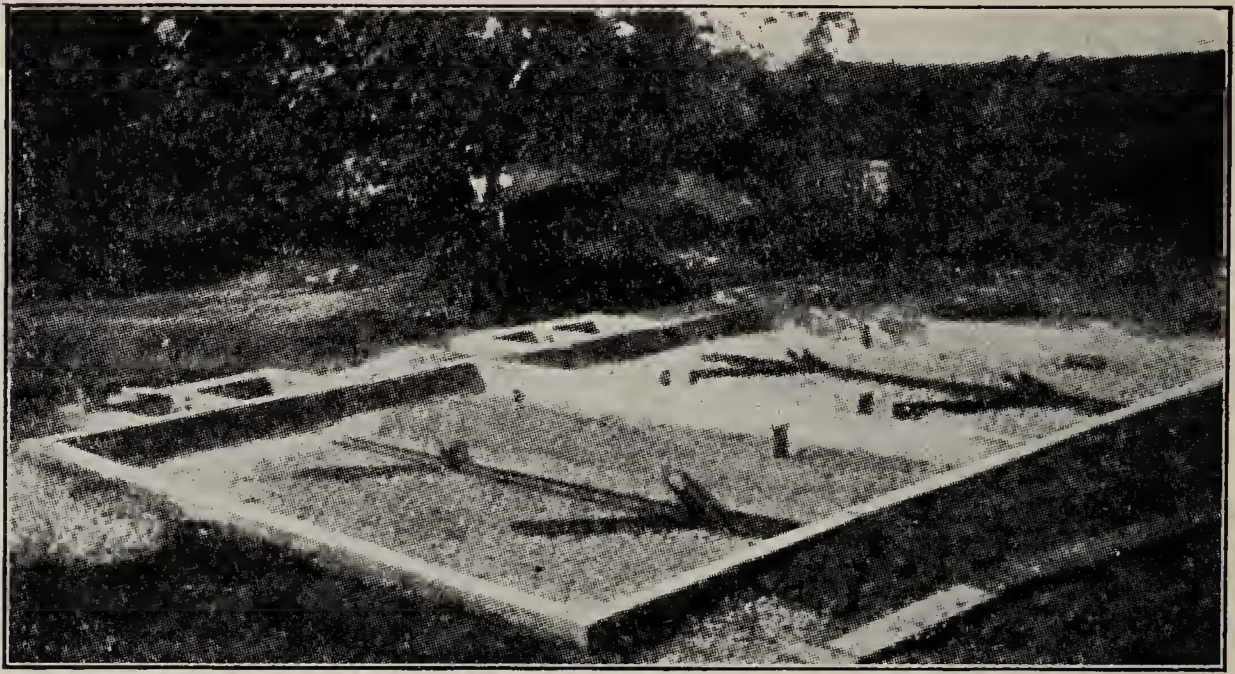


FIG. 271.—Contact filters of stone. (Julietta, Ind.) Sewage is discharged from tank, Fig. 270, to these beds. (Courtesy of Chas. Brossman.)

523. The Complete Oxidation of the Sewage.—In the septic tank only partial oxidation of the organic matter in the sewage ever takes place. While the outflowing sewage from the septic tank should be fairly clear and free from sediment, it still contains large amounts of undecomposed organic matter in solution. The methods followed and apparatus used to accomplish the final and complete oxidation of the sewage depends upon surrounding conditions and the amount of sewage to be handled. If small amounts of sewage only are to be disposed of, and the character of the soil permits, the final oxidation may be accomplished by means of SUBSOIL DRAINS and UNDERDRAINS only (Fig. 267). If large amounts of sewage are to be disposed of, or if the surrounding soil is not reasonably open, porous soil, CONTACT FILTER BEDS or SPRINKLING FILTER BEDS are generally provided (Figs. 269, 271, 272 and 273). In either case the same general principles are applied; namely, *suitable conditions are provided whereby aerobic bacteria may work upon the sewage, completing its oxidation to mineral matter.*

524. The Subsurface Drain.—After passing through the siphon the sewage enters the SUBSURFACE DRAIN (see Fig. 267). This is merely a line of drain tile laid a few inches beneath the surface of the soil. The septic tank must evidently be constructed on higher land than the plot used for the drainage. All joints between the tile are left slightly open, from ¼ to ½ in. To prevent dirt from entering through these open joints, a piece of a larger tile is laid over each joint. The liquid sewage readily passes out into the soil through these open joints. Here it is attacked by AEROBIC BACTERIA (Art 318) and is completely decomposed, *i.e.,* it is completely mineralized.

Since aerobic bacteria live and multiply only in the presence of an abundance of air, they are to be found in large numbers only near the surface of well-drained soil. It is because the aerobic bacteria can not survive without an abundant supply of air that the INTERMITTENT SIPHON is used to empty the septic tank. If the discharge from the tank were constant and steady, the ground surrounding the upper end of the drain would constantly be water-soaked, thus preventing air from entering the soil, and therefore preventing the sewage from being acted upon by aerobic bacteria By using the siphon, the contents of the tank are completely discharged into the drain once in from 6 to 24 hours, and the volume discharged, at one time, is sufficient to fill the drain its entire length. The area covered by the drain is intended to be great enough to insure the complete oxidation and mineralization of the sewage of one discharge before the next discharge occurs.

525. The Contact Filter Bed.—When the amount of sewage to be handled is too great, or the character of the soil is such as not to permit of the successful use of the subsoil drain, CONTACT BEDS or SPRINKLING FILTER BEDS are provided (Figs. 269 to 273). Contact beds are merely beds of gravel. broken stone, or coarse sand. The sewage is run out from the dosing tank upon the surface of these beds. As it soaks down through the sand or gravel, the organic matter adheres to, or is deposited upon, the surface of the rock particles, where it is attacked and destroyed by aerobic bacteria. The sewage is retained in the contact bed for a fixed period of time and then is drawn off, thus permitting air to enter all spaces between the rock particles, a necessary condition for the growth and multiplication of aerobic bacteria. The water drawn off

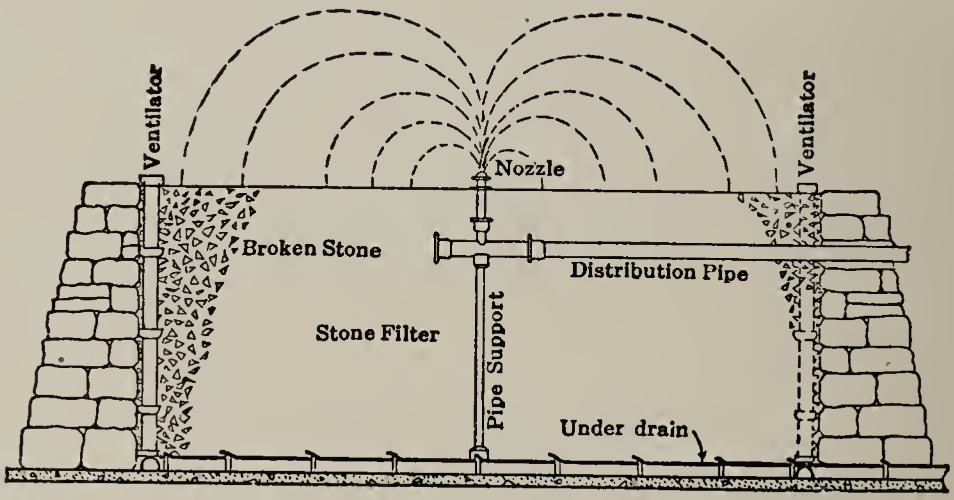


FIG. 272.—Diagram of a Sprinkling Filter.

from such a bed should be practically free from organic or other injurious matter.

526. The Sprinkling Filter Bed.—A more effective and now generally used filter bed, is the SPRINKLING FILTER BED (Figs. 272 and 273). In any filter bed the growth and rapid multiplication of aerobic bacteria depends upon three factors: first, plenty of suitable food; second, plenty of oxygen; third, a moderate temperature. In the contact bed the first and third conditions are easily obtained. The second condition, that of supplying the bacteria with plenty of oxygen is not so easily met.

The sprinkling filter bed is now in general use because it provides for furnishing the sewage with a larger amount of oxygen. Instead of merely running the sewage over the bed and allowing it to soak into the bed, the sewage is under some 8 or 10 feet of "head" *i.e.*, the sewage in the dosing tank is 8 or 10 ft. above the level of the sprinkler, and is allowed to pass through sprinklers which throws the sewage into the air in a fine spray just as a garden sprinkler throws a fine

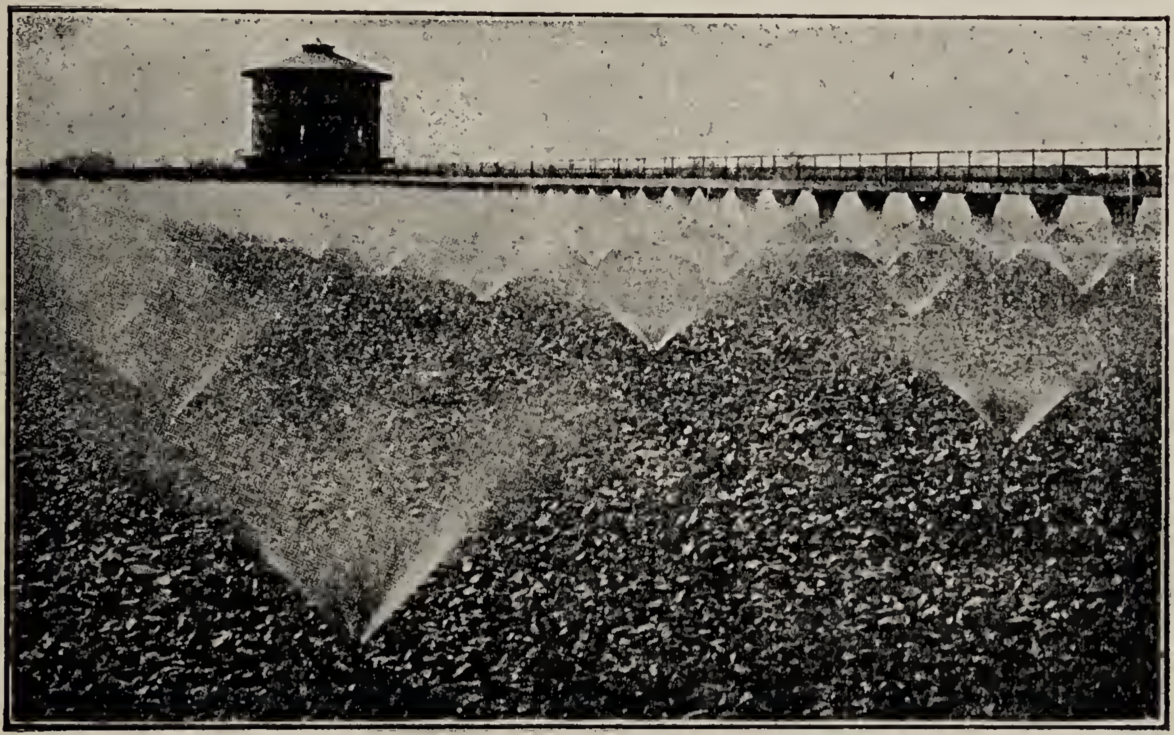


FIG. 273.—Sprinkling filter in operation at Columbus, Ohio. (Courtesy of John Wiley & Sons.)

spray of water upon the lawn. This fine spray of sewage absorbs oxygen from the air until it is saturated.

527. The Activated Sludge Process.—The ACTIVATED SLUDGE PROCESS is a method of sewage disposal which is just coming into use if necessary. It is a still more rapid process of changing the organic matter in sewage to mineral matter through the action of aerobic bacteria.

In the activated sludge process much less land is required for the plant. The original cost of the plant is less than it is when the Imhoff tank and either a contact filter or a sprinkling filter is used. It costs more to operate the plant, however.

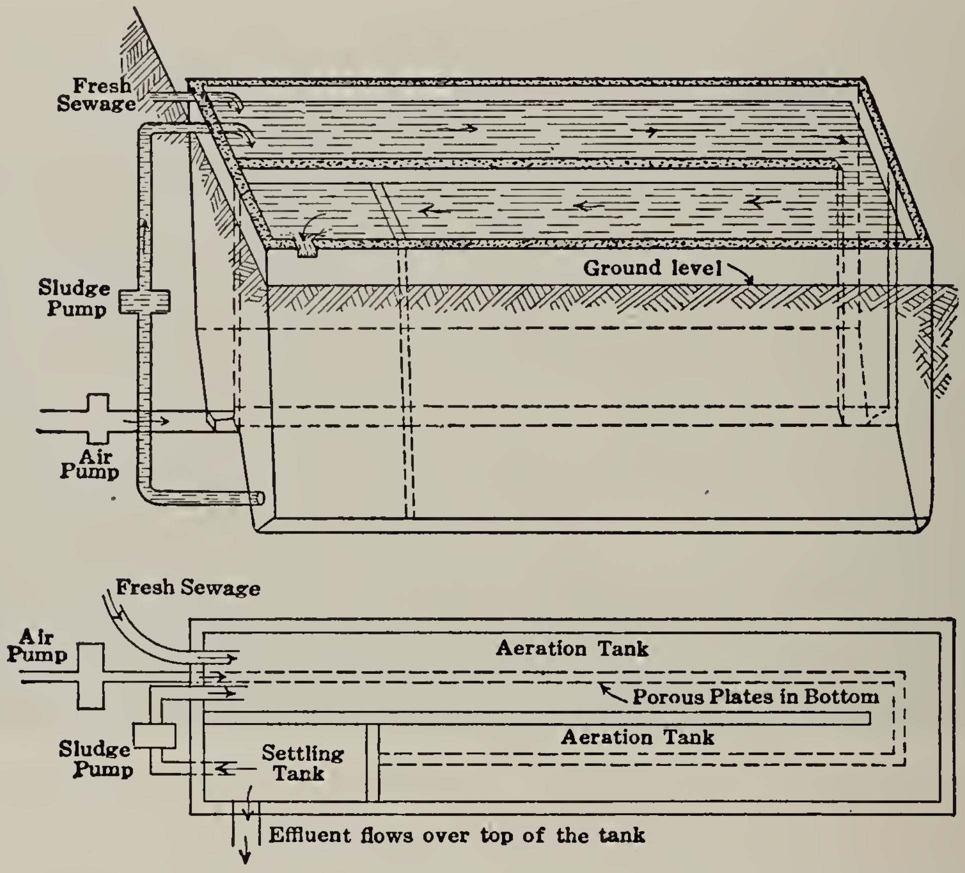


FIG. 274.—Diagram of an Activated Sludge Tank. Upper portion is cornering view in perspective; lower portion is the top plan.

The activated sludge process is easily understood. The equipment consists of a concrete tank, often a hundred feet or more in length and perhaps 10 or 12 feet wide and about 8 or 10 feet deep. In the bottom of this long tank porous plates are placed above a passage through which air is pumped.

The air passes up through the porous plates in very numerous and small bubbles which rise through the sewage. The sewage, as it passes along through the tank appears to be boiling violently, on account of the bubbles of air coming up through it. Thus, we see, plenty of oxygen is furnished the bacteria in the sewage.

Fresh sewage, however, does not contain many bacteria. The name of this process, "activated sludge process," comes from the fact that about ⅓ of the thick, chocolate-colored sludge which has settled at the bottom of the tank at the end farthest from end where the fresh sewage enters is pumped over into the first end of the tank and there mixed with the fresh sewage. This sludge fairly swarms with aerobic bacteria. The purpose of pumping the sludge into the first end of the tank with the fresh sewage is to furnish plenty of bacteria to consume the organic matter which is in the fresh sewage, Fig. 274.

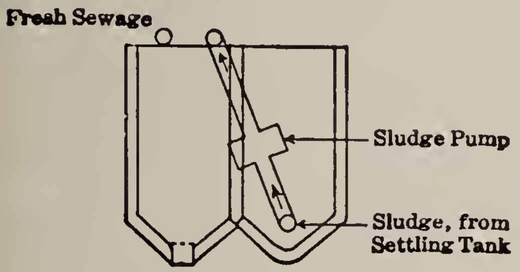


FIG. 274A.—View of the left end of the activated sludge tank.

528. Summary of Sewage Disposal.—The following points should be learned and remembered:

First, Mother Nature has provided that bacteria shall live upon the dead bodies of plant and animal life, and upon the waste organic materials which are produced by animals and plants while still living. The dead bodies of plants and animals and waste materials which are produced by plants and animals while living are the natural food materials for a vast number of bacteria.

Second, There are many different kinds of bacteria which thus live upon the waste materials of plant and animal life. Some of the forms of bacteria live and develop only in the absence of oxygen. These kinds are called ANAEROBIC BACTERIA. Most, if not all, offensive odors resulting from the "decay of organic matter" are produced by the activities of these anaerobic bacteria. Few, if any, offensive odors, are produced by the activities of AEROBIC BACTERIA.

Third, Generally the activities of anaerobic bacteria do not result in the complete changing of organic wastes into mineral matter which becomes food for plant life. Only a portion of such organic wastes are changed into mineral matter by anaerobic bacteria.

Fourth, If the wastes from plant and animal life are spread thinly upon the soil, or slightly covered by soil, aerobic bacteria quickly changes them into mineral matter, few, if any, offensive odors resulting.

If, however, the organic waste matter is found in large masses, such as the dead bodies of animals or large accumulations of other wastes, anaerobic bacteria first attacks the matter. The results are these: Some of the organic matter is decomposed into mineral matter but the principal effect is the breaking apart of the matter so that oxygen can enter and make it possible for aerobic bacteria to live and feed upon the waste material. While the anaerobic bacteria are working offensive odors are given off.

Fifth, Every successful attempt to dispose of sewage has been an application of these facts.

Sixth, The term "sewage" is applied to waste matter, much of which comes from animal and plant life, which is disposed of by being washed into underground sewers by means of water.

Seventh, All waste matter resulting from plant or animal life may be disposed of by the following methods:

(1) While comparatively dry it may be spread upon the surface of the soil or slightly covered.

(2) If a stream of water is available in which a sufficiently large amount of water is flowing, such wastes may be placed in the stream without greatly polluting it. Sewage run into such a stream is said to have been disposed of "BY DILUTION."

(3) If suitable soil in suitable areas is available, sewage may be disposed of by applying the sewage to the surface or

near the surface of the soil at suitable intervals, *i.e.*, at such intervals as will permit the aerobic bacteria to decompose each dose before the next dose is applied. Such a method is called "BROAD IRRIGATION BY SEWAGE."

(4) An Imhoff tank and contact filter bed may be used where little land is available or where the land is not suitable for broad irrigation.

(5) The sprinkling filter bed is regarded as more reliable and satisfactory than the contact filter bed and has generally replaced it. The oxygen supply is more reliable than in the contact bed.

(6) The activated sludge method of sewage disposal has lately come into use and is regarded by many sanitary engineers as the best method of sewage disposal. Theoretically it is the ideal method of sewage disposal because the fresh sewage is thoroughly seeded with aerobic bacteria and the mixture is thoroughly saturated with oxygen.

CHAPTER XI

MACHINES, WORK, AND ENERGY

I. MACHINERY IN THE HOME AND ON THE FARM

529. The Tools of the Early Colonist and Pioneer.—In early colonial days practically all work was done by hand. When machines were used they were of the simplest kind. This has always been the case with pioneers. When the colonist or pioneer wished to build a new home, he supplied himself with a rifle, a knife, and an ax, a hatchet, and a saw and went forth into the woods. With his rifle and knife he supplied himself with food. With his ax he felled the trees and constructed his log house. He made all his own furniture—his chairs, his table and his bedstead. He fashioned out of wood such other conveniences as he needed.

530. Agricultural Tools of the Colonist and Pioneer.—When the pioneer had "cleared" a small space around his cabin, he naturally wished to raise some grain and garden truck. At first, the land was generally very fertile and free from weeds; little cultivation was necessary. In the spring the seed was scratched into the soil. In the fall the crop was harvested by using such tools as the pioneer could make. The corn was shelled and the wheat threshed by hand. The corn and wheat were ground into meal and flour between stones.

Later, as the pioneer's efforts at agriculture became more varied and he had oxen to help him, he secured a cast-iron plow. He also secured a hand sickle and finally a cradle to aid him in harvesting his grain. He likewise made a flail for threshing it. As settlers became more numerous, grist mills were built upon the streams, and settlers from far and near carried their grain to these mills to be ground into meal and flour. Even then, their agricultural tools were so few and so poorly adapted to their needs that the farmer of today, were he obliged to use them, would feel helpless.

531. Household Tools of the Colonist and Pioneer.—The kitchen equipment and dishes of the pioneers were few indeed. A kettle or two, a few plates, and some knives and spoons constituted their cooking and serving equipment. But very early they found use for other household tools. It was impossible for them to buy clothing, therefore, they soon began to raise flax and wool in the northern colonies and cotton in the southern colonies and to make their own clothing. To do this they were obliged to make tools for carding, spinning, and weaving of ''homespun'' cloth. While these tools were crude and simple, they answered the purpose for which they were intended, and every member of the household became skilful in using them.

532. Pioneers were Skilful in the Use of Tools.—Although the colonists and pioneers had few tools to use, they were far more skilful in the use of such tools as they did have than are most of us to-day. There were no factories to manufacture the many articles they needed for their comfort, nor did they have money with which to buy them. We can, perhaps, appreciate the skill of the colonists in the use of tools when we realize that they not only sheared the sheep, cleaned, washed, picked, carded, spun, dyed, and wove the wool into cloth and made the cloth into clothing, but were also obliged to make practically all the utensils used in these processes.

533. The Coming of the Factory.—About the beginning of the 19th century (1800) improved machinery, driven by water power, began to be used in the making of cloth. It was soon found to be more economical to buy cloth made in the factory than to make it in the home. During the 19th century, cotton and woolen mills with power-driven machinery were developed. At the present time no one thinks of manufacturing cloth in the home. Today much of the cloth is made up into garments ready to wear before leaving the factory.

The 19th century was a period where there were few machines and labor-saving devices in the home. All this means that knowledge concerning machines and machinery largely disappeared from the home.

534. Knowledge of Machinery again Becoming Necessary in the Home.—While almost all the *primitive* industries have disappeared from the home, there have recently come into the home many new forms of machines and devices all of which make necessary some knowledge of applied science. Lighting systems of various kinds, heating devices, systems of water supply, plumbing, vacuum cleaners, sewing machines, washing machines, cream separators, and motors for the operating of machinery of various kinds—all these conveniences require knowledge of applied science. The housewife with no knowledge of the laws of science can not expect to handle successfully the conveniences of the modern home.

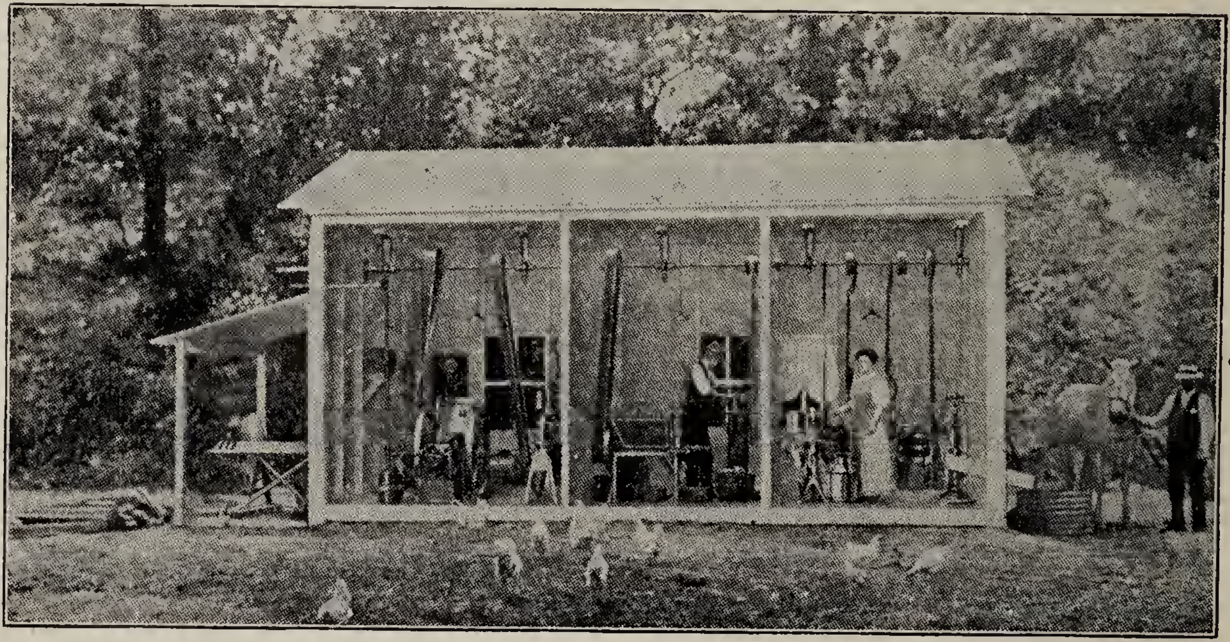


Fig. 275.—A farm power house.

535. Knowledge of Mechanics Necessary for the Farmer.—Today the farmer requires a knowledge of mechanics at every turn. Most of the work on the farm is now done by means of machinery. The farmer with no knowledge of the laws of mechanics can not operate intelligently his plows, cultivators, mowing machines, binders, seeders, or numerous other tools found upon every farm. Moreover, many farms are now supplied with a power house in which a gasoline engine furnishes the power which runs the pump, cream separator, churn, corn sheller, feed grinder, and possibly a dynamo for generating the current for electric lighting and a circular saw for sawing wood (Fig. 275). Many farmers now own automobiles, and these machines require a good knowledge of mechanics if they are to be handled with safety and economy. If all auto drivers were familiar with the laws of mechanics, many accidents would be avoided.

536. **This, an Age of Machinery.**—The farmer and the housewife need to learn a lesson from the factory and the well-organized industrial plant. There, one man often operates a machine which does the work formerly requiring the labor of 10, 100, or possibly 1000 men. Rapidly the farmer is learning to avail himself of the advantages of using machinery. As yet, the housewife has made too little use of machinery to aid her in her household duties. The cleaning of the house, washing and ironing, skimming of the milk and churning of the butter—these and many other processes are carried on by hand with little thought of using easily obtained labor-saving devices.

Make a list of the labor-saving machines for use on the farm and in the home.

II. SOME COMMON MACHINES

The Sewing Machine

537. **Earliest Sewing Machines.**—The first sewing machine of which there is authoritative record was invented by an Englishman, Thomas Saint, in 1790. It was not known that he made more than one machine. This machine, as well as others made during the following 50 years, was intended for embroidery and fancywork, not for practical purposes, such

as the making of garments or other useful articles. All of the earlier machines were run by hand and were awkward, clumsy affairs constructed chiefly of wood and having many serious defects. The sewing machine did not seriously affect American life until after the middle of the 19th century. About 1850 really practical machines were invented. Even these machines were crude compared with the machines of today (Fig. 276).

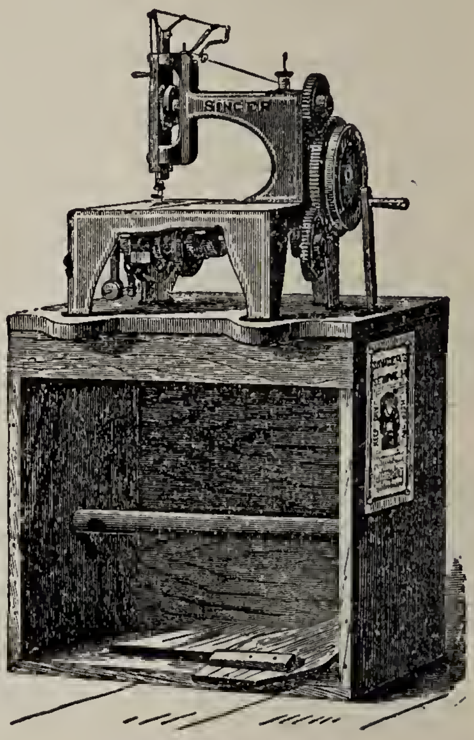


FIG. 276.—Sewing machine, 1850. The shipping box was used as a table for the machine.

538. Classes of Sewing Machines.—Sewing machines may be classified according to the kind of stitch they make. Although a great variety of stitches have been used at different times—some 75 in number—practically only three kinds of stitches are today in use. They are the LOCK STITCH, the CHAIN STITCH, and the BUTTONHOLE STITCH. The lock stitch is the most common and, for most purposes, the most satisfactory. Chain stitch machines, however, have advantages for certain purposes:

Exercise 82.—A Study of the Chain-stitch Seam and the Lock-stitch Seam

Secure samples of the chain-stitch seam and the lock-stitch seam, each sewed in loosely woven cloth cut on the bias. First, examine each seam to see which is more elastic, and second, note the ease with which each seam may be ripped. Can you rip out the entire chain-stitch seam by merely breaking one stitch and pulling upon the broken thread? Can the lock stitch seam be ripped in this manner?

1. Chain-stitch machines are simpler in construction and generally use but a single thread. 2. The thread, when

sewed into a seam, is readily removed, *i.e.*, the seam is quickly ripped out by the mere breaking of the thread. 3. The seam sewed by means of the chain stitch is elastic, while the lock-stitch seam is not. 4. The chain-stitch machine can be operated satisfactorily at a higher speed than the lock-stitch

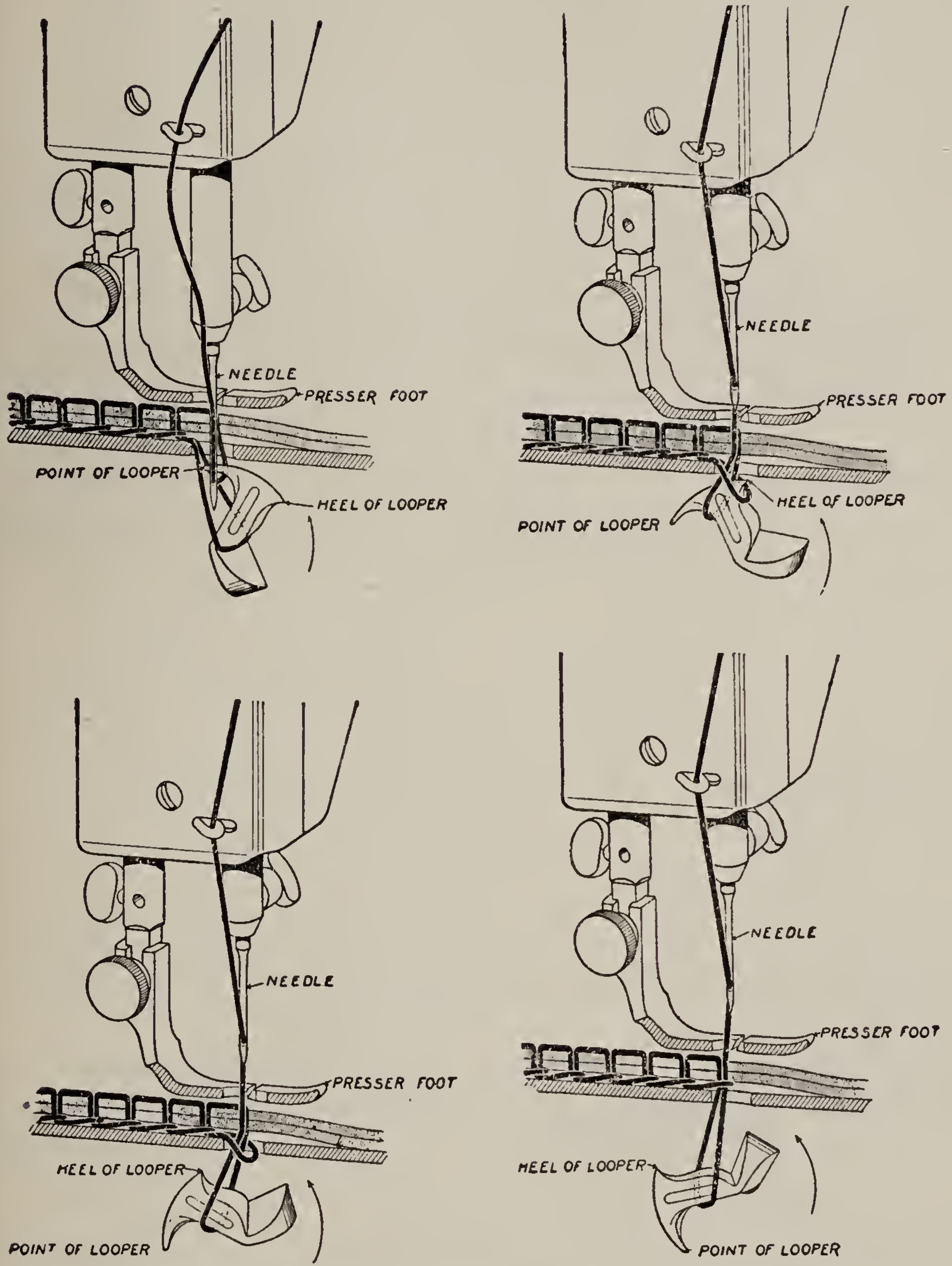
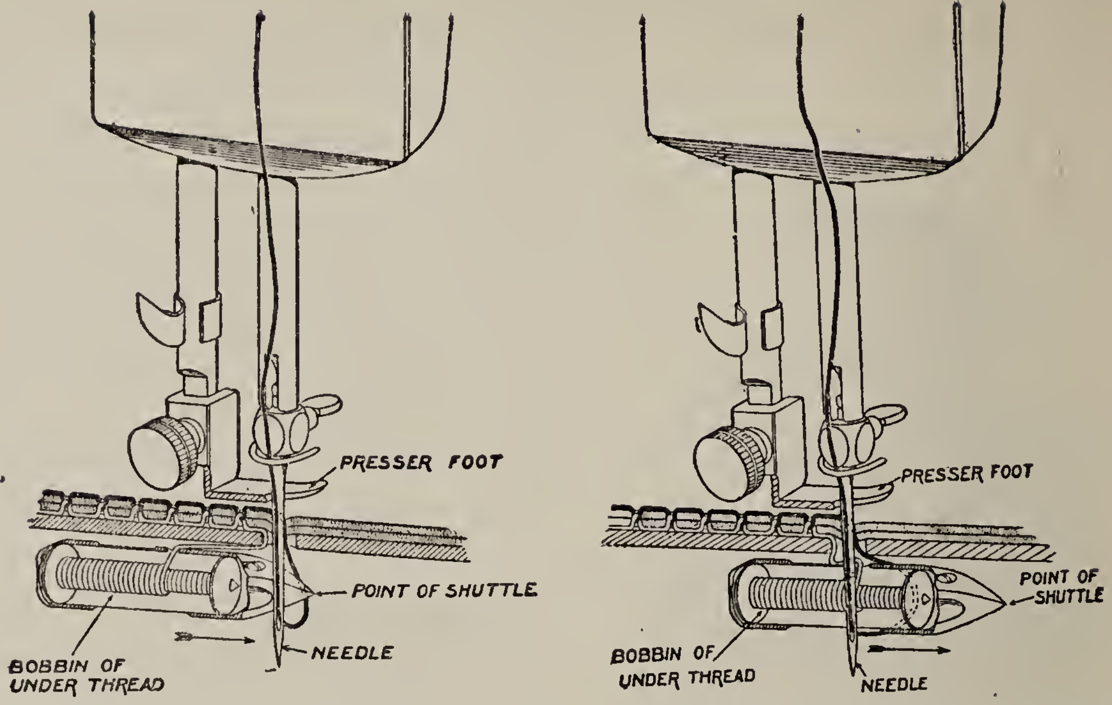
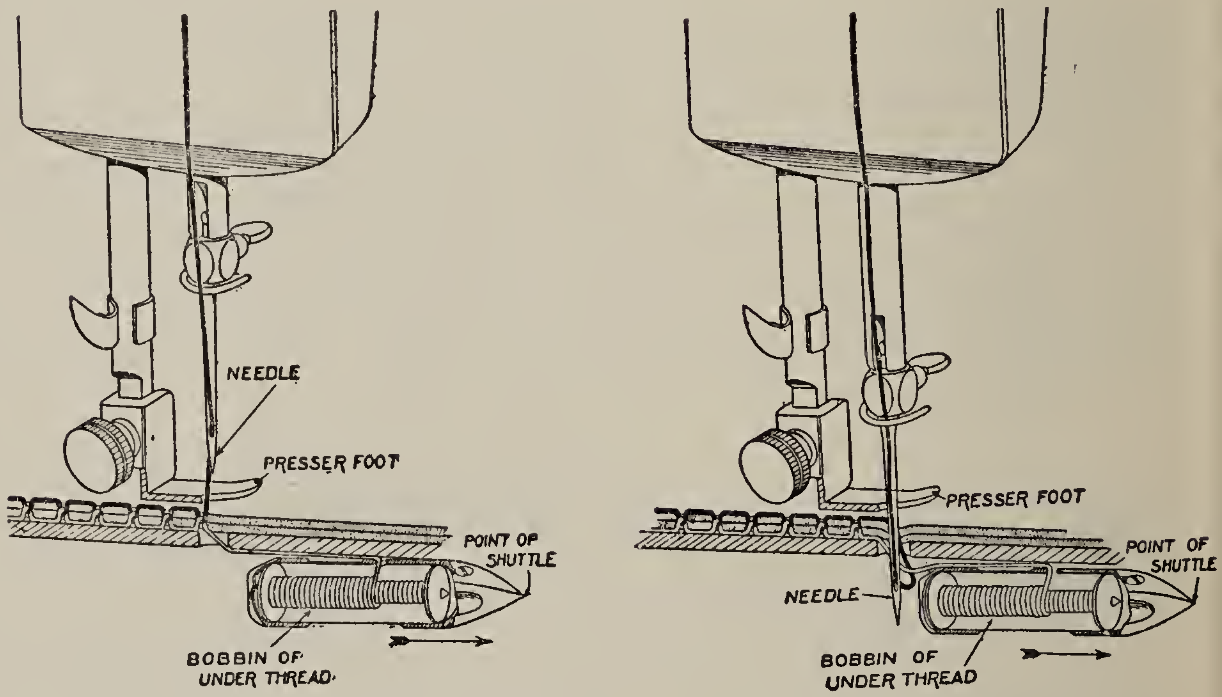


FIG. 277.—How a chain-stitch machine forms the knot.



1. Point of shuttle entering loop of needle thread.

2. Shuttle in loop of needle thread.



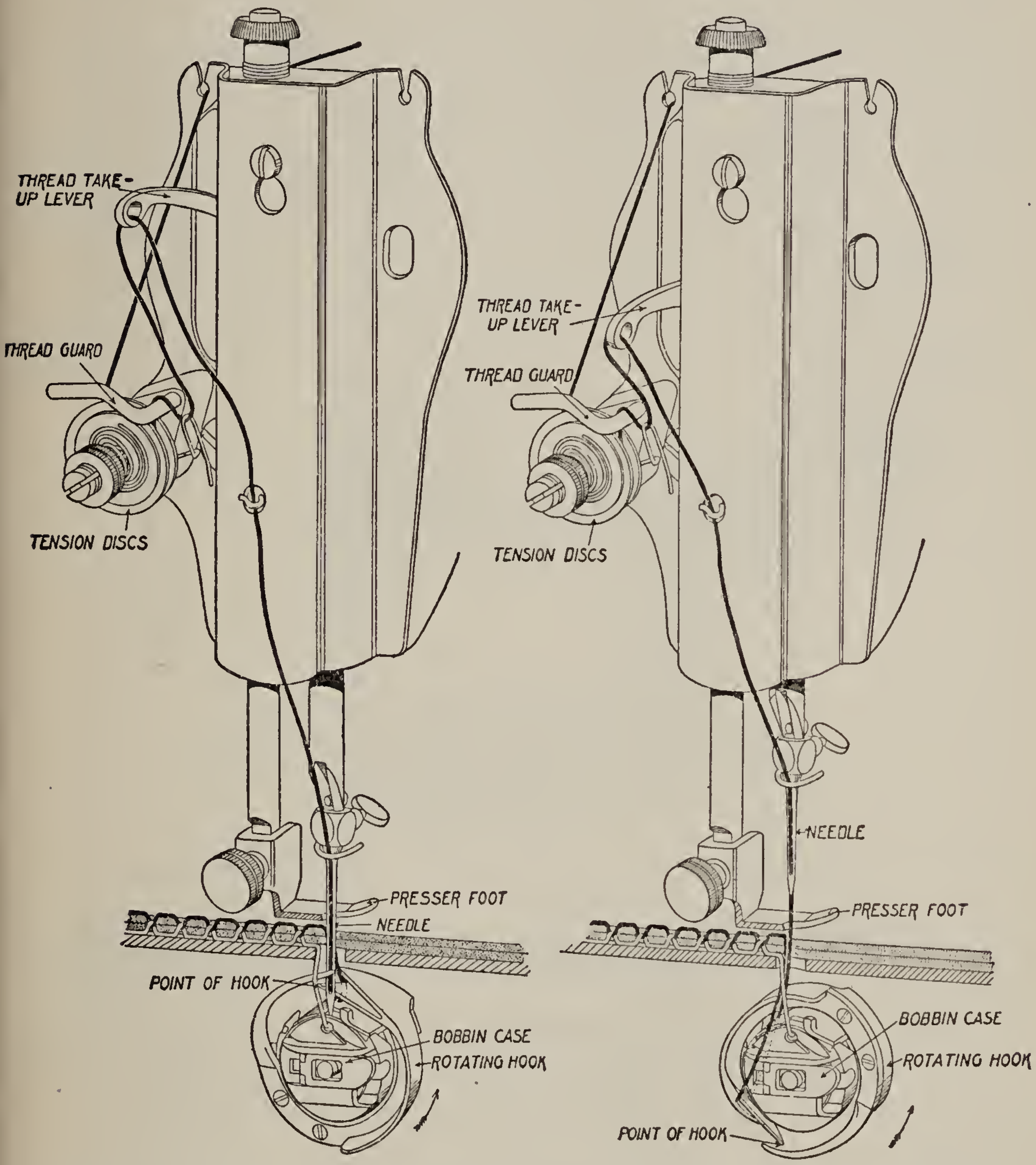
3. Shuttle thread enclosed by needle thread.

4. Stitch completed.

Fig. 278.—How a vibrating-shuttle machine forms the knot.

machine. Figure 277 shows the manner in which the chain-stitch machine forms the stitch.

Chain-stitch machines are frequently used in factories producing ready-made garments on account of their greater speed. Owing to the ease with which a chain-stitch seam may be ripped, and the liability of a stitch's being broken by ac-

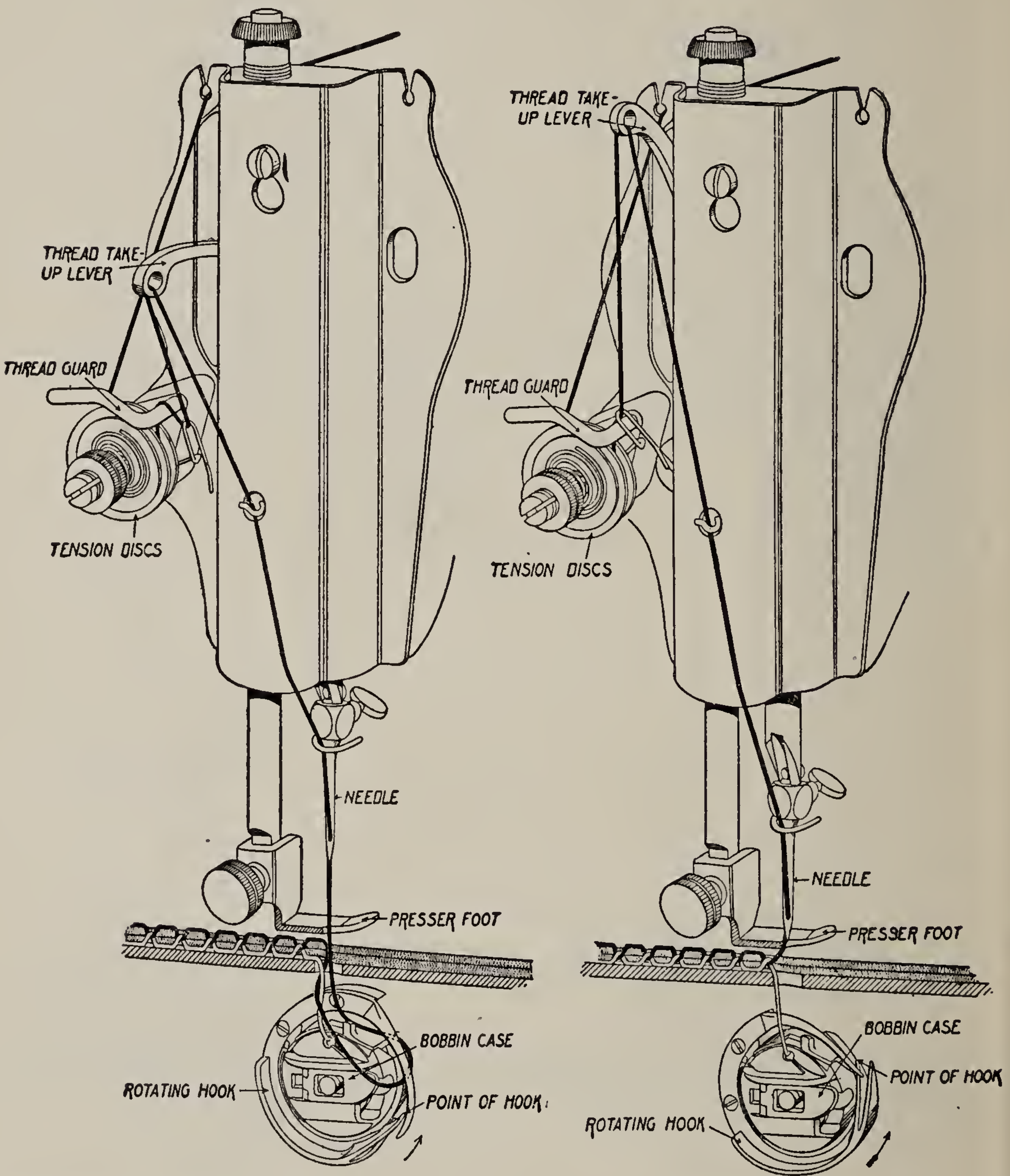


1. Hook entering the loop of the needle thread.

2. Loop of needle thread enclosing bobbin case.

FIG. 279.—How a rotary hook makes the knot.

cident, the chain-stitch seam is not regarded as satisfactory for many purposes.



3. Under thread enclosed by needle thread. 4. Stitch completed.

Fig. 280.—How a rotary hook makes the knot.

539. Classes of Lock-stitch Machines.—Lock-stitch machines are classified according to the way in which the stitch is formed. The common classes are ROTARY-HOOK, OSCILLAT-

ING-HOOK or OSCILLATING-SHUTTLE machines, and VIBRATING-SHUTTLE machines.

While the majority of all lock-stitch machines in use today are of the vibrating-shuttle type (Fig. 278), certain rotary-hook machines have been among the most successful from the first. In 1851, Mr. A. B. Wilson invented a rotary-hook machine, the first of that type, which was very successful. Figures 279 and 280 show the way in which the rotary-hook machine forms the stitch.

In the rotary-hook machines, the hook makes one complete rotation for each stitch.

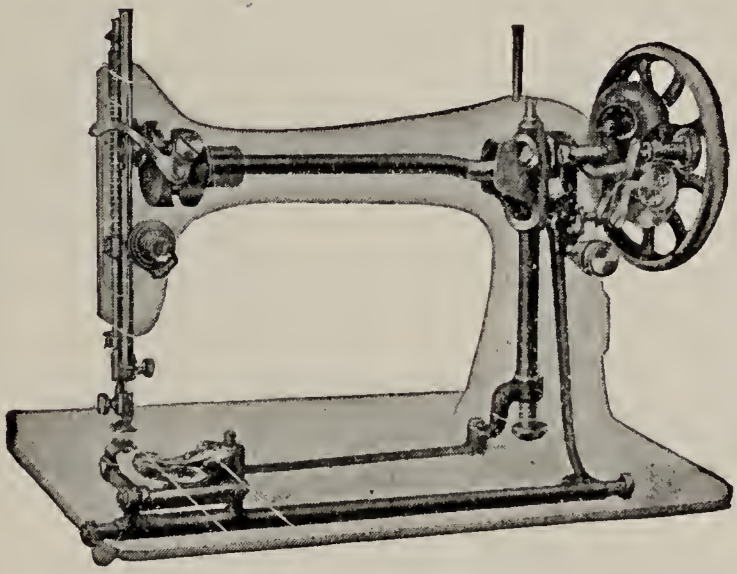


FIG. 281.—Head of a vibrating-shuttle machine.

In the oscillating-hook or oscillating-shuttle machine, the hook or shuttle makes one-half of a rotation, *i.e.*, turns one-half way around on its axis, and then reverses and returns to its former position, for each stitch.

In the vibrating-shuttle machine the shuttle may move in a straight line or in the arc of a circle. In either case, the shuttle makes one complete vibration, *i.e.*, a motion forward and back, for each stitch.

Exercise 83.—A Study of the Sewing Machine

(This exercise may be studied at home if no machine is available at school.)

1. Note the name of the machine.

2. Note just how the motion of the treadle is transferred to the drive wheel by means of the PITMAN. One complete vibration of the treadle produces how many revolutions of the drive wheel?

3. Measure the diameter of the drive wheel. What, then, is its circumference? Measure the diameter of the pulley on the head of the machine over which the belt passes. What is its circumference?

4. Provided there is no slipping of the belt, how many revolutions of the pulley will be produced by one revolution of the drive wheel?

5. The top of the balance wheel moves from you when the machine is running in the right direction on some machines. On other machines the balance wheel turns in the opposite direction, *i.e.,* the top of the wheel moves towards you. It is always best to discover the proper direction in which to turn the balance wheel before attempting to sew. Turning the wheel in the wrong direction is likely to break the thread.

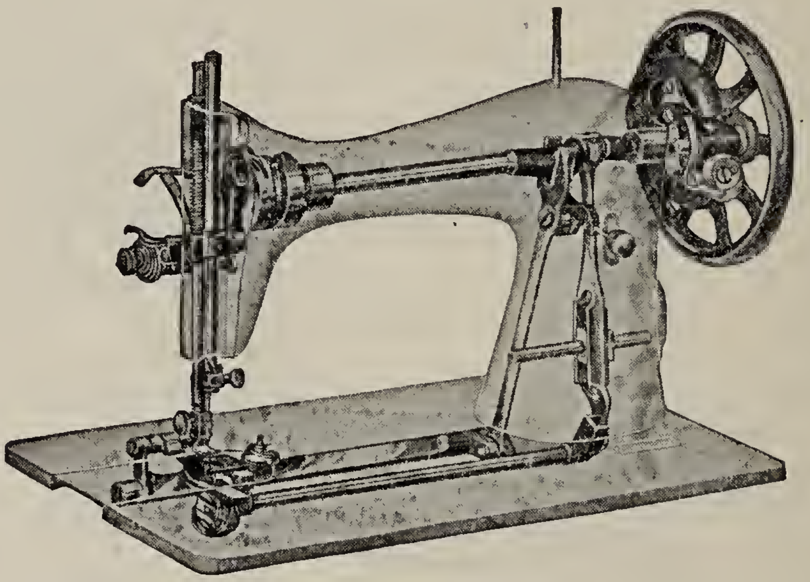


FIG. 282.—Head of a rotary-hook machine.

By watching the movement of the FEEDER beneath the presser foot can you tell which is the proper direction in which to turn the balance wheel in starting the machine? If possible, find out the proper direction on several different kinds of machines.

6. Turn the pulley carefully and see how many stitches are taken by the needle for each revolution of the pulley. How many stitches are taken, then, to each complete vibration of the treadle? Move the treadle through one complete vibration and count the number of stitches taken to check your calculation.

7. Place a piece of cloth in position and stitch a seam for 10 seconds by the watch. Let one assistant watch the time while a

second assistant counts the number of vibrations of the treadle. How many stitches, then, are taken per minute? (Some manufacturers claim that as many as 3000 stitches per minute have been taken with their machines.)

8. Remove the face plate, if removable, and discover exactly how the rotary motion of the pulley is changed to a vibratory motion of the NEEDLE and the TAKE-UP LEVER.

9. Note exactly how the presser-foot is raised from the cloth. What is its purpose?

10. Examine the feeding device and determine how it works. Just how is the length of the stitch regulated? Does the length of the stitch depend upon the speed with which the needle acts or upon the motion of the feeder? Be certain that you understand the regulation of the length of the stitch.

11. Is the machine studied a chain-stitch or a lock-stitch machine? Note exactly how the stitch is made.

12. If the machine is a lock-stitch machine, determine whether it is (a) a rotary-hook machine, (b) an oscillating-hook or oscillating-shuttle machine, (c) or a vibrating-shuttle machine.

13. Determine exactly how the knot is produced. Does the loop which forms the knot pass completely around the hook or shuttle? If so, describe exactly how it does so. Can the hook or shuttle, then, be rigidly attached to any fixed or moving part of the machine? Do not decide this point till you have made a careful study of the way in which the knot is produced.

THE CREAM SEPARATOR

540. Importance of the Cream Separator.—The cream separator is found nowadays in almost every creamery, in every city milk-supply house, in many dairies, and on most farms where any considerable quantity of milk is produced. It is one of the most common and useful machines. As its name implies, it is a machine used to separate the cream from the other portions of whole milk.

541. Former Methods of Separating Cream.—Primitive man doubtless separated cream from the other portions of milk from the time he first began to use as food the milk from his herd of goats. Until recent times the separation was usually made by placing the milk in shallow crocks, jars, or pans. The cream, being lighter than the other portions of the milk, rose to the top and could then be removed, leaving the skim milk undisturbed. Frequently the skimming was not made until the milk had become sour, thus giving the cream as much time as possible to separate. This method is known as the SHALLOW SETTING METHOD.

Several years ago the DEEP SETTING METHOD largely displaced the shallow setting method in the better dairies. In the deep setting method, the milk is placed in deep cans which are usually placed in vats of cool water. By thus keeping the milk at a low temperature, souring is delayed and, consequently most of the cream has time to become separated while the milk is still sweet and of greater use as food for man and his domesticated animals.

A third method of cream separation is sometimes employed. It is known as the WATER DILUTION METHOD. If fresh milk is diluted by the addition of cold water (about half and half) the cream separates much more rapidly. This method is not often used because the separation of cream is not generally so complete as in the case of the other methods, and because the skim milk is so diluted that it is less valuable.

542. Principle of the Cream Separation.—In each of the three methods of cream separation given, the difference in weight, or more correctly stated, the difference in density of the cream and the skim milk is utilized to cause the separation. It is much as if we were to fill a peck measure with a mixture of buck shot and peas and were then to shake the measure. The lead shot, being heavier than the peas, would settle to the bottom of the measure and the peas would be forced to the top.

If, however, we were to fasten the measure securely to a rapidly rotating platform, the contents of the measure would fly out against the sides of the measure. The shot being heavier, or more dense, than the peas, would be forced more strongly against the outside of the measure. The shot would therefore be found to gather against the outside of the measure while the peas would form a sort of lining on the inside of the shot. The force which holds the shot and peas away from the center of the measure is called CENTRIFUGAL FORCE (*centri*, center and *fugal*, to fly from).

The shallow setting, the deep setting, and the water dilution methods of separating cream all depend upon the force of gravity to cause the separation and are therefore called GRAVITY METHODS. With the cream separator, however, centrifugal force is employed to cause the cream and skim milk to separate.

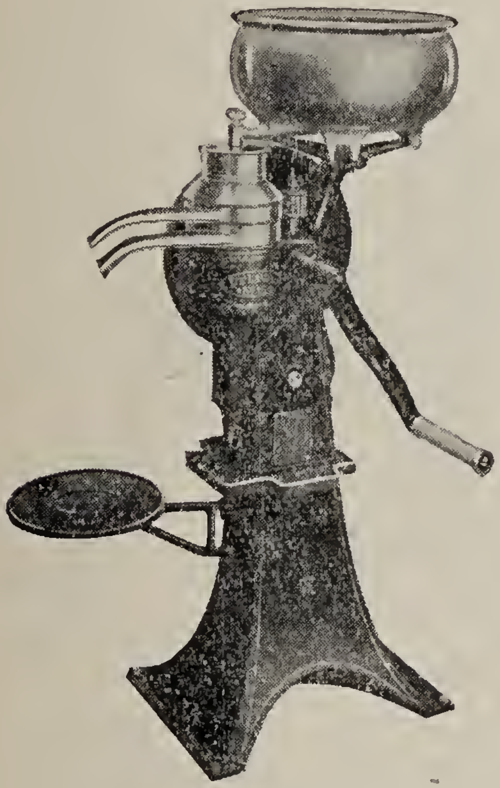


FIG. 283.—The cream separator.

X-ray view. Centrifugal force holds water against side of pail.

Exercise 84.—To Illustrate and Study Centrifugal Force

1. Suspend from the ceiling by means of a braided cord (such as a small window-sash cord) a 12-qt. pail or bucket. Place about 2 qt. of water in the pail. Seizing the bail of the pail, cause it to rotate rapidly (see X-ray of pail above). Watch the effect upon the surface of the water. When the motion dies down, give it another whirl in the same direction. Continue thus to whirl the pail till the braided cord has acquired considerable twist. Now, by placing the hand in the water, bring it to rest, at the same time preventing the

cord from untwisting till the water is quiet. Now, let the cord untwist; it will cause the pail to rotate rapidly. Watch the effect upon the water in the pail. The shape which the water assumes will be more evident if numerous small fragments of paper or some saw dust be placed in the water.

2. Place some water in a small pail and then swing the pail rapidly in a vertical circle over your head. Can you do so without allowing any of the water to fall out of the pail? Does this show that the centrifugal force may be greater than the force of gravity? Explain.

Fig. 284.—Showing the construction and operation of the cream separator.

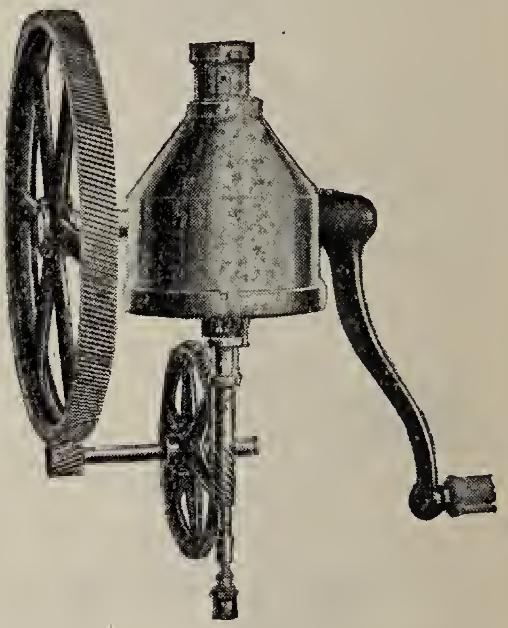


Fig. 285.—The gearing of the cream separator.

543. The Cream Separator.—In a cream separator (Fig. 283) the heavier portions of whole milk, which constitute the skim milk, are separated from the lighter portions, which constitute the cream, by centrifugal force. In the type here illustrated, the whole milk is fed slowly down through the top opening 1 (Fig. 284). This tubular shaft is closed at its lower end but it has vertical slots in its lateral wings, 2 and 2. Through these vertical slots the milk passes in thin sheets between rapidly revolving disks, 4 and 4, each of which is shaped somewhat like an inverted funnel. In the illustration the space between the upper disks is greatly exaggerated for the sake of clearness. This disks revolve at a rate of from 5000 to 10,000 r.p.m. (revolutions per minute). Figure 285 shows the gearing by means of which this high rate motion is obtained.

The resulting centrifugal force is very great. The heavier, *i.e.*, denser, portion of the milk in each of the thin sheets is thrown outward or against the under side of the disk above, while the cream being lighter, *i.e.*, less dense, remains against the upper side of the disk just below. Thus it is that the cream is separated from the skim milk. The cream accumulates at the center of the separator as shown by the lighter shading, 3, 3, in the illustration (Fig. 284), while the heavier skim milk is forced to the outside of the separator and finally past the lower rim of the disks as shown by the darker shadings in the illustration. It will be noted that the wings, 2 and 2, through which the whole milk passes, extend past the rising column of cream, thus avoiding any remixing of the cream with the milk. Since the fresh supply of whole milk is constantly flowing into the separator down the tubular shaft, it forces the separated cream upward and out at the cream outlet as shown by the dark arrows on the light background, and it also forces the separated skim milk upward and out at the skim-milk outlet as shown by the light arrows on the dark background.

544. Advantages of the Cream Separator.—The advantages of using a cream separator are many: 1. The separation is more complete than by other methods. 2. The separation is best made while the milk is still warm, making it unnecessary to cool and store large quantities of milk. 3. The skim milk is more valuable for feeding purposes when thus obtained while still fresh. 4. The cream obtained can be "ripened" more evenly (see Art. 397), thus producing butter of better quality and flavor. 5. In most states and cities whole milk offered for sale as food must contain a certain percentage of butter fat (Art. 395). Practically all of the butter fat is contained in the separated cream. It is common practice in many states for milk dealers to separate the cream from the skim milk in the milk they handle. By then mixing the cream and skim milk in certain definite proportions they can produce milk containing an unvarying amount of butter fat.[1] 6. It is common practice for farmers to separate the cream from the skim milk, shipping the cream to the creamery where it is made into butter and feeding the skim milk on the farm, thus saving much cost for transportation.

III. MASS, WEIGHT, FORCE, WORK, AND POWER

545. Meaning of Terms.—In all study and use of machines we need to understand exactly the meaning of certain terms. No two people can talk intelligently about machinery and its operation unless both use the same terms to express exactly the same thought; moreover, we must gain much of our knowledge concerning machinery from reading and it is impossible for us to understand what we read unless we know the exact meaning of the terms used. The terms used in all text-books, in reliable magazines, in all government reports, and in most advertising circulars, are carefully chosen and have certain definite meanings. If we are to be intelligent people and are to speak accurately when referring to mechanical matters, we must know the exact meaning of the terms we use.

546. Mass.—By MASS we mean the *quantity of matter in an object*. We never mean its weight, its size, or its density. When we buy a certain quantity of flour, sugar, eggs, bananas, potatoes, or coal, we are paying for a certain *mass* of the article purchased. We may determine and speak of the mass purchased in several ways: We generally speak of buying a certain number of pounds of sugar, or a certain number of eggs or bananas, or a certain number of pecks or bushels of apples. In every case, however, what we endeavor to do is to determine the *mass* of the article purchased. It is becoming

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[1] This practice is prohibited by law in some states.

more and more common for all such commodities to be bought and sold by the POUND-MASS. A dozen bananas is an indefinite quantity; likewise, a dozen eggs does not indicate clearly the amount of mass because they vary so greatly in mass. Some cities, states, and national governments have passed laws obliging all dealers to buy and sell by the mass instead of the dozen, or the peck, or the bushel. Nearly all commodities are thus bought and sold when handled in large quantities. For example, while we speak of buying oats or corn at a certain price per bushel, we actually pay the price for 32 lb.-mass of oats or for 56 lb.-mass of corn. We shall see soon that we generally determine the mass by first determining the weight, but we must never confuse the weight of an object with its mass.

547. The Units of Mass.—The common UNIT OF MASS used in the United States is the POUND. Originally the old English pound-mass was the mass of 7680 grains of wheat. During the reign of Henry VIII (1509 to 1547) the standard pound was reduced somewhat till it represented the mass of 7000 grains of wheat, hence we say there are 7000 grains in 1 lb. The English government, many years ago, prepared a piece of platinum equaling this mass and declared that to be the STANDARD POUND. Since colonial days we have always accepted this mass as the mass of a STANDARD POUND.

Two other standard UNITS OF MASS are the GRAM and the KILOGRAM of the metric system. The metric system of weights and measures is now used by all civilized nations except Great Britain and the United States. The gram-mass is the mass in 1 c.c. of water at 4°C. The kilogram equals 1000 grams. In 1893 the United States government defined the *avoirdupois pound as equal to* 453.6 *grams.* The kilogram is, then, equal to as many pounds as 453.6 is contained times in 1000, or approximately 2.2. If the metric system of weights and measures is ever generally used in the United States, as it is now used in most of Europe, we shall buy butter and sugar by the kilogram instead of the pound.

548. Weight, Gravitation and Gravity.—By the WEIGHT of an object we mean the *pull of the earth upon that object.* We all know that any object which is free to fall does fall toward the earth. This is because both earth and object attract each other. Physicists and astronomers have proved that every body in the universe attracts every other body. In general, this attraction of bodies for other bodies is called the force of GRAVITATION. When, however, we are speaking of the attraction between the earth and any object near its surface we speak of the force as the PULL OF GRAVITY.

Now, if we support a body so that it is not free to fall towards the earth, it then exerts a push or a pull upon the support. It is this push or pull which we call the WEIGHT of the object. The weight of an object, then, is merely the measure of the force of gravity upon it. We shall see later that weight is merely one form of FORCE. It is now very evident that we do not go to the grocery to purchase a certain *weight* of sugar or to the meat market to buy a certain *weight* of meat. What we do wish to buy is a certain *mass* of sugar or *mass* of meat.

549. How Weights and Masses are Determined.—The easiest way to determine the mass of an object, however, is to determine its weight. A 1-lb. mass has just 1 lb. of weight. Knowing this, we see that determining the weight of an object tells us at once its mass. This is not at all new to us when we stop to think of it. We have been used all our lives to seeing masses determined by determining the weights of those objects. We want to purchase a certain mass of meat; the dealer determines the mass by determining the weight of the meat. While it is possible to determine the mass of an object without determining its weight at all, ordinary scales and balances simply tell us the weight of the object and *it is because we accept the fact that a pound-mass weighs just 1 lb. that we are willing to accept this method of determining the mass of our purchases.*

550. Beam Balances.—The most common, as well as the most accurate, devices for determining the weights of objects are the various forms of BEAM BALANCES. A beam balance consists of a rigid beam mounted horizontally upon a sharp, hard support called a KNIFE-EDGE or FULCRUM (Fig. 286). Each end of this beam carries a pan which is also suspended from a "knife-edge." Great care is taken to eliminate friction. If the two arms of the balance are of exactly equal lengths, a 1-lb. mass upon one scale pan will axactly balance a 1-lb. mass upon the other pan. If the two arms of the beam balance be of unequal lengths, in order to balance each other, the two masses must be *inversely proportioned to the lengths of the arms.* A common example of a beam balance with unequal arms is the old-fashioned steelyards (Fig. 287). If in such a balance, the object whose weight is to be determined is 2 in. from the point of support while the known mass is 20 in. from the support, then the weight of the unknown object is exactly 10 times that of the known mass.

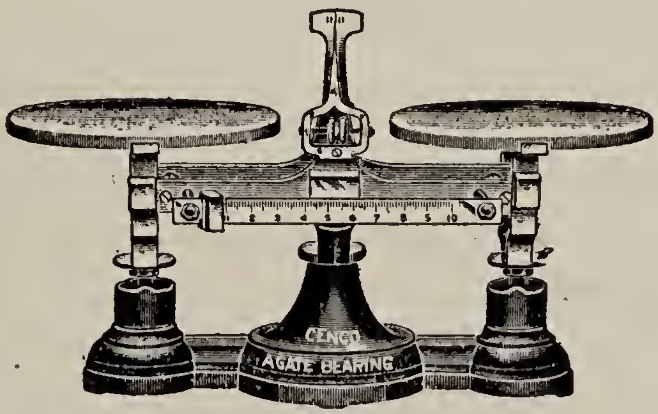

FIG. 286.—Beam balance.

The weight of the known mass : the weight of the unknown mass :: 2 : 20.

The weights are inversely proportioned to the lengths of the arms.

Generally, scales used in weighing heavy objects are constructed by using several such beams in combination. The common wagon scales are a familiar example of such a combination of unequal armed beam balances (Fig. 288). In such cases, it is common for the beams to be so combined that a 1-lb. mass will balance, perhaps, 1000 lb. or more.

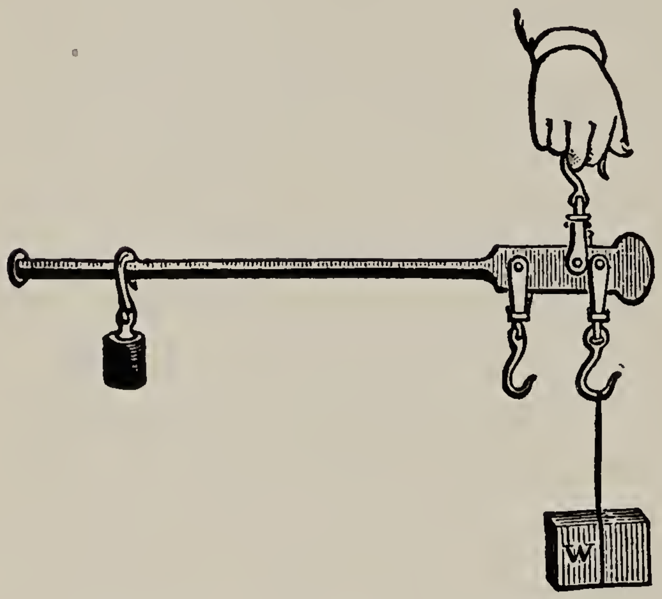

Fig. 287.—Common steelyards.

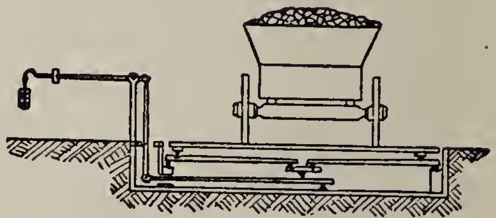

Fig. 288.—Wagon scales.

551. Spring Balances.—The principle of the SPRING BALANCE is very different. A coiled steel spring is mounted within a metal case (Fig. 289). The upper end of this coiled spring is secured to the upper end of the case; the lower end of the spring is free but carries a small rod or wire which, in turn, carries the hook upon which the mass whose weight is to be determined is hung. A small pointer, or index, fastened to the lower end of the spring is so mounted that it hangs just in front of the face of the case, upon which is stamped the scale. When a mass is suspended on the hook, the coiled spring is stretched and the index indicates the weight.

Spring balances are very convenient and easy to handle but usually they are not very accurate. Even though a spring balance may be carefully made and fairly accurate when new, it is likely to wear with use and give false readings later.

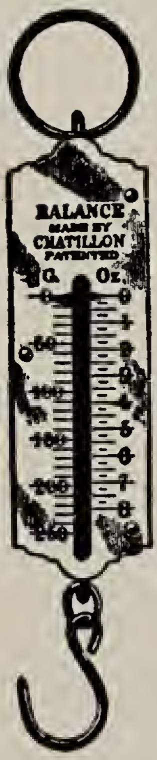

Fig. 289.—Spring balances.

552. Force.—By FORCE we mean a *push or a pull. It is force which tends to produce motion in a body or to change the direction or speed of a moving body.* All forces are pushes or pulls. Solids may be either pushed or pulled; liquids and gases, however, must be moved by being pushed. A railroad train may be either pushed or pulled; but water and air can be moved only by being pushed. Explain why this is so (see suction, Art. 284).

553. The Units of Force.—The names given to the units of force are the same as those given to the units of mass. We speak of a POUND OF FORCE and a POUND OF MASS; of a GRAM OF FORCE and a GRAM OF MASS; of a KILOGRAM OF FORCE and a KILOGRAM OF MASS. This use of the *same names* for units of mass and units of force is unfortunate and confusing. Many people do not clearly see the difference between a pound of force and a pound of mass. *We must never forget that a pound of mass is a certain quantity of matter while a pound of force is a certain amount of push or pull.* We can eat a pound-mass of beefsteak but we exert a pound of effort when we lift the steak against the pull of gravity.

554. Comparison of Force and Weight.—A pound of force is equal to the weight of a 1-lb. mass; the gram-force is equal to the weight of a 1-gram mass; the kilogram-force is equal to the weight of a 1-kg. mass. It must be remembered, however, that while weight always acts in a vertical line, *i.e.*, toward the center of the earth, forces may act in any direction whatever. A team of horses pulling a plow exerts a force, but the direction of the force is in a nearly horizontal line. A locomotive usually exerts a pull, *i.e.*, a force, which is almost exactly horizontal. A boy may throw a ball in any direction he chooses, but in doing so he exerts a force upon it. Weight, then, is a term which we apply to a force due to a certain cause —the pull of the earth—and is always acting in a vertical line. Before we go further in this study of machinery we should be certain that we clearly understand the difference between:

A pound-mass, a pound-weight, and a pound-force;
A gram-mass, a gram-weight, and a gram-force;
A kilogram-mass, a kilogram-weight, and a kilogram-force.

555. Work.—By WORK we mean a push or a pull acting through distance. The table or desk which supports your books does no work. The columns which support the porch roof do no work. A man attempting to lift a piano which he is unable to lift, or a team of horses attempting to pull a loaded wagon which it is unable to move, does no work. As the term work is used in mechanics, no person or machine does work unless a force actually acts through space. A force exerted in an attempt to move an object which does not move is WASTED EFFORT—but no work is done.

This use of the term work is not peculiar to mechanics; it is really the common, everyday meaning of the term. When a man lets the contract for the building of a house, he agrees to pay for the work done, *never for effort put forth.* The contractor, in turn, pays his man for the work they actually do. Even though the employer pays his men by the day, he continues to employ only those who actually accomplish the required amount of work.

556. The Units of Work.—The common English unit of work is the FOOT-POUND. *The* FOOT-POUND *is the amount of work done by a force of one pound acting through a distance of one foot.* Since a 1-lb. mass weighs 1 lb., we do 1 ft.-lb. of work when we lift the 1-lb. mass 1 ft. against the pull of gravity; we also do 1 ft.-lb. of work when we support it so as to prevent it from falling while we lower it 1 ft. We do 1 ft.-lb. of work whenever we exert a 1-lb. push or pull and succeed in moving the object pushed or pulled through one foot of distance. The direction in which the push or pull acts makes no difference if it is measured in the direction the object moves. We do work when we climb a flight of stairs; we also do the same amount of work when we descend the same flight of stairs.

The most common metric unit of work is the KILOGRAM-METER. It is the *amount of work done when a force of one kilogram acts through a distance of one meter.*

PROBLEMS

1. How many foot-pounds of work does a 150-lb. man do in climbing a flight of stairs 10 ft. in height? How much does he do in descending the same flight?

2. If a horse exerts an average pull of 100 lb. while plowing, how much work does he do while plowing a furrow 1 mile in length? If he walks at the rate of 3 miles per hour, how many foot-pounds of work does he do per hour?

3. A boy carries a scuttle of coal weighing 10 Kg. up a flight of stairs 3 meters in height. How many kilogram-meters of work does he do?

557. **Time is not a Factor in Work.**—Time is not considered in determining amount of work. The amount of work done by a man in shoveling a ton of coal into a wagon is independent of the time required to do it. It requires neither more nor less work to plow an acre of land if the plowing be done in an hour or in a day. We all recognize this in everyday life. We are willing to pay no more for the shoveling of the coal or the plowing of the ground because the man who does the work requires a longer time in which to do it. In fact, we are often willing to pay a little extra if the work be done in the shorter time.

558. **Power, Activity or Rate of Work.**—The unit in which POWER, ACTIVITY, OR RATE OF WORK is measured is the HORSE-POWER. A machine is said to be a ONE-HORSE-POWER MACHINE when it is capable of doing 33,000 *ft.-lb. of work per minute, or* 550 *ft.-lb. of work per second.* This unit of power was chosen and named by James Watt (see Art. 599); he supposed that an average horse could work at about this rate. In order to work at this rate, however, a horse must exert an average pull of 125 lb. while walking at the rate of 3 miles

per hour, or he must exert an average pull of 150 lb. while walking at the rate of 2½ miles per hour. (Calculate.) A strong horse weighing 1400 lb. can stand it to work at this rate, 10 hours each day (see Art. 576). An average man can stand it to work at the rate of about ⅐ of a horse-power, eight hours each day.

IV. MACHINES

559. Machines and Their Uses.—*Any device is called a machine if it is used to transfer or transform energy, or if it is used to change the direction, or magnitude of a force doing work* (see Art. 81, Definition of Energy).

Man uses machines for a great variety of purposes. A crowbar, a set of pulleys, or a jackscrew enables a man to move a body whose weight is so great that he would be unable to move it without the use of the machine. A fishing pole enables the boy to drop his hook quietly into the pool at a point he otherwise could not reach; it also enables him to jerk the hook more quickly. The sewing machine enables a woman to operate the needle by moving her foot while both hands are free to handle the work; moreover, the needle makes several stitches while her foot is making a single motion (Art. 539, Ex. 83). The plow, the cultivator, the mowing machine, or the binder enables the farmer to utilize the efforts of horses. Steam engines, gas engines, electric dynamos and motors enable man to utilize the energy in fuel at a small fraction of the cost of hiring the same amount of work done by men or even by horses (Fig. 290). Moreover, one man often operates such a machine while it does the work which would otherwise have to be done by hundreds of men. Waterwheels enable men to utilize the energy in running water—energy which would otherwise go to waste. When this energy has been transformed into electricity it can be transmitted on wires many miles and then be used to light our homes, run our trains and street cars, and do a large portion of the work which has been done by men in days past (see Arts. 587 and 592).

560. Mechanical Advantages of a Machine.—Man uses a machine only when he gains some *advantage* by so doing. *This advantage gained by using a machine is called the* MECHANICAL ADVANTAGE *of the machine.* Machines may offer mechanical advantages of several different kinds:

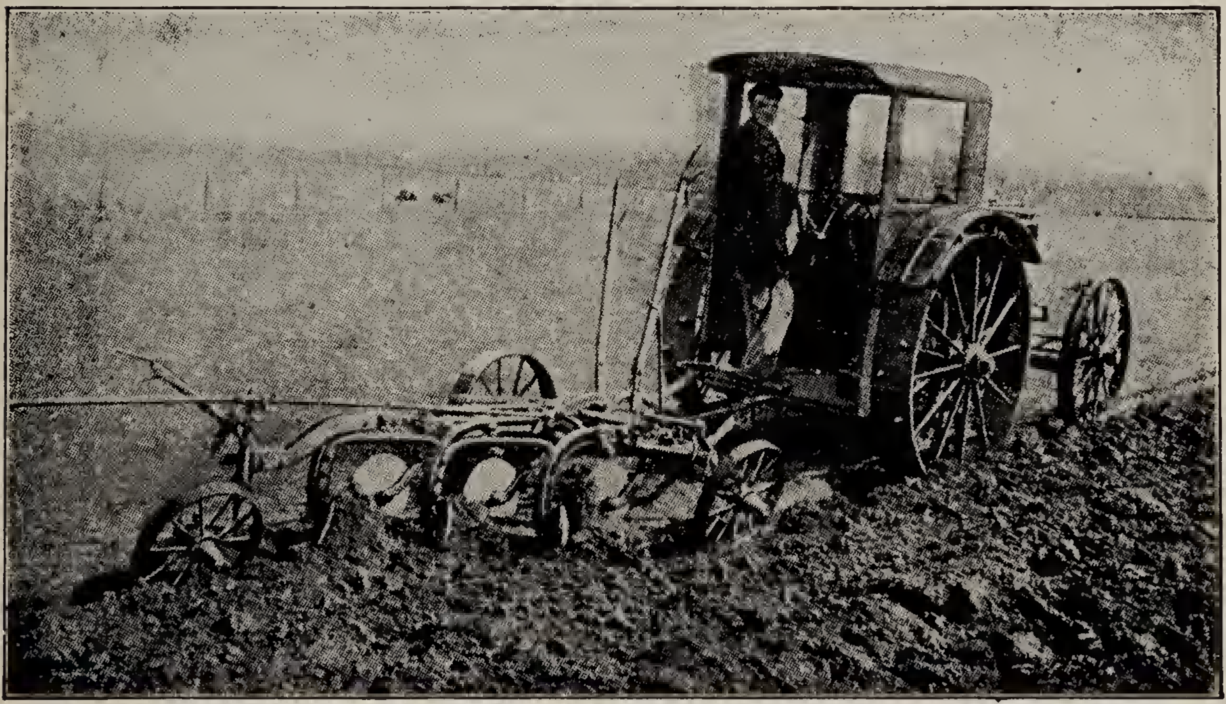

FIG. 290.—A farm gasoline tractor pulling a three-bottom plow and doing the work of 6 or 8 horses or of 50 men.

1. A machine has MECHANICAL ADVANTAGE OF FORCE when, by using it, a greater force is exerted than could otherwise be exerted. Examples: By using a pinchbar—a crowbar of a certain shape—a man is able to move a heavily loaded freight car which he could not move without it. By using a common claw hammer, a man can draw a nail which otherwise he could not pull. Give as many other examples as possible.

2. A machine has MECHANICAL ADVANTAGE OF SPEED when it is used to increase the speed with which the force acts. Examples: A fly swatter, a sewing machine, an egg beater, an old-fashioned spinning wheel. Name as many other examples as you can.

3. A machine may have MECHANICAL ADVANTAGE OF DIRECTION OR OF POSITION. Examples: By using a single fixed pulley the direction of the force is changed and the operator may choose his own position. The handle of the common pump, the key of the typewriter, the wheel or handle of the washing machine, the common door knob—all these and many other devices are advantageous because they aid in changing the direction of the applied force or they enable the operator to choose his position, or both.

A machine may have mechanical advantages of two or more kinds at the same time. *It is impossible, however, for a machine to have both mechanical advantage of force and mechanical advantage of speed at the same time.* What advantages are afforded by the sewing machine over those of the hand needle?

561. Numerical Expression of Mechanical Advantage.—Mechanical advantage of force and mechanical advantage of speed are each frequently expressed numerically, *i.e.*, in numbers. The ratio of the force delivered by a machine to the force applied to the machine is said to express the mechanical advantage of force of the machine.

$$\text{Mechanical advantage of force} = \frac{\text{Number of units of force delivered}}{\text{Number of units of force applied.}}$$

Example: A man by using a crowbar exerts a force of 1000 lb. upon a rock while exerting a force of 100 lb. upon the handle of the crowbar. In this case the mechanical advantage of force is $\frac{1000 \text{ lb.}}{100 \text{ lb.}} = 10.$

The ratio of the speed with which the force acts to the speed of the applied force is said to express the mechanical advantage of speed of the machine.

$$\text{Mechanical advantage of speed} = \frac{\text{Number of units of speed of the force delivered}}{\text{Number of units of speed of force applied.}}$$

Example: The knives of an egg beater pass 5 times around a 2-in. circle while the handle on the drive wheel passes once around a circle of the same diameter. In this case the mechanical advantage of speed of the machine is

$$\frac{5 \times 2 \times 3.1416 \text{ in.}}{2 \times 3.1416 \text{ in.}} = 5.$$

It is evident that the mechanical advantage of direction or position can not thus be expressed in numbers.

562. Simple and Compound Machines.—Six SIMPLE MACHINES are generally recognized: The LEVER, the WHEEL and AXLE, the PULLEY, the INCLINED PLANE, the WEDGE, and the SCREW. Most machines are COMPOUND MACHINES, *i.e.*, they are combinations of two or more of the simple machines. A sewing machine, a typewriter, a clock, a binder, a threshing machine, or an automobile is made up by combining large numbers of simple machines.

Exercise 85.—Study of a Compound Machine

Examine carefully a sewing machine, a typewriter, a clock, or any other complex machine, noting the simple machines involved and how they are combined.

563. Friction.—FRICTION *is the resistance which opposes an effort to slide or roll one surface over another.* Every surface is more or less rough. Even the hardest and best polished surfaces are found to be rough, to have uneven surfaces, when examined under a magnifying glass. When we attempt to slide one surface over another, the rough places on one surface catch upon the rough places upon the other. This roughness of the surfaces is the cause of friction.

The operation of any machine is affected by friction to some extent. (1) Oiling all moving parts which come into contact lessens friction. (2) In general, there is less friction between two surfaces of different material than between surfaces of the same material. For this reason bearings are usually made of different material from that of the axles which rest upon them. (3) Friction is less between two surfaces when one of them rolls upon the other than when one slides upon the other. A ball bearing, therefore, has less friction than a common sliding bearing. Every boy or girl who rides a bicycle or uses roller skates knows that a ball-bearing wheel runs easier than one without ball bearings.

Exercise 86.—A Study of Ball Bearings

Examine the ball bearings in a bicycle or a roller skate to see exactly how they are constructed and how they work.

564. The Effect of Friction on the Use of Machines.—We saw in Art. 550 that the length of the arms of a steelyard determines the usefulness of the machine in finding the weight of objects. The poise at the left (Fig. 287) must be placed near the left end of the scale in order to balance a heavy object which is to be weighed. In this case there is very little friction and therefore the mechanical advantage of the steelyard may be determined by measuring this distance from the point of support to the hook where the object is supported and to the point where the poise is placed.

In general, though, when we use even simple machines to aid us in our work, we find that friction is so great that measuring the dimensions of our machine gives us but little information as to the amount of force which must be applied to move an object. *The term "mechanical advantage" is therefore, largely of theoretical value only.* If there were no such thing as friction, we could determine the mechanical advantage of almost any machine easily and quickly by measuring the size of its various parts.

It is sometimes desirable to know approximately the force which must be applied to a machine in order to lift or move an object. *We shall see, however, in the following articles that it is far more important that we know how much work we must put into a machine in order that we may get a certain amount of work out of that machine.*

565. The Law of Machines.—The work (or energy, see Art. 81) put into a machine and also the work (or energy) taken out of a machine must, of course, be measured in work units, *i.e.,* in such units as foot-pounds, or gram-centimeters, or kilogram-meters. The work put into a machine is equal to the product of the applied force and the distance through which that force acts; the work delivered by a machine equals the product of the force delivered and the distance through which it acts. If there were no friction, the work delivered by a machine would exactly equal the work put into it.

LAW OF MACHINES.—*The work or energy put into a machine would equal the work or energy delivered by the machine—if there were no friction.*

566. Friction Generally Hinders but Sometimes Helps.—In fact, however, the work delivered by a machine is never exactly equal to that put into it. In most cases the work delivered by a machine is *less* than that put into it because of friction in the machine. Occasionally, however, a machine is used in such a manner as to yield an output greater than the input. For example, if a set of pulleys, an inclined plane, or an elevator is used to *lower* a heavy object from the top floor of a building to the basement, the work put into the machine is less than that taken out of it. Friction, in this case, tends to keep the body from falling; it is working with the operator.

567. Efficiency of a Machine.—*The* EFFICIENCY OF A MACHINE *is measured by the ratio of the work (or energy) delivered by a machine to the work (or energy) put into it.*

$$\text{Efficiency of a machine} = \frac{\text{Work or energy delivered, or output}}{\text{Work or energy put in, or input}}$$

It is generally expressed in percentage. It is usually less than 100 per cent. but it may be greater than 100 per cent. Illustrations:

1. If a block and tackle, *i.e.*, a set of pulleys, be used to raise a piano from the ground to the top floor of a building, we

find that we are obliged to put considerably more work into the machine than we get out of it. If the piano weighs 1000 lb. and it is raised 50 ft., how much work is accomplished? In this case we are obliged, not only to do this amount of work. but we must also do work in overcoming friction. The efficiency of the machine in this case is not likely to be more than 50 to 75 per cent.

2. Supposing now that we wish to lower the same piano from the top floor of the building to the ground again. If we use the same block and tackle we shall find that we are not now obliged to put as much work into the machine as we get out of it. Exactly the same amount of work will be accomplished in lowering the piano as was accomplished in raising it but the friction of the machine tends to keep the piano from falling. Friction is now aiding us—it is working with us. The efficiency of the machine will now probably be from 133 to 200 per cent.

568. Friction is Often Useful.—We generally find it an advantage to reduce friction in a machine as much as possible; sometimes, however, we find friction of great service to us. When we wish to haul a heavy load *up* a hill we make every effort to reduce friction. When we start *down* hill, however, we set the brakes, or possibly chain one rear wheel, in order to increase friction. A locomotive owes its power to pull a train to the friction between its drive wheels and the rails (Fig. 291). If this locomotive were attached to a train requiring a force of more than 60 tons to move it, the locomotive would be unable to start the train because its drive wheels would then slip on the rails. A bicycle or an automobile is likewise propelled by the friction between its wheels and the ground. Men working upon the ice wear ice creepers on their shoes to increase friction between their shoes and the ice. After an ice or sleet storm, horses are almost useless for hauling loads unless they are sharp shod. Why? Give as many cases as you can where friction is of service to us. How do the brakes of a railroad train bring the train to rest? How

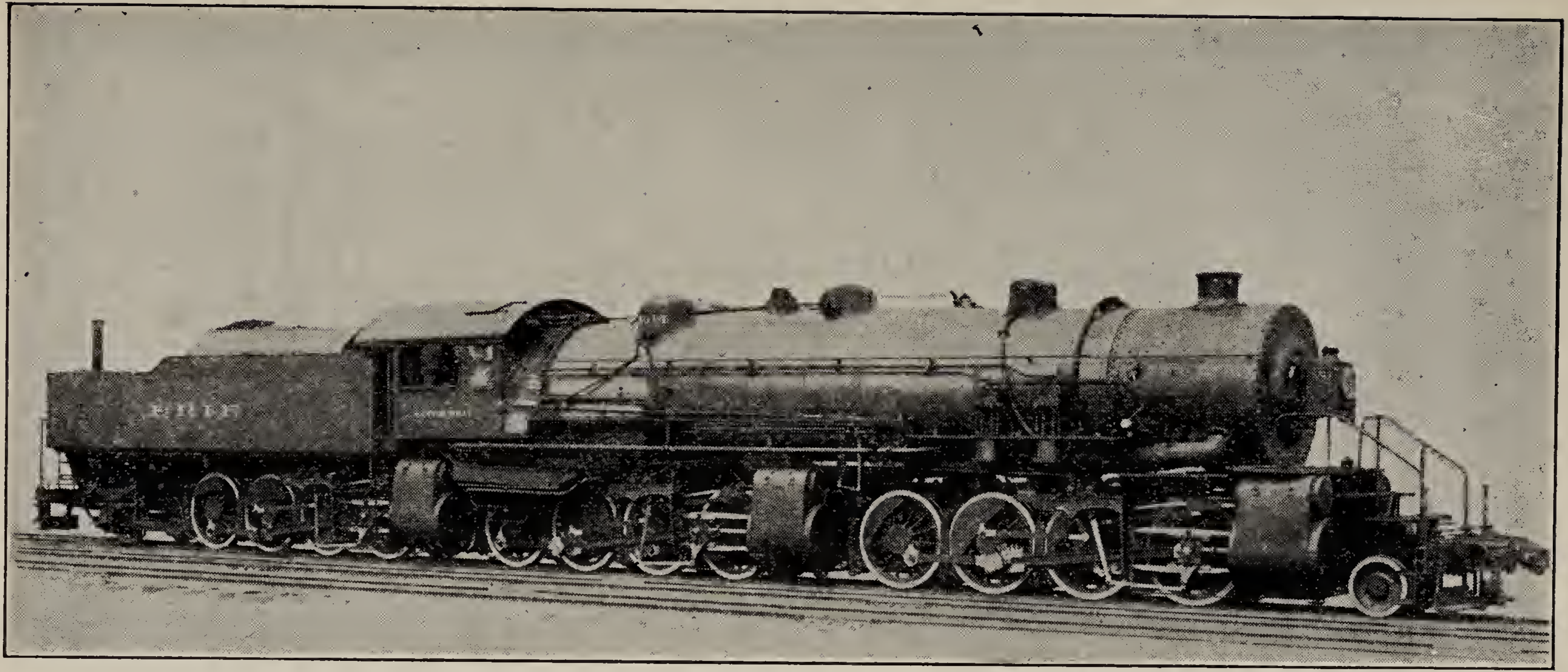

Fig. 291.—One of the largest locomotives ever built. (Courtesy of the Erie Railroad Company.) This locomotive weighs 336 tons and can exert a pulling force of 60 tons. It can easily pull a train of 200 cars, each weighing 100 tons. It owes its pulling power to the friction of its drive wheels upon the rails.

is friction involved in feeding the paper through a typewriter or printing press? Explain how a leather belt is used to drive a sewing machine or a threshing machine.

V. ENERGY AND ITS RELATION TO THE USE OF MACHINES

569. What is Meant by Energy?—Anything which is capable of doing work possesses ENERGY. ENERGY is the capacity for doing work (Art. 81). Man, by putting forth effort, does work; therefore he possesses energy. A horse may do work; therefore, he possesses energy. A steam engine, as long as it is supplied with fuel and water and is properly controlled, can do work; therefore it possesses energy. The machine by itself, *i.e.*, without fuel and water, can do no work. It is the fuel which gives it the ability to do work. The energy comes from the fuel, not from the mechanism of the engine. We have seen in Chap. VII that it is from food that man or the horse gets his supply of energy.

570. Motors.—Any machine or animal used to transform energy into work is called a MOTOR. A steam engine transforms the energy in coal, wood or oil into work. A gasoline engine transforms the energy in gasoline into work; it is a GASOLINE MOTOR. A machine which transforms the energy in an electric current into work is an ELECTRIC MOTOR. To the extent that any man or animal simply transforms the energy in the food eaten into mechanical work, he is a motor. Agriculturists speak of the work horse as an ANIMAL MOTOR.

A steam engine or gasoline engine is capable of doing work only as long as it is consuming fuel; as soon as it ceases to consume fuel it ceases to be able to do work. It is equally true that a man or a horse soon ceases to be able to do work unless supplied with food. It is the energy in the food eaten which enables man or animal to do work. Thus we see that man may differ little from a machine if he consumes food merely for the purpose of transforming the energy in the food into mechanical work.

571. One Difference between an Animal Motor and a

Mechanical Motor.—While a mechanical motor, such as a steam engine or a gasoline engine, ceases to be able to do work almost at the instant that the fuel supply is exhausted, an animal motor can continue to do work for some time after its food supply is exhausted. This is because the fat and other tissue of the body can be converted into energy when necessary. Any animal, however, which is obliged to do hard labor without a sufficient supply of food will lose weight rapidly and will soon die.

572. Efficiency of Various Motors.—Many experiments performed show that the average efficiency of man as a motor is about 20 per cent. That is, it has been found that a man is able to convert about 20 per cent. of the energy in the food he eats into mechanical work. Similar experiments show that the horse can also convert about 20 per cent. of the energy in its food into work. A steam engine will convert from 4 to 10 per cent. of the energy in coal into work; therefore it has from 4 to 10 per cent. efficiency. A few years ago in a series of tests made by the Northern Pacific Railroad it was found that the efficiency of its best freight locomotives was but 3.8 per cent. Good gas and gasoline engines have an efficiency of from 20 to 35 per cent. Electric motors frequently develop an efficiency of 75 to 90 per cent. From these figures one might conclude that the electric motor was the least expensive motor and that the steam engine was the most expensive motor for us to employ to do our work. Such a conclusion, however, is hasty and incorrect. The fact is that the steam engine is one of the least expensive motors to operate while the electric motor is rather expensive to operate. Can you suggest any reason why this should be so? Before we finish this chapter we shall see what the explanation really is.

573. The Work Equivalent of a Calorie of Heat.—Many experiments have been made to determine the amount of work which is equivalent to a calorie of heat. In 1840, an Englishman, Joule, made such a determination. He suspended masses of iron by means of cords in such a manner that they might slowly fall and in so doing revolve a set of paddles immersed in a vessel of water. The paddles, in stirring the water, produced friction which produced heat and therefore raised the temperature of the water. He noted the weight of the iron masses and the distance through which they fell. From these figures he determined the amount of work done. He also noted the weight of the water and the number of degrees of temperature through which it rose. From these figures, he determined the number of calories of heat produced. Other experimenters have used other methods of determining this relation. It is now known that 1 greater calorie (1 Cal.) (Art. 102) is equal to 3080 ft.-lb. (Art. 556) of work. This means that, if all the energy in food or fuel could be converted into work without loss, we should be able to produce 3080 ft.-lb. of work for every calorie of heat energy in the food or fuel. We have seen that it is impossible to do this. The horse is able to convert but about 20 per cent. of the energy in his food into work. Therefore we can not hope to secure more than about 616 ft.-lb. of work for each calorie (1 Cal.) of energy in the food the horse eats.

574. Calories of Energy Needed to Do 1 Horse-power-hour of Work.—We have seen that 1 horse-power is the ability of a motor to do 33,000 ft.-lb. of work per minute (Art. 558). A horse-power-hour of work, then, is 60 × 33,000 ft.-lb. or., 1,980,000 ft.-lb. Since 1 greater calorie of heat equals 3080 ft.-lb., we see that 640 Cal. of energy are required to do 1 horse-power-hour of work. A motor having an efficiency of 100 per cent. would, then, consume 640 Cal. of food or fuel while doing 1 horse-power-hour of work.

640 *greater calories of heat* = 1 *horse-power-hour of work*

575. Cost of 1 Horse-power-day of Work by the Steam Engine.—One lb. of coal when burned yields from 3000 to 3600 Cal. of heat (Art. 102). Since the average stationary steam engine has an efficiency of from 5 to 8 per cent., it utilizes only from 150 to 275 Cal. to the pound of coal. Even then it requires only from 2.5 lb. to 4.5 lb. of coal to do 1 horse-power-hour of work. In practice, a steam engine is considered as being in fair condition if it does 1 horse-power-hour of work on 4 lb. of coal. A steam engine, having the usual efficiency, will probably require from 25 to 35 lb. of coal per horse-power-day of 8 hours. The cost of this coal at $5.00 per ton would be from 6 cts. to 9 cts. per horse-power-day. (The student should verify these calculations in every case.)

576. How Much Work a Horse Can Do.—King, in his *Physics of Agriculture,* says that it is commonly agreed that for steady and continuous work 10 hours per day, walking at the rate of 2½ miles per hour, a horse should not be asked to pull (exert a force of) more than about ⅒ or ⅛ of its own weight. The work performed by horses of different weights would, then, be about as follows:

WORK PERFORMED PER DAY BY HORSES OF DIFFERENT WEIGHTS WALKING AT THE RATE OF 20 MILES PER DAY, OR 2½ MILES PER HOUR

Weight of horse	Pull exerted	Rate of work at 2½ miles per hour
800 lb.	80 to 100 lb.	0.53 to 0.67 horse-power.
1000 lb.	100 to 125 lb.	0.67 to 0.83 horse-power.
1200 lb.	120 to 150 lb.	0.80 to 1.00 horse-power.
1400 lb.	140 to 175 lb.	0.93 to 1.17 horse-power.
1600 lb.	160 to 200 lb.	1.07 to 1.33 horse-power.

(The student should verify these figures.)

577. Why the Horse Can Not Compete with the Steam Engine as a Motor.—We have seen that a strong horse can not work steadily at a rate faster than 1 horse-power. We shall presume that 8 hours, working at full capacity, makes a full length day for a horse to labor. Now, although a horse can convert 20 per cent. of the energy in its food into effective work, it still is true that the food of the horse is so much more expensive than the fuel of the steam engine that the horse is quite unable to compete with the engine.

The principal food of the horse is corn or oats. Smith, in *Profitable Stock Feeding,* says that a horse weighing 1200 lb. at severe labor, needs 16 lb. of oats and 12 lb. of hay per day. Other authorities give the following rule for feeding a working horse: 1½ lb. of oats or corn and 1 lb. of hay per day for each 100 lb. of weight. The energy in a pound of oats is about 1500 Cal. (see Table VII, Art. 386. Remember that the husk of the oat is removed in making oat meal; that the energy in a pound of corn is about 1650 Cal.).

PROBLEMS

1. We shall consider that a 1200-lb. horse is able to do 1 horse-power of work for eight hours per day. We shall consider his food as 18 lb. of oats per day, and omit any consideration of the hay or "roughage" consumed because the available energy in it is not great. What is the efficiency of this horse as a motor?

First: 18 lb. of oats contain 18 × 1500 Cal. of energy, or 27,000 Cal. of energy. But these 27,000 Cal. = 83,160,000 ft.-lb. of work (Art. 573).

Second: 1 horse-power for eight hours = 8 × 60 × 33,000 ft.-lb. or 15,840,000 ft.-lb. of work.

$$\text{Hence: Efficiency of the horse} = \frac{15{,}840{,}000 \text{ ft.-lb.}}{83{,}160{,}000 \text{ ft.-lb.}} = 0.19 \text{ or } 19$$

per cent.

What is the cost of feeding this horse? We shall suppose that oats are worth 50 cts. a bu. (32 lb.). The cost of 18 lb. will be about 28 cts. If we count the cost of the 12 lb. of hay at $15 a ton, we must add 9 cts. more, making the cost for feed 37 cts. per day. Thus we see that, considering the cost of feed and coal only, the horse is some four or six times as expensive as is the steam engine when used as a motor (Art. 575).

How do you think that the cost of care and shelter of such a horse would compare with the cost of care and shelter for a 1 horse-power steam engine? What is true about the cost of caring for a horse and such an engine when they are not at work? How would the money invested in the horse compare with that invested in a 1-horse-power steam engine? Do you see why all these things must be considered when comparing a horse with a steam engine as a motor?

578. A Man Can Not Compete with Either the Horse or the Steam Engine as a Motor.—It is generally agreed that a man of average strength can work at the rate of ⅛ to ⅙ of a horse-power for eight hours a day. This means that it requires six or eight men working one day to do a full horse-power-day of work. Now the cost of a man's daily food varies greatly, but it is probably true that the cost of food for a laboring man is generally somewhere from 50 cts. to $1.00 a day. The food for a man is not nearly so great in quantity as that consumed by a horse nor does it contain so many calories of heat, but it is of much finer quality, it should be much more varied, and it must be cooked and prepared so that its cost per pound is several times as great. It is probably true that the cost of food for the well-fed workingman is as great as that of the well-fed working horse. Since man can do but about one-seventh as much work as the horse, it is evident that man is an expensive motor when compared with either a horse or a steam engine.

When thus considering merely the cost of the food of the workingman, we are entirely neglecting the cost of comfortable shelter, of clothing, of reading matter, of traveling expenses, of amusements, and all the other elements of higher living which make life really worth while. Moreover, the laboring man is usually the head of a family and therefore must provide food, shelter, clothing, school books, and all the other necessities of life for the several members of his family. When we consider all these things, we see clearly that no working man can possibly compete with other forms of motors. He must labor at tasks which other motors are unable to perform.

COST OF 1 HORSE-POWER-DAY OF WORK, CONSIDERING FUEL AND FOOD ONLY

By steam engine	6 to 9 cts.
By gasoline engine	15 to 20 cts.
By horse	40 to 50 cts.
By man	$4.00 to $8.00

579. Why We often Use the Horse instead of the Steam Engine.—The horse not only does *useful* work, but while doing it he is obliged to do a large amount of *useless* work. The stationary engine does no useless work in moving its own mass through space. One of the reasons why the efficiency of the stationary engine is greater than that of the locomotive is that the locomotive does a large amount of useless work in transporting its own mass.

There are many kinds of work, however, which can be done at a lower cost by the horse than by the steam motor. In excavating for a house or in grading up around the house after it is built, for most hauling about the farm, for the delivery of grain to the local market, for the cultivating and the harvesting of crops on the ordinary farm, the horse is still often the most practical motor we have.

580. Why We often Employ the Labor of Man instead of the Horse or the Steam Motor.—Just as we still employ the horse instead of the steam engine to do many kinds of work, so in spite of the high cost of his labor we still find it profitable to employ man to do much of our work. In the construction of buildings there will probably always be a demand for laborers to handle the brick and mortar, and the wheelbarrow and spade, as well as to handle the hammers, the saws, the planes, and the trowels. In most lines of work there is some rough work which might possibly be done by machines but which can at present be more cheaply done by the cheapest of human labor. More and more, however, work of this nature is being done by other motors and *man is finding that he must prepare himself for doing such work as requires thoughtful, intelligent action.*

VI. SOME COMMON MECHANICAL MOTORS

581. Common Mechanical Motors.—In the last section we saw that, while man and the horse were both more efficient motors than the steam engine, it still is true that the steam engine is a much less expensive motor to operate—*that the* *most efficient motor is not necessarily the least expensive to employ.* In this section we shall study briefly the principles of some of the more common mechanical motors.

Nearly all power used today to run the machinery in factories and mills and about mines, to pump the water for city water systems, and to light city streets and homes by electricity, to propel ships at sea, and railroad and interurban trains on land, to run street cars and automobiles—in fact, to operate machinery for any purpose—is derived from a few different kinds of mechanical motors. These motors are (1) water motors, (2) steam motors, (3) gas motors, including gasoline or crude oil motors, and (4) electric motors.

Fig. 292.—The overshot water wheel.

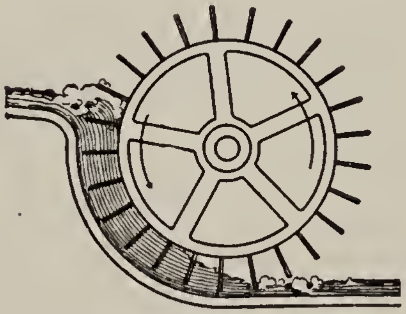

Fig. 293.—The breast wheel.

Water Motors

582. Kinds of Waterwheels.—Running and falling water has been used since the beginning of civilization to produce power and do work for man. Waterwheels of different kinds have been used. Overshot, breast, and undershot wheels are the older types, while the impulse and turbine wheels are of recent origin.

583. Overshot Wheels.—Overshot wheels have generally been used when a small stream having a considerable fall is available (Fig. 292). Why? Such wheels are sometimes 50 or 60 ft. in diameter and may develop an efficiency of 80 or 90 per cent. How is the power produced by such a wheel?

584. Breast Wheels.—Breast wheels are generally used when a larger flow of water is available but less fall can be secured (Fig. 293). How does this wheel differ from the overshot wheel? The efficiency of the breast wheel is usually less than that of the overshot wheel. Can you see why this should be so?

585. Undershot Wheels.—Undershot wheels are used when only a slight fall of water is obtainable (Fig. 294). While the weight of the falling water is the principal source of power in the overshot and breast wheels, in the case of the undershot wheel, the force of the impact of the water against the blades or paddles is the chief source of power. Undershot wheels frequently have low efficiency. Why is this so?

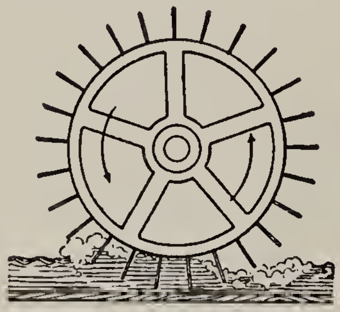

Fig. 294.—The undershot wheel.

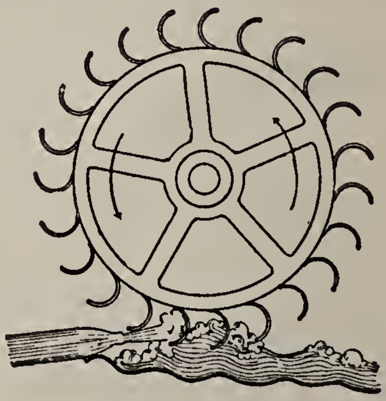

Fig. 295.—The Pelton wheel or impulse wheel.

586. Impulse Wheels.—Impulse wheels are used when there is a small supply of water but available under a great "head" or pressure. Frequently small streams or lakes located high up in a mountain may be utilized for power purposes. In such cases the water is often conveyed down the mountain side in strong iron pipes. At the foot of the mountain, the water under high pressure is permitted to escape through a nozzle at high velocity. This stream is directed against cup-shaped buckets on the rim of the wheel (Fig. 295). After striking the buckets, the water falls to the ground robbed of its energy.

These wheels have some advantages over other kinds of waterwheels: They can easily be changed in location. They are small compared with other wheels for the amount of power they are able to produce. One such wheel constructed several years ago was but 3 ft. in diameter and received its supply of water from a stream 2100 ft. above the wheel. The diameter of the nozzle was but ½ in. and yet the wheel did

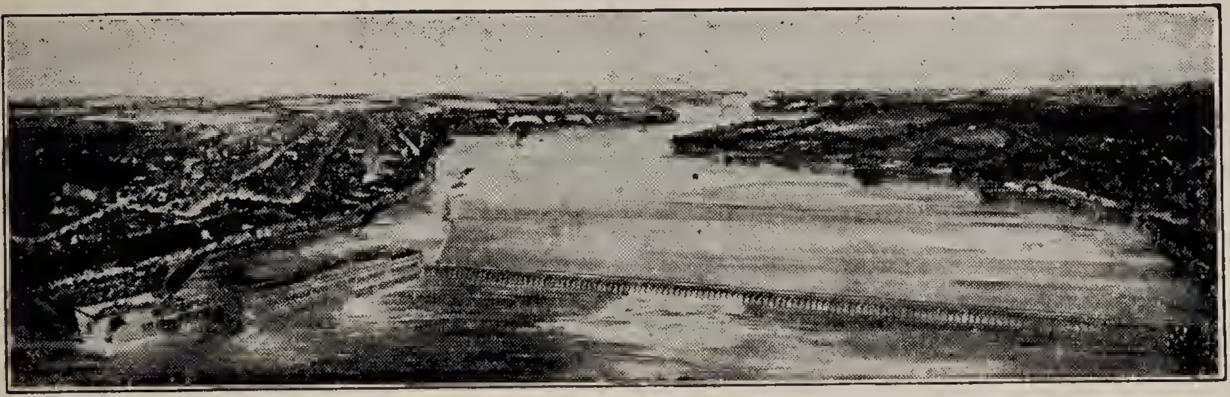

Fig. 296.—General view of the Mississippi River, the locks, the power house and the dam at Keokuk. The power plant is capable of producing 300,000 horse-power. It cost $25,000,000.

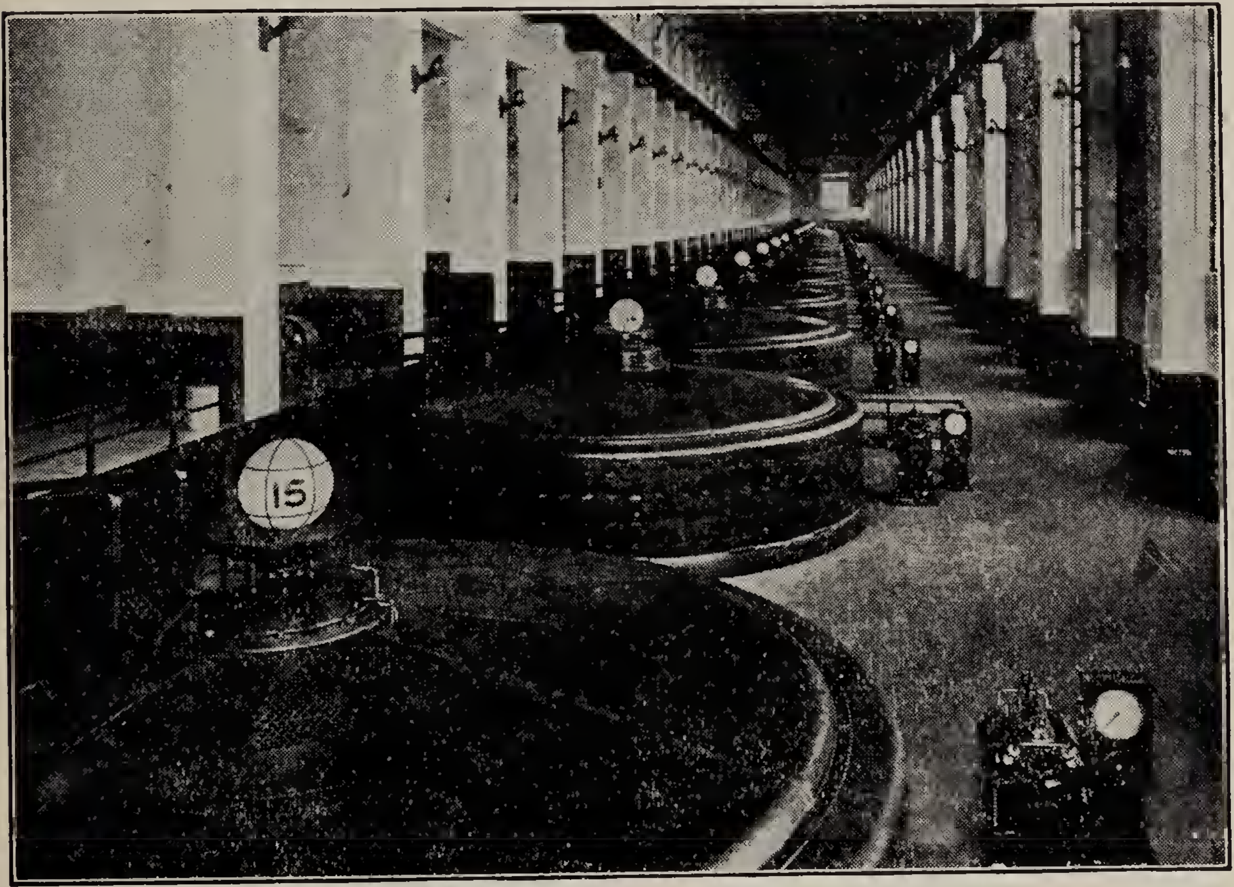

Fig. 297.—Interior view of the power house at Keokuk showing the 15 generators now installed, each of which produces 10,000 horse-power of electrical energy.

100 horse-power of work. The efficiency of impulse wheels is frequently 80 or 90 per cent.

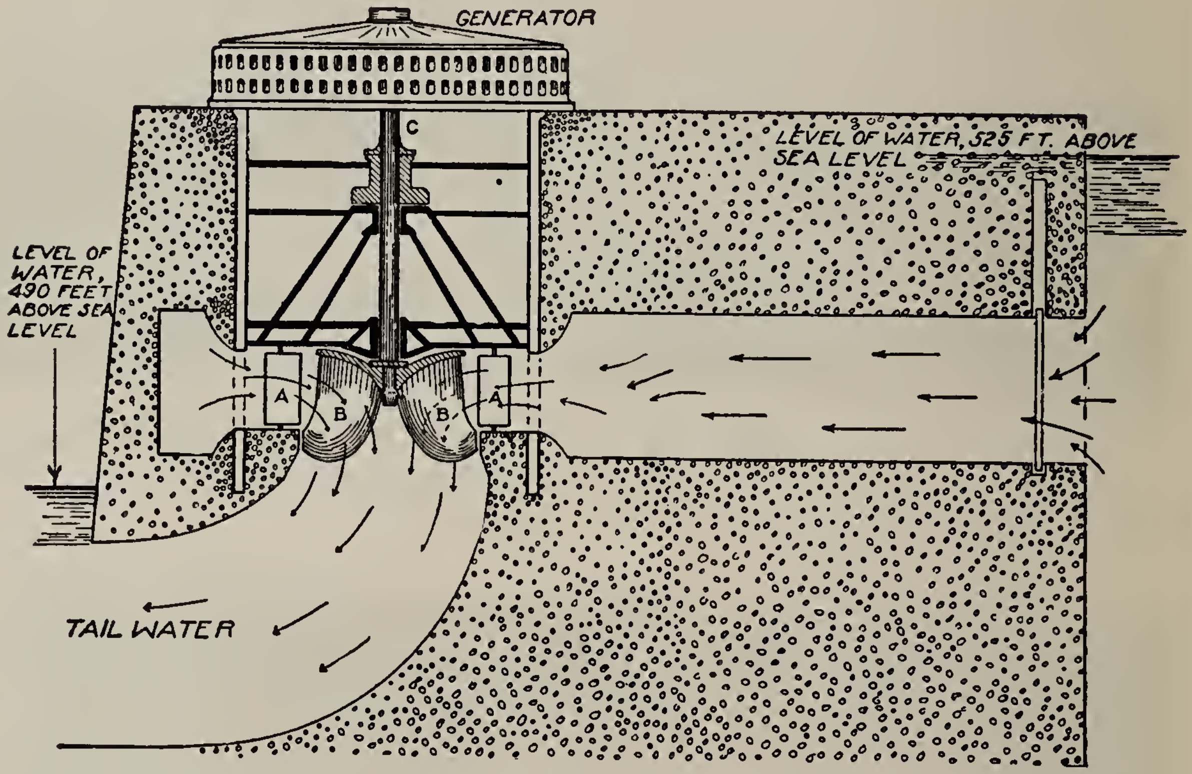

Fig. 298.—Vertical cross section of the turbine pit.

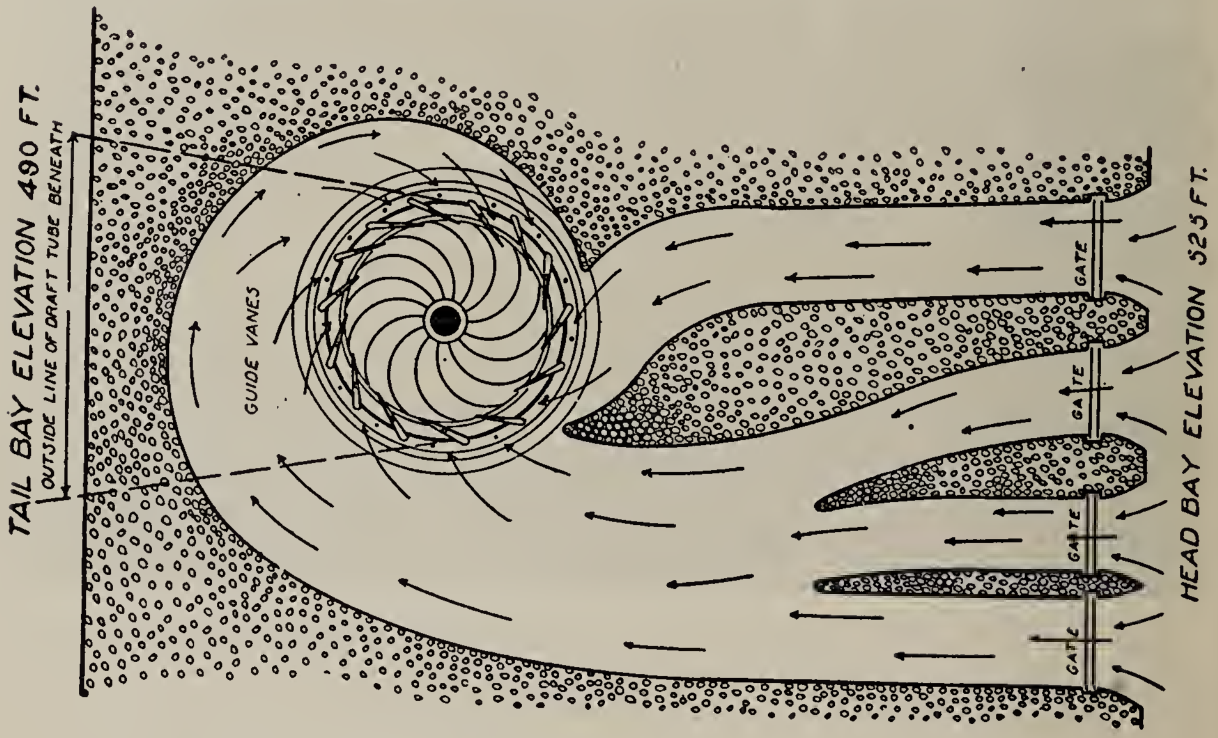

Fig. 299.—Horizontal cross section of the turbine pit.

587. Turbine Wheels.—Turbine wheels are now generally taking the place of the older types of wheels. The water power at Niagara Falls as well as that of the Mississippi River at Keokuk, Iowa (Fig. 296), is developed by means of turbine wheels. At Niagara they operate under a "head" of about 170 ft. and at Keokuk with a "head" of about 30 ft. At the present time 500,000 horse-power is developed at Niagara Falls and 150,000 horse-power at Keokuk (Fig. 297).

The turbine wheel is placed at the bottom of a cylindrical well or pit. The water at the bottom of the well is under high pressure and is forced horizontally through spaces between fixed or stationary vanes set at a certain angle (Figs. 298 and 299). The water strikes against the vanes or blades of the movable wheel causing it to rotate (Fig. 300). After its energy is expended upon the vanes of the movable wheel, the water drops into the outlet, or TAILRACE. A shaft which revolves with the wheel extends upward above the surface of the water where it runs a dynamo or other machinery.

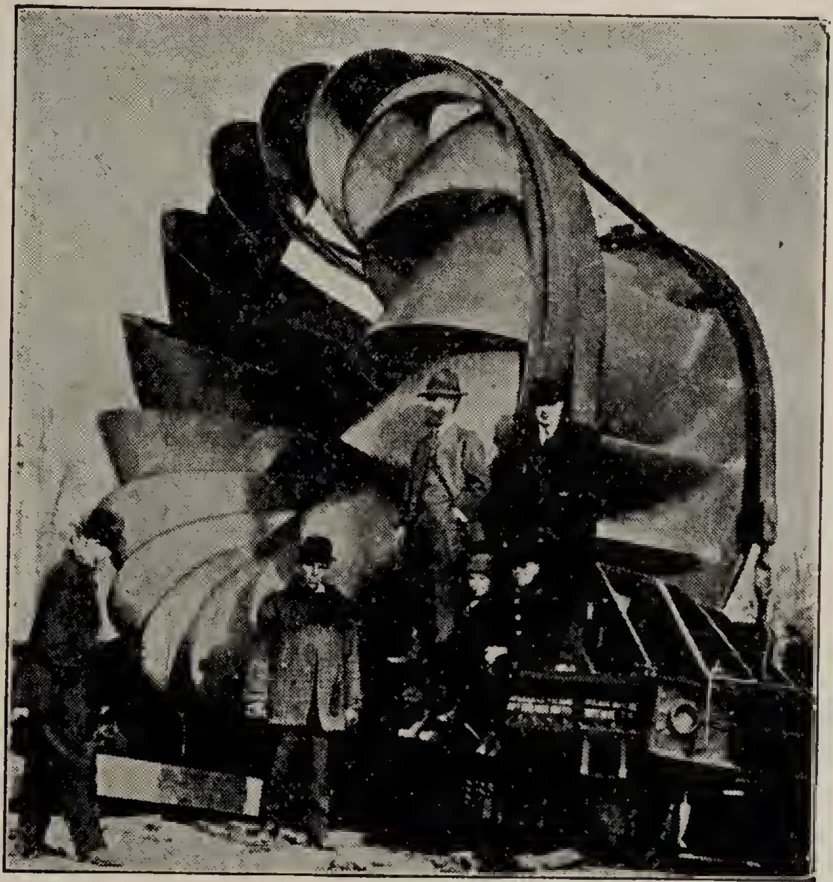

FIG. 300.—One of the turbine wheels in the Keokuk power plant. It hangs on the bottom of a steel shaft over two feet in diameter and turns one of the 10,000 h.p. generators shown in Fig. 297.

Turbine wheels are generally used where a large flow of water under a moderate ''head'' is available. They often give an efficiency of 80 or 90 per cent.

SOURCE OF ALL ENERGY

588. The Sun is the Source of All Energy.—The original source of the energy in water power is the sun. We have seen that water is constantly evaporating when exposed to the air. Evaporation is constantly taking place from every body of water, from every moist surface, and from the leaves of plant life (Art. 12 and 176). We have also seen that evaporation always means the absorption of heat and the production of cold (Art. 178). It would seem, therefore, that this constant evaporation ought to result in the lowering of the temperature of the earth's surface. Moreover, the heat of the earth's crust is constantly radiating through the atmosphere into space. Why, then, does not the earth's surface become so chilled that all of the water upon it is frozen and all life disappears? See Chap. IV, Arts. 219 to 223, for your answer. Review the cause of precipitation, *i.e.*, of rain and snow. The source of energy in running and falling water is the elevation of water by evaporation and the distribution of the water vapor over the earth's surface by winds, both of which are due to energy from the sun.

We have seen that the energy in all plant and animal life is also originally obtained from the sun (Chap. VII, Art. 373). Coal is known to be the product of the remains of plant life long ago buried in the earth's crust. Geologists tell us that petroleum also is the result of decomposed plant and animal matter which was buried ages ago. *The sun is the original source of all stored-up energy which man may use to produce power.*

589. Water Power, the Cheapest of All Power.—Water power is today the least expensive of all available power. So long as the sun continues to pour its energy down upon the earth, so long will evaporation continue to take place, the rain will continue to fall, and running water will be available to do work for mankind. The largest expense connected with obtaining power from running water is the cost of constructing the necessary dams and installing the machinery of the plant. This often requires a large outlay of capital. The cost of producing the power after the plant is once installed is small. When man wishes to obtain power from coal or petroleum, he must first raise them to the earth's surface, and this requires much labor and expense.

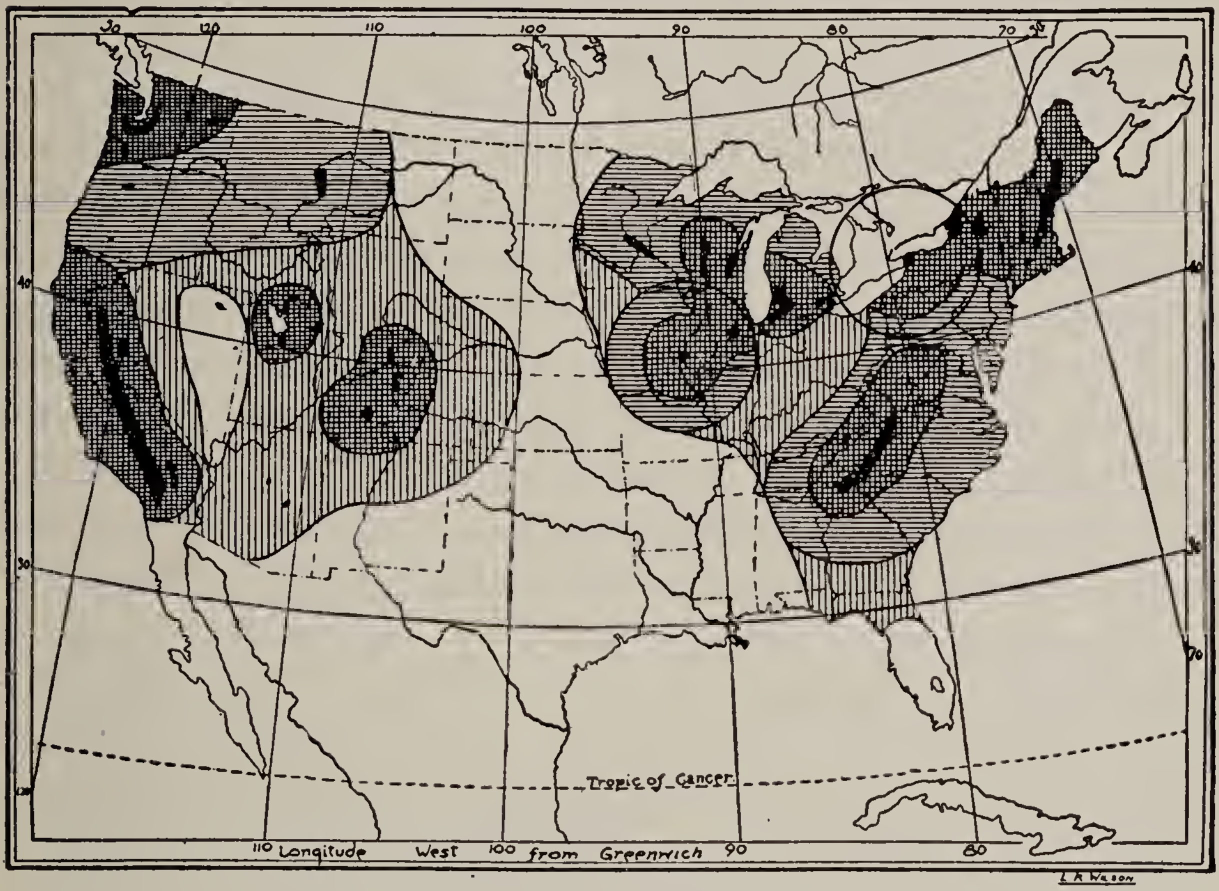

FIG. 301.—Distribution of water power of United States. The heavily shaded portions show the regions where water power is easily available; the horizontally shaded portions, where hydro-electric power is easily available; the vertical shading, where hydro-electric power is possibly available.

AVAILABLE WATER POWER OF THE UNITED STATES

590. Amount of Water Power Available.—The government has estimated that there is sufficient available water power in the United States, if it were utilized, to run every machine in all our factories and mills, to propel all our railroad trains, street cars, and automobiles, to light all our streets and homes—in fact to operate every machine in the United States. Only about one-fifth of this power is, however, now being utilized, the rest is running to waste. About 50,000,000 horse-power is now required in the United States for power purposes. About 10,000,000 horse-power of water power has thus far been developed. The use of water power is, however, growing rapidly.

591. Distribution of Water Power.—One of the principal reasons why so small a portion of our available water power has been developed is the fact that generally water power can be developed only in mountainous, or at least, in hilly regions. Why? Most of the water power thus far developed is located in New England, New York, and Pennsylvania; along the Appalachian Mountains from Georgia northward; in Michigan, Wisconsin, and Minnesota; and along the Rocky and Sierra Nevada Mountains in the west (Fig. 301). The largest power plants in the United States are those at Niagara Falls and on the Mississippi River at Keokuk, Iowa. Much of the available water power is located some distance from the great manufacturing centers where it would be most useful.

592. Transmission of Power.—Recently it has been found possible to transmit energy in the form of electric current a distance of 200 miles with profit. On the map (Fig. 301), a circle with a 200 mile radius has been drawn about the power plants at Niagara Falls and at Keokuk, Iowa. Any point lying within these circles may easily be supplied with power from these plants. St. Louis, Missouri, 137 miles distant, is now consuming the larger portion of the power generated at Keokuk (Fig. 302). Much of the power generated at Niagara Falls is sold in the cities of western New York. Many of the cities on the coast of California receive practically all their power from HYDRO-ELECTRIC PLANTS located many miles distant in the Sierra Nevada Mountains.

THE STEAM ENGINE

593. Importance of the Steam Engine.—No other device or machine invented by man has had as great an influence upon the material advancement of civilization as has the steam engine. It is estimated that the steam engines of the world are today doing from 150 to 200 million horse-power of work. This is many times the amount of work the entire population of the civilized world could do were every adult human being working daily at hard manual labor. The steam

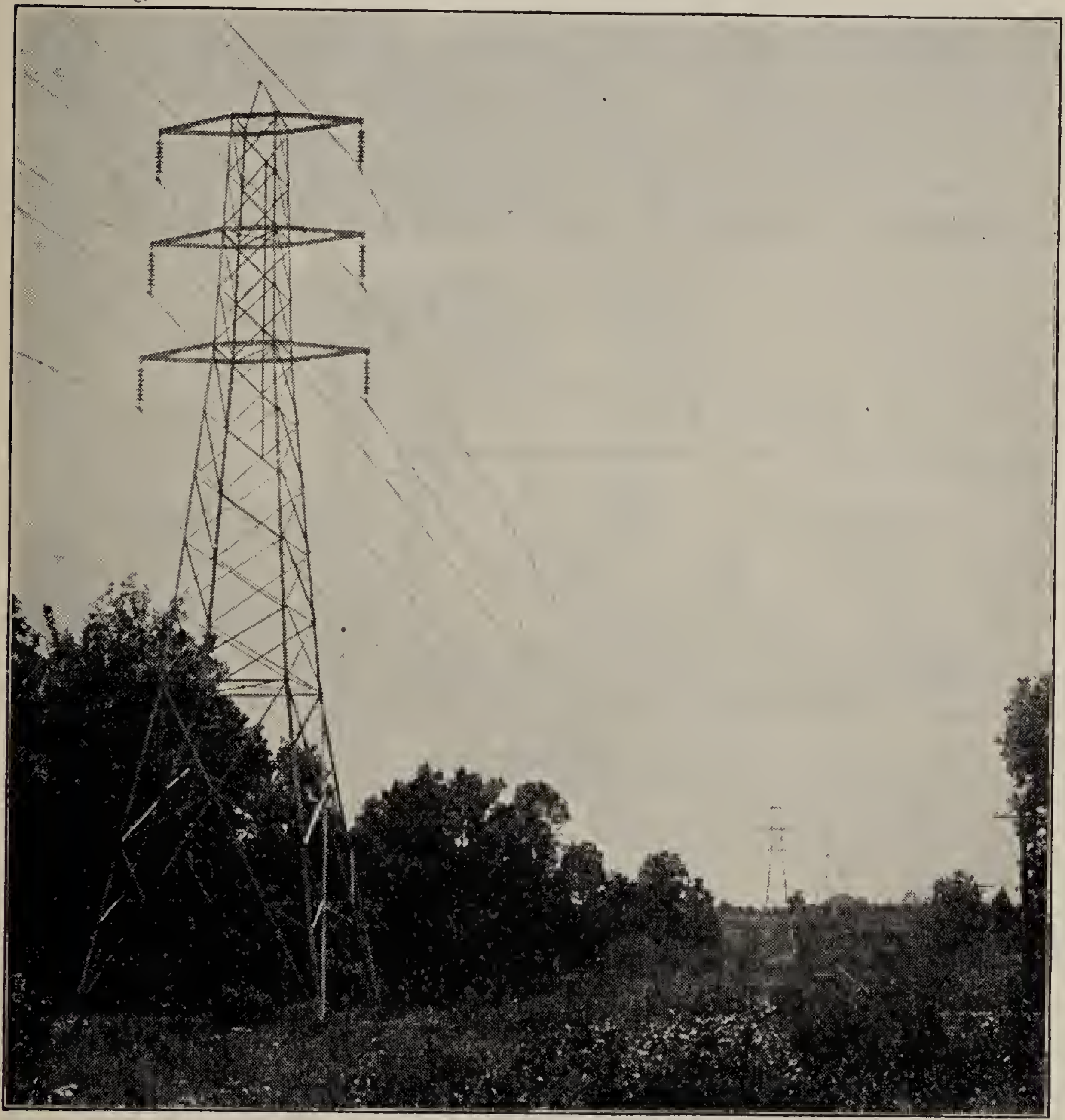

FIG. 302.—Line for transmission of electric power from Keokuk to St. Louis.

engine during the last century has largely freed civilized man from hard labor. It has made possible the mine, the mill, the factory, the steam ship, and the railroad. It has made man almost the complete master of the physical forces of the world.

594. Use of the Earliest Steam Engines.—It was just at the beginning of the 18th century (1700) that the steam engine first began to be recognized as a useful machine. During the 18th century, however, practically the only use to which it was put was the pumping of water from the mines of England. Before the invention of the steam engine many of the coal mines were frequently flooded and some were actually abandoned.

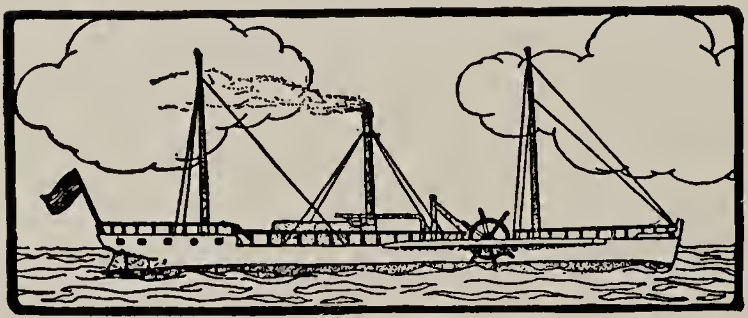

Fig. 303.—Fulton's steamboat, Clermont. (From *Stories of Useful Inventions.* Courtesy of the Century Company.)

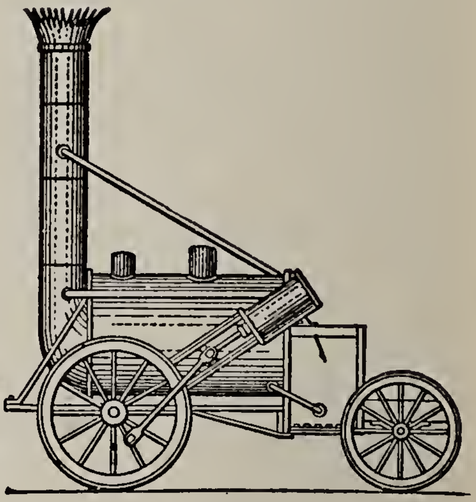

Fig. 304.—The Rocket. (From Hoadley's *Essentials of Physics.* Courtesy of American Book Co.)

It was not until the closing years of that century that people really began to believe that the steam engine could be used successfully for other purposes. It was about 1785 that the first experimental steamboats were made and not until 1807 that Fulton made the Clermont (Fig. 303), the first really successful steamboat. It was not until 1825 that Stevenson constructed the Rocket (Fig. 304), the first successful locomotive. Today the steam engine is probably doing three-fourths of the work done in the civilized world.

595. Source of Power in the Steam Engine.—When water is changed into steam it expands about 1600 times in volume; a cubic inch of water becomes nearly a cubic foot of steam. If the boiling water and steam are confined in a closed vessel, a boiler, the steam soon develops great pressure and it is this pressure which is utilized in the steam engine.

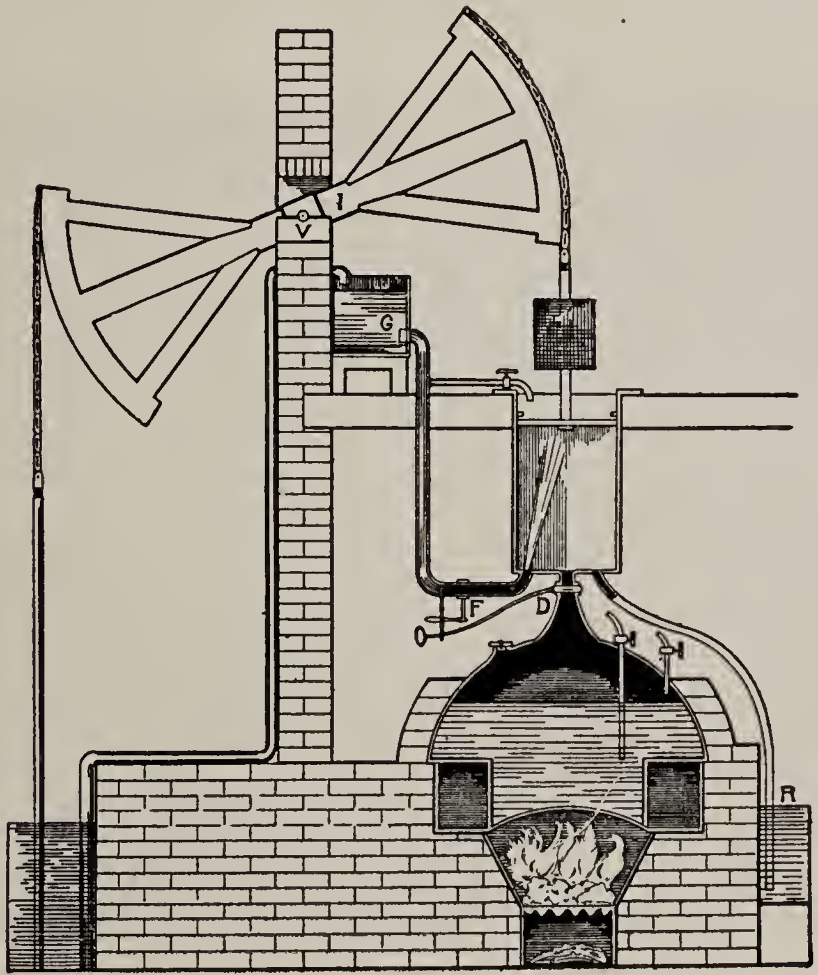

FIG. 305.—The Newcomen air-steam engine, 1705.

596. The Newcomen Air-steam Engine.—Although several devices using steam had earlier been invented, the first really useful engine was invented by an Englishman named Newcomen in 1705. The NEWCOMEN ENGINE, however, was an *air-steam* engine; in fact, it was not steam pressure but air pressure which actually did the work. For about three-quarters of a century, or until about 1874, this air-steam engine was the only type known and used.

597. Principle of the Newcomen Engine.—The principle of this engine is shown in Fig. 305. The only use to which this engine was put was pumping water. The pump-rod and piston were balanced at the two ends of a beam, *I*, which was free to rotate on its axis, *V*. The piston moved up and down in the cylinder. When the valve, *D*, was opened, steam rushed into the cylinder as the piston moved up and the pump-rod descended. The valve, *D*, was now closed and the valve, *F*, opened. This permitted a spray of cold water from the tank, *G*, to enter the cylinder. This spray of cold water condensed the steam in the cylinder, producing a vacuum in the cylinder beneath the piston. The air pressure upon the upper surface of the piston then forced the piston down to the bottom of the cylinder. This raised the pump-rod and plunger. This was the working stroke. The water spray was then cut off and the water and condensed steam drained off into the reservoir, *R*, which had to be placed about 30 ft. below the cylinder. Do you see why? [Review air pressure (Arts. 150-152) and pumps (Art. 483 to 486).] The valve, *D*, was again opened, the spray of water again admitted and a second stroke was completed.

598. **Humphrey Potter's Invention.**—At first the valves, *D*, and *F*, were operated by hand. It was an easy task and a boy did the work. Only about six or eight strokes were usually made each minute. It is recorded that an ingenious boy, Humphrey Potter, in 1713, tiring of this task, contrived a system of levers and strings fastened to the moving beam in such a manner as to operate the valves automatically (Fig. 306). This boy's invention doubled the amount of work which the engine could do, for the valves were now opened and shut exactly at the right moment. With this improvement the Newcomen engine made 15 or 16 strokes each minute. But at its best this engine was extremely wasteful of fuel. It required 35 to 50 lbs. of coal to do a horse-power-hour of work, some eight to ten times as much as is required by steam engines today (see Art. 575).

599. **Watt's Improvement.**—It remained for James Watt,

a Scotchman, to perfect the steam engine. About 1774, Watt so perfected the steam engine that it became practically the engine of today. He discovered the chief source of energy loss in Newcomen's engine and overcame it. He saw that the chief difficulty with Newcomen's engine was the loss of heat energy about the cylinder. He was determined to reduce this loss; to do so he made three important improvements:

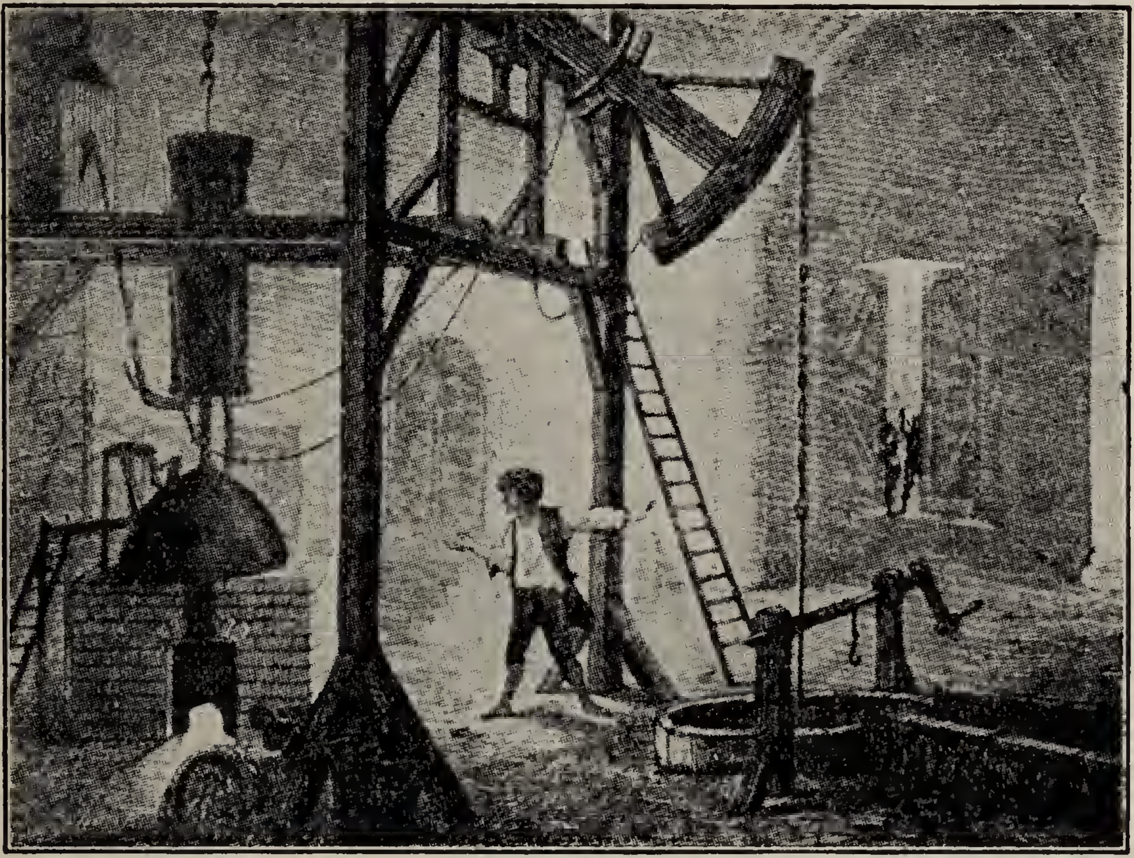

FIG. 306.—Humphrey's latches and strings. (From *Stories of Useful Inventions.* Courtesy of the Century Company.)

First, Watt saw that the spray of cold water forced into the cylinder at each stroke so cooled the cylinder and piston that a large amount of the energy in the steam admitted at the next stroke was consumed in reheating the cylinder. He therefore provided for the condensation of the exhaust steam in another vessel (H, Fig. 307) which was constantly surrounded by cold water. He also surrounded the cylinder with a jacket of steam.

Second, Watt made his an *all-steam-engine* whereas Newcomen's was an *air-steam* engine. His purpose in doing so was to keep the cylinder hot. The upper end of the cylinder of Newcomen's engine was open to the air and air pressure was used to force the piston down. The piston and cylinder were, therefore, constantly losing heat to the air. Watt closed both ends of the cylinder of his engine and made the piston rod work through a STUFFING BOX, a small opening packed steam-tight, just as steam engines are constructed today.

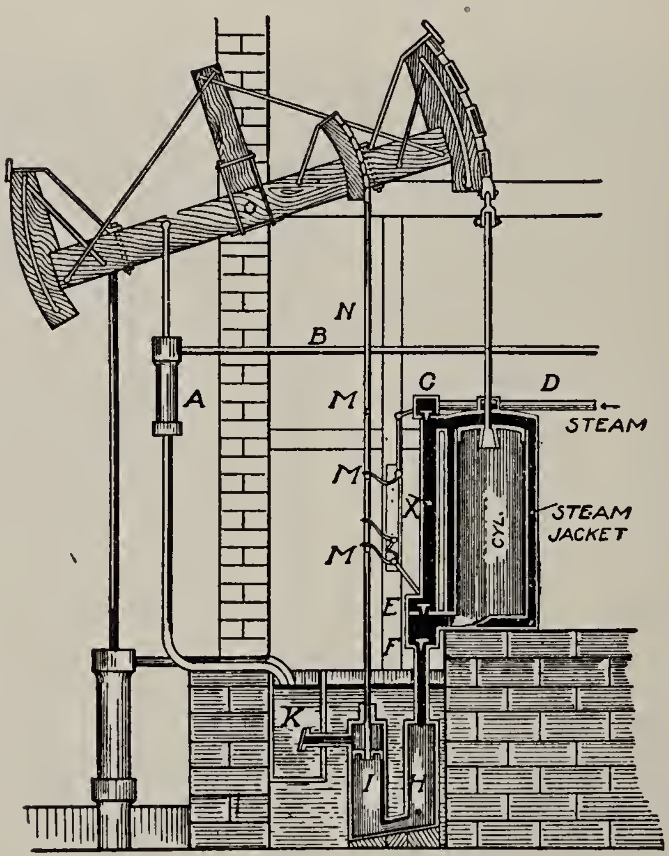

FIG. 307.—Watt's engine.

Third, Watt's third improvement was to use oil to lubricate the piston and prevent the steam from passing it. It was impossible in those days for mechanics to make the pistons and cylinders as true and close fitting as they are made today. To prevent the steam from escaping past the piston as well as to lubricate it, Newcomen kept a stream of water running constantly upon the upper surface of the piston of his engine (Fig. 305). This water absorbed a large amount of the heat from the steam.

These improvements by Watt greatly increased the efficiency of the steam engine. It now did the same amount of work while using but about one-fourth as much coal as Newcomen's engine used. We must remember that Watt's motto was: "Keep the cylinder and piston as hot as possible all the time," a rule which is followed in all steam-engine construction today.

600. How Watt's Engine Worked.—In Watt's engine the steam entered through the pipe (*D*, Fig. 307). Just as the piston reached the top of the cylinder the valves *C* and *F*, were opened and the valve, *E*, closed. The opening of the valve, *C*, permitted the steam to flow into the cylinder above the piston forcing it downward. The opening of the valve, *F*, permitted the steam in the cylinder below the piston to escape into the vessel, *H*, where it was condensed by the surrounding cold water. The condensation of this steam tended to produce a vacuum in the lower portion of the cylinder. The steam also entered the jacket surrounding the cylinder; thus the cylinder was always kept hot. Just as the piston reached the bottom of the cylinder the valves, *C* and *F*, closed and the valve, *E*, opened. The steam could then no longer enter from the pipe, *D*, but it could flow through the pipe, *X*, from the upper portion of the cylinder into the lower portion. The pressure was now the same on both sides of the piston and the weight of the pump-rod pulled that end of the beam down and so raised the piston again to the top of the cylinder. The valves were operated by the pins, *M*, *M*, *M*, on the rod *N*. The water formed by the condensation of steam was forced by the pump, *I*, into the hot well, *K*. The pump *A*, raised this warm water from the hot well and forced it into the boiler again through the pipe, *B*.

601. Watt's Double Acting Engine.—While the engine just described was by far the most economical and effective engine which had ever been made, still, Watt was not satisfied. Live steam, *i.e.*, steam under full pressure, entered only one end of the cylinder and actually did work only while forcing the piston downward. About 10 years later, 1784, Watt invented a DOUBLE ACTING ENGINE, *i.e.*, one in which the steam under full pressure entered first one end of the cylinder and then the other. In this way the piston was forced first to one end of the cylinder and then the other end by the live steam.

602. The Modern Steam Engine.—The Construction and operation of the modern steam engine is shown in Fig. 308.

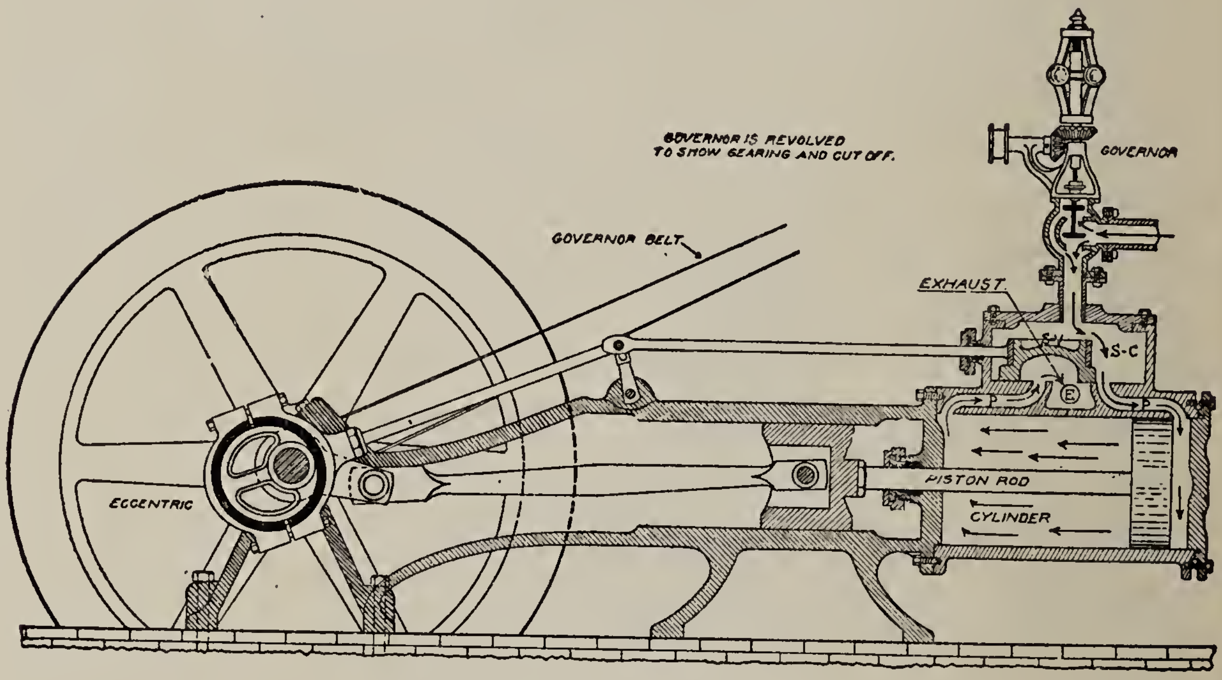

FIG. 308.—The modern steam engine.

The governor controls the speed of the engine by controlling the rate at which the steam enters the cylinder. The governor belt running from the shaft of the flywheel causes the governor to revolve. As the speed increases, the heavy balls, owing to centrifugal force (Art. 542, Ex. 84), tend to swing farther out, *i.e.*, revolve in a larger circle. As they do so they force the cut-off valves down, thus reducing the flow of steam. As the flow of steam decreases, the force with which the piston is driven becomes less and the speed of the flywheel is lessened. As the speed of the flywheel becomes less, the cut-off valves again rise admitting more steam. Thus the speed of the engine is automatically controlled.

After passing the governor cut-off valves, the steam enters the steam chest, *S-C*. From the steam chest it passes through the port, *P*, into the right-hand end of the cylinder. The steam pressure then forces the piston to the left. The steam in the left end of the cylinder escapes through the other port, *P*, to the exhaust, *E*, whence it escapes to the air or the condenser.

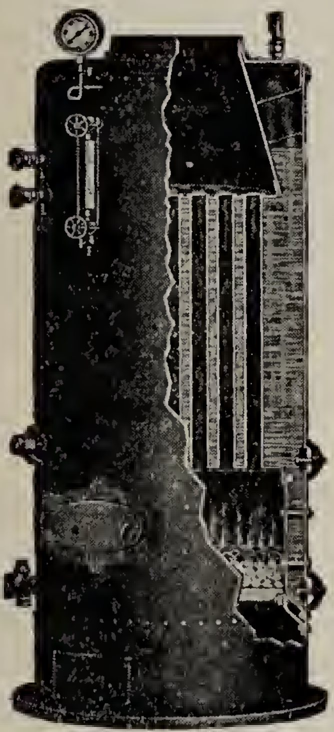

FIG. 309.—An upright boiler with casing cut away, showing the tubes.

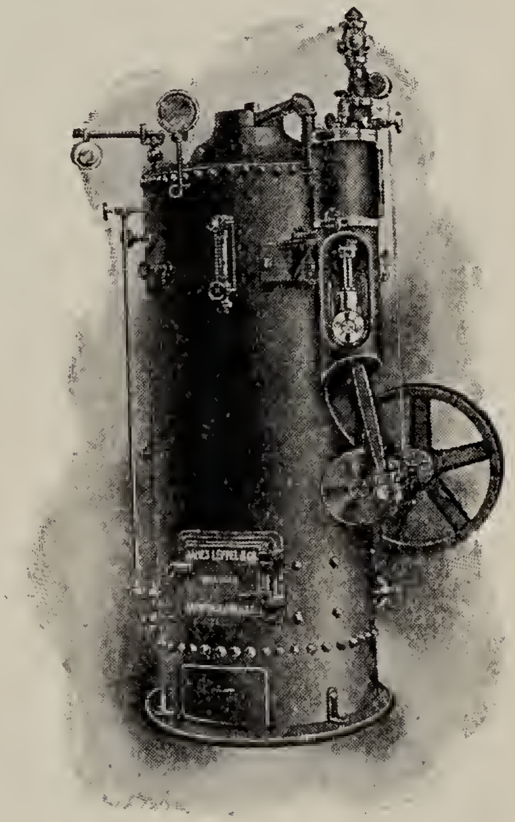

FIG. 310.—An upright boiler with the engine attached to the side of the boiler.

An ingenious device called the ECCENTRIC on the shaft of the flywheel operates the slide valve, *S-V*. Just as the piston reaches the left end of the cylinder, the slide valve is moved far enough to the right to admit the steam to the left end of the cylinder and allow the steam in the right end of the cylinder to escape through the exhaust.

THE GAS ENGINE

603. The Internal Combustion Engine.—We have seen that in the case of the steam engine the fuel is burned beneath the boiler, producing steam which is then conveyed to the engine. It is evident that the boiler may be located some distance from the engine. In gas engines, however, the fuel is burned *within* the cylinder of the engine. Such engines are, therefore, called INTERNAL COMBUSTION ENGINES.

604. The Fuel of Internal Combustion Engines.—Such engines may burn almost any kind of combustible gases. Everybody is somewhat familiar with such engines burning gasoline and used in automobiles or on farms. But internal combustion engines, or gas engines as they are commonly called, may also use as fuel natural gas, coal gas, water gas, kerosene, crude petroleum, or alcohol.

605. The Earliest Gas Engines.—The first really successful internal combustion engines burned gasoline. They were made in France and Germany in 1861 and 1862. The first successful gas engines made in the United States were made in 1873.

606. Importance of the Gas Engine.—For many years these engines were not of great importance. They were then used only where small amounts of power were needed occasionally and in places where other power was not easily obtainable. In recent years, however, engines burning gasoline, crude petroleum, and gas produced from coal, as a waste product from blast furnaces, have become of great importance.

607. The Gasoline Engine and the Automobile.—Many attempts have been made during the past two centuries to produce self-propelled vehicles adapted to use on public streets and country roads (Fig. 311). Until the gasoline engine was perfected little progress was made in this direction. The ordinary steam engine was found to be too heavy and cumbersome to be easily adapted to this use. The modern gasoline engine for use in automobiles weighs but about

10 or 15 lbs. to the horse-power; moreover, it is ready for use at all times and can be started at a moment's notice. The chief advantages, then, of the gasoline engine for this purpose are its comparative lightness and the fact that no time need be lost in heating it ready for service.

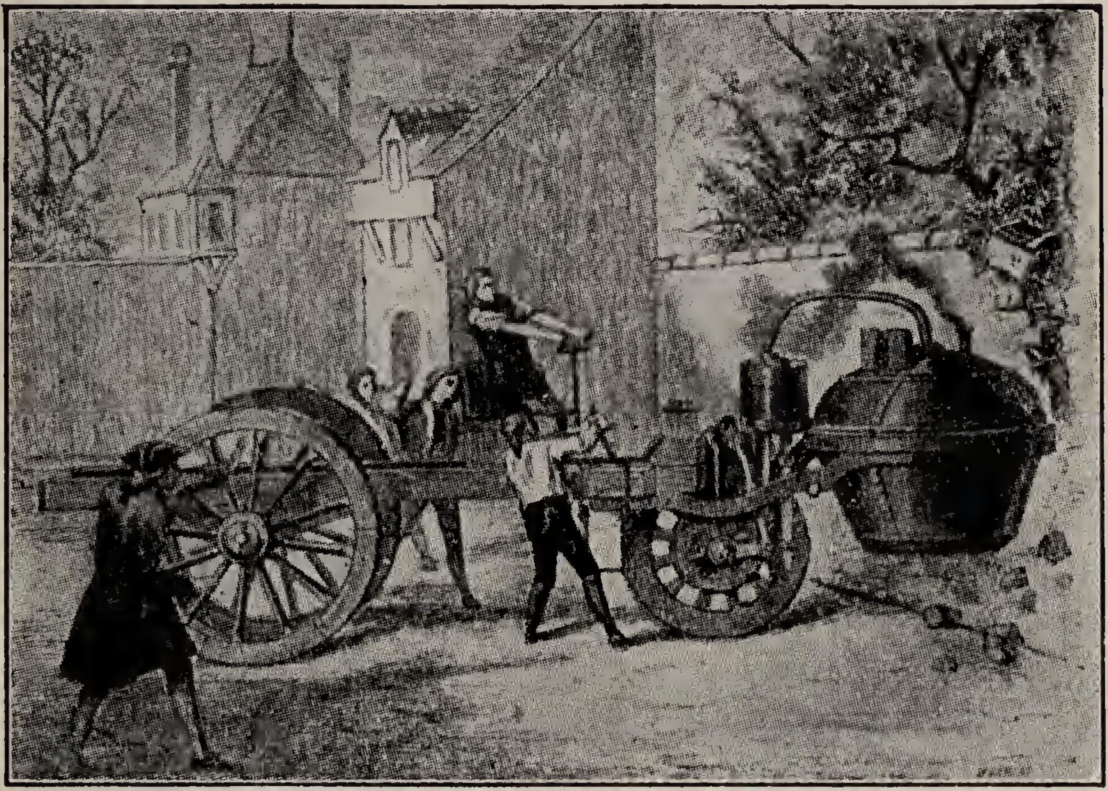

FIG. 311.—Cugnot's steam carriage, 1769. (From *Stories of Useful Inventions.* By Courtesy of the Century Company.)

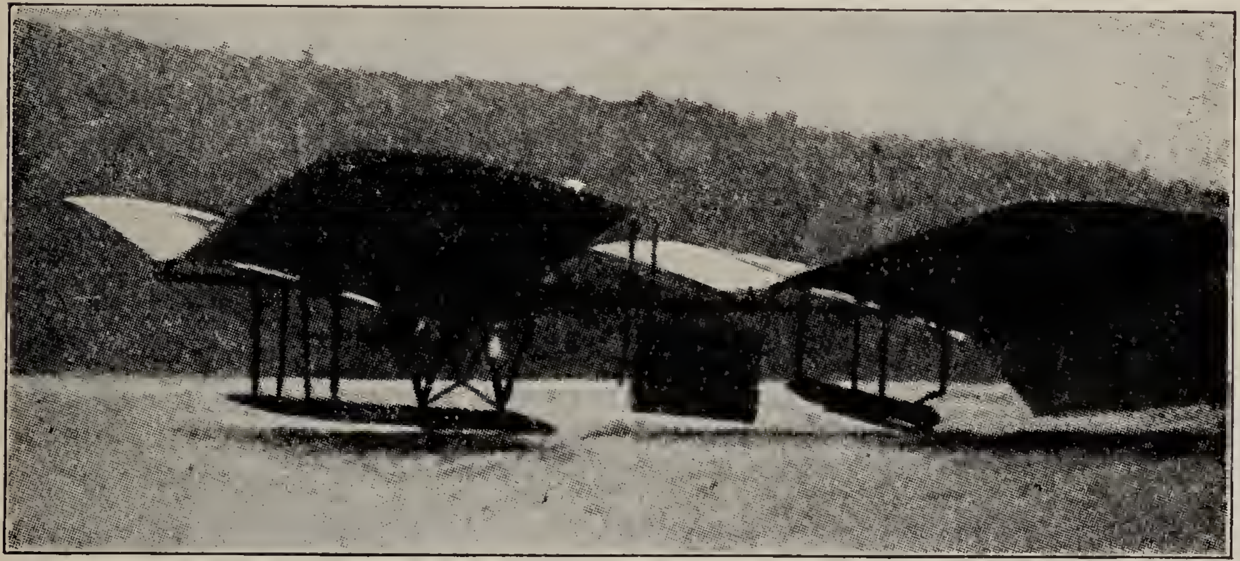

FIG. 312.—The Langley aeroplane flying, May 28, 1914.

608. Gasoline Motors and Aeroplanes.—For many centuries men have looked forward to the day when they should be able to navigate the air, to fly as birds do. Experimenters realized the necessity of producing a motor of great power with as little weight as possible. Before the end of the last century, in 1896, Prof. Langley at Washington, D. C., constructed a steam-driven flying machine which flew without a passenger several times, once more than a half mile over the Potomac River before its fuel supply was exhausted and it fell of its own weight into the water.[1] All attempts to produce a successful "heavier-than-air" flying machine failed until the gasoline engine was highly perfected. Every other type of motor has proved too heavy for the power it could

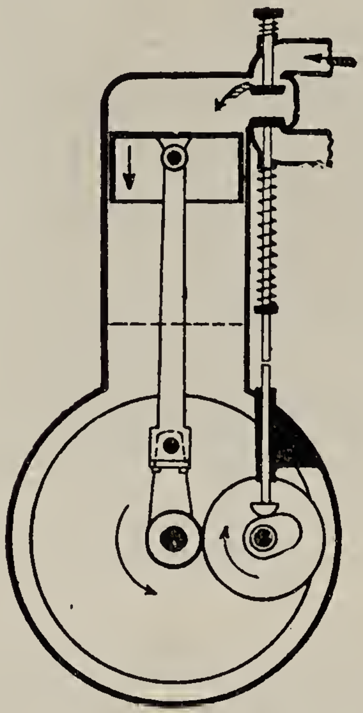

FIG. 313.—First cycle, diagram. Suction stroke.

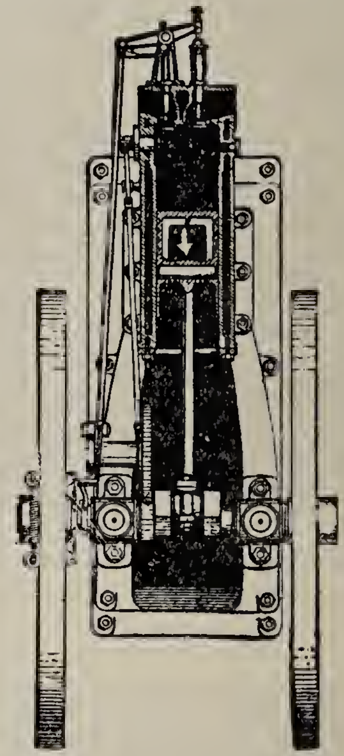

FIG. 314.—First cycle, engine. Suction stroke.

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[1] It is an interesting fact that two attempts were made in 1904 to prove that Langley's aeroplane could fly while carrying a pilot. Upon both occasions, however, the machine plunged into the river as quickly as it was launched. It is now known that the trouble lay partly in the inexperience of the pilot. On May 28, 1914, Glenn Curtis, an experienced flyer, made a successful flight with the Langley aeroplane which had rested for years in the archives of the Smithsonian Institute and had been styled "Langley's Folly" (Fig. 312).

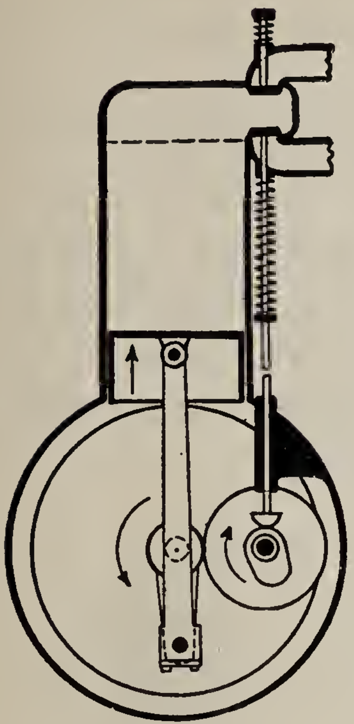

Fig. 315.— Second cycle, diagram. Compression stroke.

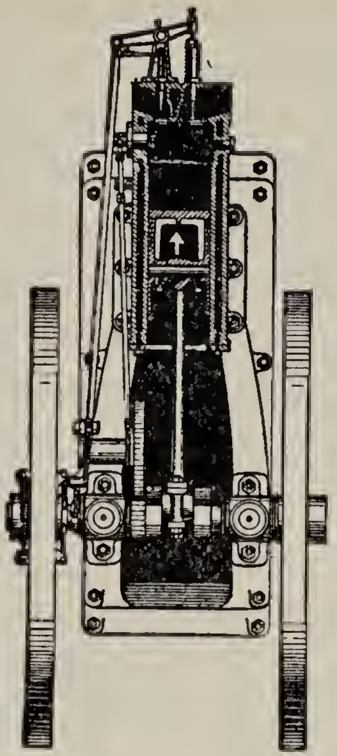

Fig. 316.— Second cycle, engine. Compression stroke.

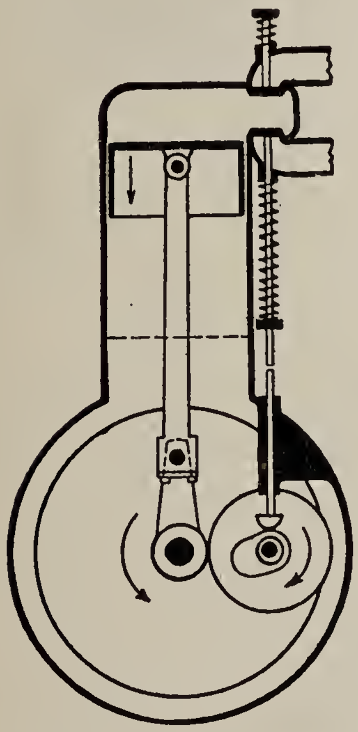

Fig. 317.— Third cycle, diagram. Working stroke.

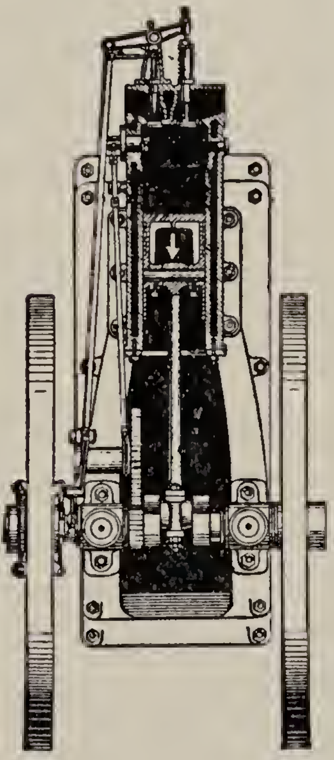

Fig. 318.— Third cycle, engine. Working stroke.

produce. Gasoline motors now used on aeroplanes are marvels of lightness and power. Such engines usually weigh but from 3 to 5 lbs. per horse-power.

609. How the Gas Engine Works.—Like Newcomen's air-steam engine, the gas engine cylinder is closed only at one end. The mixture of gas and air is admitted into the closed end of the cylinder and then ignited. Rapid combustion takes place, producing very high temperature thus expanding the gases greatly. The pressure produced drives the piston to the opposite end of the cylinder.

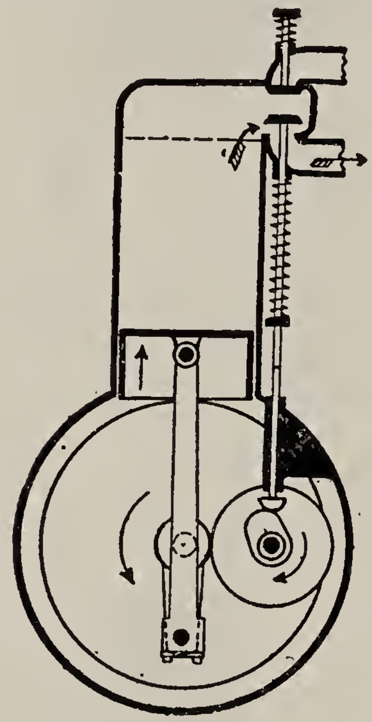

Fig. 319.—Fourth cycle, diagram. Exhaust stroke.

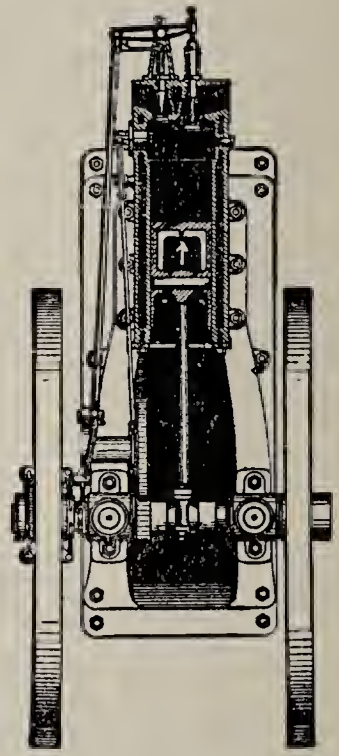

Fig. 320.—Fourth cycle, engine. Exhaust stroke.

610. The Four-cycle Engine.—Most gas engines are of the type known as FOUR-STROKE OR FOUR-CYCLE engines. By this is meant that the piston moves the length of the cylinder four times and the flywheel makes two revolutions for each explosion of gas. The operation of the engine is as follows:

First Stroke: The piston moves from the closed end of the cylinder to the open end. This produces a partial vacuum, and suction causes air charged with a gaseous fuel or a mixture of air and gas to rush in through the intake valve (Figs. 313 and 314).

Second Stroke: The piston moves from the open end of the cylinder to the closed end. This compresses the charge of fuel and air to from one-fourth to one-fifteenth of its original volume, depending upon the kind of fuel used (Figs. 315 and 316).

Ignition: Just at the end of the second stroke the charge is ignited, usually by an electric spark.

Third Stroke: This is the expansion or WORKING STROKE. The burning gases produce great pressure upon the piston and drive it toward the open end of the cylinder (Figs. 317 and 318).

Fourth Stroke: The exhaust valve is opened and as the piston returns to the closed end of the cylinder it forces the products of combustion out through the exhaust port (Figs. 319 and 320).

The four strokes are (1) suction stroke, (2) compression stroke, (3) working stroke, (4) exhaust stroke. These four strokes constitute one complete cycle or round of action.

611. Purpose of Compression.—The purpose of compressing the gas before igniting it is to secure the most rapid combustion possible. The gas in the cylinder is much like brush in a brush heap. If we wish the brush to burn rapidly we must tramp it down into a compact mass. The more compact the brush, the more rapidly it burns and the hotter the fire. In like manner the compression of the gas in the cylinder produces more rapid combustion, and hence a higher temperature. Greater pressure on the piston results.

612. Compression Must Not be too Great.—Whenever a gas is compressed heat is produced. The pump becomes hot when we "pump up" a bicycle or automobile tire. In compressing the gas in the cylinder of a gas engine, care must be taken that the temperature of the gas is not raised to the kindling temperature (see Art. 77) before the end of the compression stroke. What would be the result if the gas were ignited during the second stroke? How would this affect the power of the engine?

613. Compression for Different Gases.--Different fuels require different amounts of compression to produce the largest amount of power. In practice, the different gases are compressed about as follows:

Kerosene, compressed to about $\frac{1}{4}$ to $\frac{1}{5}$ of its original volume,
Gasoline, compressed to about $\frac{1}{5}$ to $\frac{1}{6}$ of its original volume,
Alcohol, compressed to about $\frac{1}{10}$ to $\frac{1}{15}$ of its original volume,
Natural gas, compressed to about $\frac{1}{7}$ to $\frac{1}{10}$ of its original volume,
Coal gas, compressed to about $\frac{1}{6}$ to $\frac{1}{10}$ of its original volume.

614. Keeping the Cylinder Cool.—We saw that Watt, when developing the steam engine, adopted the motto, "Keep the cylinder as hot as possible." With gas engines, however, the danger is that the cylinder will get too hot—hot enough to ignite the gas too soon. The cylinders of small gas engines are sometimes cooled by air, a fan forcing the air past the cylinder. Such engines are called AIR-COOLED ENGINES. All large gas engines are WATER-COOLED ENGINES. The cylinders of water-cooled engines are surrounded by jackets similar to the jackets Watt used on his steam engines. But in this case the jacket contains flowing water to keep the cylinder *cool* instead of steam to keep the cylinder *hot.*

615. Need of the Heavy Flywheel.—We have seen that in the four-cycle engine, force is being exerted upon the piston but one-fourth of the time, *i.e.*, during the third stroke. But the engine must continue to work all the time. We should therefore expect the engine to run with an unsteady motion. It would do so were it not for the the heavy flywheels. The heavy flywheels absorb a large amount of energy during the working stroke and give it up again during the other three strokes. Being massive they have great capacity for holding energy and therefore vary but little in speed during the cycle.

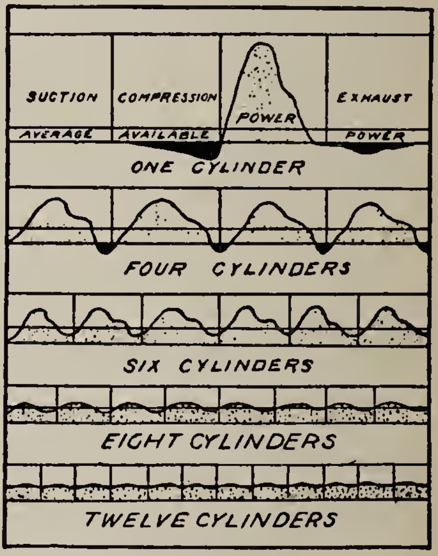

FIG. 321.—How several cylinders produce a constant, steady power.

616. Many-cylindered Engines on Automobiles.—It is undesirable to load an automobile with heavy flywheels, although a steady motion is very desirable. For this reason nearly all gasoline engines used on cars are constructed with several cylinders. The pistons of the four-cylinder engine are connected with the drive shaft in such a manner that, while one piston is performing the first stroke, another is performing the second stroke, the third piston the third stroke, and the fourth the fourth stroke. Thus we see that some one of the pistons is at work every instant. This produces a steady motion. In the six-cylinder, eight-cylinder, and twelve-cylinder engines the power is still more nearly constant (Fig. 321).

APPENDIX

WEIGHTS AND MEASURES

ENGLISH SYSTEM

LINEAR MEASURE OR MEASURES OF LENGTH

12 inches (in.) = 1 foot (ft.)
3 feet = 1 yard (yd.)
5½ yards = 1 rod (rd.)
16½ feet = 1 rod
320 rods = 1 mile (mi.)
1760 yards = 1 mile
5280 feet = 1 mile

SQUARE MEASURE OR SURFACE MEASURE

144 square inches (sq. in.) = 1 square foot (sq. ft.)
9 square feet = 1 square yard (sq. yd.)
30¼ square yards = 1 square rod (sq. rd.)
160 square rods = 1 acre (A.)
1 square mile = 1 section
36 square miles, or 36 sections = 1 township

CUBIC MEASURE OR MEASURE OF VOLUME

1728 cubic inches (cu. in.) = 1 cubic foot (cu. ft.)
27 cubic feet (cu. ft.) = 1 cubic yard (cu. yd.)

AVOIRDUPOIS WEIGHT

27.34 grains (gr.) = 1 dram (dr.)
16 drams = 1 ounce (oz.)
16 ounces = 1 pound (lb.)
100 pounds = 1 hundredweight (cwt.)
2000 pounds = 1 ton (T.)
2240 pounds = 1 long ton[1]
437½ grains = 1 ounce
7000 grains = 1 pound

[1] The long ton is used at the United States custom houses and often in wholesale transactions in coal and iron, as well as being in general use in Great Britain.

MEASURES OF TIME

60 seconds (sec.) = 1 minute (min.)
60 minutes = 1 hour (hr.)
24 hours = 1 day (da.)
7 days = 1 week (wk.)
365¼ days, or 12 months = 1 year (yr.)
10 years = 1 decade
10 decades, or 100 years = 1 century

UNITED STATES LIQUID MEASURE

4 gills (gi.) = 1 pint (pt.)
2 pints = 1 quart (qt.)
4 quarts = 1 gallon (gal.)

231 cubic inches = 1 gallon
31½ gallons = 1 barrel (bbl.)
57.75 cubic inches = 1 liquid quart

UNITED STATES DRY MEASURE

2 pints (pt.) = 1 quart (qt.)
8 quarts = 1 peck (pk.)
4 pecks = 1 bushel (bu.)

32 quarts = 1 bushel
67.2 cubic inches = 1 quart
2150.4 cubic inches = 1 bushel

HOUSEHOLD MEASURES (APPROXIMATE VALUES)

1 drop = 1/10 cubic centimeter
1 teaspoonful = 5 cubic centimeters
1 tablespoonful = 3 teaspoonfuls
16 tablespoonfuls = 1 cup
2 cups = 1 pint, liquid
1 pint, liquid = 473.1 cubic centimeters
1 pint, dry = 550.5 cubic centimeters

MISCELLANEOUS

1 United States gallon of water weighs 8.33 pounds
1 cubic foot of water weighs 62.3 pounds
1 cubic foot of dry air at sea level weighs 1.23 ounces
1 gallon of gasoline weighs about 6 pounds
The average air pressure at sea level = 1033 grams per square centimeter, or 14.7 pounds per square inch
1 horse power = 550 foot-pounds per second or 33,000 foot-pounds per minute
1 greater calorie (1 cal.) = 3080 foot-pounds
1 horse power-hour = 1,980,000 foot-pounds
1 horse power-hour = 640 greater calories
1 pound of coal yields from 3000 to 3200 greater calories of heat

METRIC SYSTEM

LINEAR MEASURE OR MEASURES OF LENGTH

10 millimeters (mm.) = 1 centimeter (cm.)
100 centimeters = 1 meter (m.)
1000 meters = 1 kilometer (km.)

SQUARE MEASURE OR MEASURES OF SURFACE

100 square millimeters (sq. mm.) = 1 square centimeter (sq. cm.)
10,000 square centimeters = 1 square meter (sq. m.)
1,000,000 square meters = 1 square kilometer (sq. km.)

MEASURES OF VOLUME OR CAPACITY

1,000 cubic millimeters (cu. mm.) = 1 cubic centimeter (cu. cm.)
1,000,000 cubic centimeters = 1 cubic meter (cu. m.)
1,000 cubic centimeters = 1 liter (l.)

MEASURES OF WEIGHT OR MASS

1000 milligrams (mg.) = 1 gram (g. or gm.)
100 centigrams (cg.) = 1 gram
1000 grams = 1 kilogram (kg.)
1000 kilograms = 1 metric ton

MISCELLANEOUS

1 cubic centimeter of water at 4°C. or 39.2°F. weighs 1 gram
1 liter of water at 4°C. or 39.2°F. weighs 1 kilogram
1 cubic centimeter of dry air at the sea level weighs 0.001293 grams
1 liter of dry air at the sea level weighs 1.293 grams
The average air pressure at sea level = 1033 grams per square centimeter

METRIC AND ENGLISH EQUIVALENTS

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 quart (U. S. liquid) = 0.9464 liter
1 quart (U. S. dry) = 1.101 liters
1 ounce (avoirdupois) = 28.35 grams
1 pound (avoirdupois) = 0.4536 kilogram
1 centimeter = 0.3937 inch
1 meter = 39.37 inches
1 liter = 1.051 quarts (U. S. liquid)
1 liter = 0.9081 quart (U. S. dry)
1 kilogram = 2.205 pounds (avoirdupois)

MENSURATION RULES

Circumference of a circle = diameter × 3.1416, or π

Area of a circle = ½ circumference × radius,
diameter squared × 0.7854, or
radius squared × 3.1416

Surface of a sphere = diameter × circumference, or
4 × 3.1416 × square of radius

Volume of a sphere = diameter cubed × 0.5236, or
4/3 of radius cubed × 3.1416

Lateral surface of a cylinder = circumference of base × altitude

Volume of a cylinder = area of base × altitude

GLOSSARY

TERMS DEFINED AS USED IN THIS TEXT

absolute humidity.—Weight of water vapor, grains per cu. ft.
acclimatize, ă-clī′ma-tīz.—Adaption of plants and animals to a climate.
activated, ăc′ti-vāt″ed.—Rendered active, as activated sludge.
aeration, ā″ẽr-ā′shŏn.—To supply or charge with air.
aerobic, ā″ẽr-ō′bĭc.—Applied to organisms which live in free oxygen.
aeroplane, ā′ẽr-o-plān.—A heavier-than-air flying machine.
anaerobic, ăn-ā″ẽr-ō′bic.—Said of organisms which thrive without free oxygen.
anthracite, ăn′thrā-sīt.—Coal containing but little volatile matter.
antiseptic, ăn″tĭ-sĕp′tic.—That which prevents the growth of organisms.
antitoxine, ăn″tĭ-tŏx′ĭn.—A substance which neutralizes toxines.
Appalachian, ăp″a-lăch′i-ăn.—Mountain range in eastern United States.
apparatus, ăp″a-rā′tŭs.—Appliances and materials used in performing experiments.
aqua ammonia, ā′kwȧ ă-mō′ni-a.—Ammonia dissolved in water.
aqueduct, ăk′wĭ-dŭkt.—A conduit for conveying water.
Archimedes, är″ki-mē′dēz.—Greek mathematician, 287–212 B.C.
artesian, är-tē′zhan.—Deep well, usually flowing. First found in Ärtois, France.
artificial, är″ti-fĭsh′al.—Produced by art, not by nature.
assimilate, ă-sĭm′i-lāt.—To transform food into protoplasm.
atmosphere, ăt′mos-fēr.—All the gases surrounding the solid earth.
attenuate, ăt-tĕn′yụ-āt.—To weaken, especially in virulence.
automatic, a̤″tō-măt′ic.—Self-moving, self-regulating.
automobile, a̤-tō-mō′bĭl.—Self-propelling vehicle.
axle, ăks′l.—A support upon which a wheel turns.
bacillus, ba-çĭl′ŭs (pl. bacilli).—A rod-shaped bacterium.
barograph, băr-o-ḡrȧf.—Instrument which writes continuous record of atmospheric pressure.
barometer, ba-rŏm′e-tẽr.—An instrument for measuring the atmospheric pressure.
Baume′, bō″mā′.—Antoine (ăn-tŏin′) Baume, a French chemist, 1728–1804.
bituminous, bi-tū′mi-nŭs.—Coal with much volatile matter. Soft coal.
Boyle, bŏyl.—Robert Boyle, English physicist and chemist, 1627–1691.
buoyancy, boi′ăn-si.—Power or tendency to keep afloat (noun).
buoyant, boi′ănt.—Tendency to float (adjective).
calorie, kăl′o-re.—a heat unit.

calorific, kăl″o-rĭf′ĭk.—Heat producing.

calorimeter, kăl″o-rĭm′e-tẽr.—An apparatus for measuring heat.

calorimetry, kăl″o-rĭm′e-try.—Process of measuring heat.

camphor, ȼăm′for.—A fragrant, gum-like compound.

capillarity, căp″il-lăr′i-ty.—Force or process by which water rises through soil.

capita, ȼăp′i-ta.—Per capita (Latin) meaning per head or for each person.

carbohydrate, kär″bo-hy′drāt.—A compound composed of carbon, hydrogen and oxygen.

carbureter, kär′bu-rĕt″ẽr.—1. A device for introducing hydrocarbons into water gas. 2. That part of a gasoline lamp or gasoline engine where gasoline gas and air are mixed.

carnivorous, kär-nĭv′o-rŭs.—Applied to flesh eating animals.

cellulose, sĕl′yụ-lōs.—A material composing the cell-walls of plant structure.

Celsius, sĕl′si-ŭs.—A Swedish astronomer, 1701–1744.

centigrade, çĕn′ti-grād.—A thermometer scale (*centum*, Latin, meaning hundred).

centrifugal, çĕn-trĭf′yụ-ḡal.—Tendency to fly from the center.

chlorine, klō′rĭn.—A greenish-yellow, gaseous, poisonous element.

cirrus, çĭr′ŭs.—A high cloud composed of hair-like fibers.

clinometer, ȼlī-nom′e-tẽr.—An instrument for determining altitude.

cloud.—Water vapor condensed into visible particles floating in the air.

coagulate, ȼō-ăḡ′yụ-lāt.—To change a substance like blood to solid form.

coccus, ȼŏȼ′ŭs (pl. cocci, ȼoȼ′çī).—A spherical bacterium.

conduit, cŏn′dĭt.—A tube or pipe for electric wires or conducting water.

conserving, cŏn-sẽrv′ing.—Preventing the waste of, as of moisture from the soil.

consomme, kôn″sō-mā.′—A clear meat soup.

convection, kŏn-vĕk′shon.—Transference of heat in liquids and gases by means of currents.

corrode, ȼŏ-rōd.—To eat away gradually, to rust.

counter-clockwise.—Turning in the direction opposite that of a clock's hands.

Croton, ȼrō′ton.—A river northeast of New York City.

culture, ȼŭl′tūr, or ȼŭl′chụr.—1. A growth of microörganisms. 2. A culture medium.

culture medium.—Material in which microörganisms will grow.

cumulus, ȼū′mū-lŭs.—A cloud of heap-like form with rounded top.

cutaneous, ȼū-tā′nē-ŭs.—Pertaining to the skin.

cyclone, çy′ȼlōn.—1. A system of winds several hundred miles in diameter, circling around a center. 2. A violent storm occurring over the Indian Ocean.

decay, dē-cā′.—Rotting, spoiling, putrefying, disintegrating.
denitrifying, dē-nī′tri-fȳ-ing.—Removing nitrogen from compounds.
dew.—Water vapor condensed on cool objects as grass or the ground.
dew-point.—The temperature at or below which dew or frost would form.
dextrin, dĕks′trĭn.—One of the carbohydrates.
dextrose, dĕks′trōs.—Grape sugar, as found in honey.
diagnosis, dī″ăg-nō′sis.—The identification of a disease.
diaphragm, dī′a-frăm.—A dividing partition or membrane.
diffused, dĭ-fūsd′.—Widely scattered, as a vapor in the air.
diffusers, dĭ-fūs′ẽrs.—Tanks in which the sugar is extracted from beets.
diffusion, dĭ-fū′zhon.—The act or process of scattering.
digestion, di-ġĕs′chon.—The process of changing food to a soluble and diffusible form.
diphtheria, dĭf-thē′ri-a.—An acute infectious disease of the throat.
disinfectant, dĭs″ĭn-fĕc′tant.—A substance which will kill bacteria.
distillation, dĭs″tĭ-lā′shun.—Operation of separating the more volatile from the less volatile portion of a liquid, as petroleum, or of a solid as wood or coal.
divining rod, di-vīn′ing.—A forked stick by means of which one pretends to be able to locate underground veins of water. A rod supposed to possess supernatural powers.
eccentric, ĕc-çĕn′tric.—A wheel having its axle one side of its center.
efficiency, ĕ-fĭsh′ĕn-çy.—Ratio of the useful work to the energy expended.
effluent, ĕf′lu-ĕnt.—Flowing out. That which flows forth.
enzyme, ĕn′zym.—A substance that induces the process of digestion.
equatorial calms, ē″kwā-tō′ri-al cäms.—The belt of calms near the equator.
equivalent, ē-kwĭv′a-lĕnt.—Equal in value.
eureka, ū-rē′ka.—"I have found it."
evaporate, ē-văp′o-rāt.—To change a liquid to a vapor at a temperature below boiling.
exhalation, ĕks″ha-lā′shon.—Breathing out.
Fahrenheit, fä′rĕn-hīt.—A German physicist, 1686–1736.
fallacy, făl′a-çy.—False or unsound reasoning.
fallowing, făl′o-ing.—To cultivate land without attempting to raise a crop.
faucet, fa̤′çĕt.—A spout or tap for drawing water.
fermentation, fĕr″mĕn-tā′shon.—Chemical changes induced by the enzymes of organisms.
filament, fĭl′a-mĕnt.—A thread-like body, as the filament of an electric light bulb.
flagella, fla-ġĕl′a (sing. flagellum).—The swimming organs of microörganisms.
Flügge, flüg′ge.—A German scientist now living.

fluorine, flōō'or-ĭn.—A pale, greenish, gaseous, exceedingly active chemical element.

franchise, frân'chĭs.—A special privilege granted by the government.

frost.—Frozen dew; formation of dew at temperatures below freezing.

fulcrum, fŭl'crŭm.—A support against which a lever rests or upon which it turns.

fungus, fŭn̲'ḡŭs (pl. fungi).—A plant of simple structure; without green color.

fusion, fū'zhon.—Melting.—Act or process of changing a solid, as ice, to a liquid.

galleries, ḡăl'ẽr-iez.—Underground passageways.

gaseous, ḡăs'e-ŭs.—Pertaining to a gas or of the nature of a gas.

gasoline, ḡăs'o-lĭn.—A colorless, volatile, inflammable distillate from petroleum.

gage, ḡāġ.—An instrument for measuring pressure, as of illuminating gas, water or steam.

gauze, ḡa̤z.—A woven wire fabric. Wire cloth-like, fabric used to distribute heat evenly.

glacial, ḡlā'shăl.—Pertaining to or caused by masses of ice.

gluten, ḡlōō'tĕn.—The sticky portion of wheat flour.

gluttenous, ḡlŭt'n-ŭs.—The act or habit of eating to excess.

gravity, ḡrăv'i-ty.—The pull of the earth upon all objects near it.

green plant.—A plant which has the green pigment chlorophyll in its leaves and other organs.

hail, hāl.—Frozen precipitation, usually composed of alternate layers of snow and ice.

heredity, he-rĕd'i-ty.—The process by which qualities are transmitted to offspring.

horizon, ho-rī'zon.—The line between the sky and the earth or sea.

host, hōst.—The organism upon which a parasite lives.

humidifier, hū-mĭd' i-fī-ẽr.—A device for increasing the moisture of indoor air.

humidity, hū-mĭd' i-ty.—Moisture or dampness. Condition of air as regards moisture.

humus, hū'mŭs.—The organic matter of the soil, usually giving it a dark color.

hurricane, hŭr'i-cān.—A violent storm of the cyclone type occurring in the West Indies.

hydrant, hȳ'drănt.—A discharge pipe connected with a city water main for fire fighting.

hydraulic, hȳ-dra̤'lĭc.—Pertaining to water under pressure, as hydraulic pressure.

hydrocarbon, hȳ″drō-kär′bon.—A compound composed of hydrogen and carbon.

hydrochloric acid, hȳ″drō-klō′rĭc ăs′ĭd.—A compound of hydrogen and chlorine.

hydrometer, hȳ-drŏm′e-tẽr.—An instrument for determining the density of liquids.

hydrophyte, hȳ′drō-fīt.—A plant which lives in water or water soaked ground.

hypha, hȳ′fa (pl. hyphæ).—The thread-like parts of a fungus.

hypocaust, hy̆p′o-cạst.—Basement chambers and flues used for heating Roman buildings.

Imhoff, ĭm′hŏf.—Inventor of a certain form of septic tank.

immunity, ĭ-mū′ni-ty.—Freedom from liability of a disease.

incandescent, ĭn″kăn-dĕs′ĕnt.—White or glowing from heat.

inclemency, ĭn-clĕm′en-çy.—Harsh, severe, rigorous, applied to weather or climate.

infection, ĭn-fĕc′shon.—To be inoculated with disease organisms.

infiltration, ĭn″fĭl-trā′shon.—Passing of liquids through small openings.

inhalation, ĭn″hā-lā′shon.—Breathing in.

inoculate, ĭn-ŏc′yụ-lāt.—To put disease organisms into the body of an animal or plant.

inorganic, ĭn″ŏr-găn′ic.—Not organic. Not formed by or pertaining to an organism.

insulation, ĭn″sū-lā′shon.—Surrounding a body with non-conductors, as of heat or electricity.

intermittent, ĭn″tẽr-mĭt′ĕnt.—Interrupted. Ceasing at intervals.

interurban, ĭn″tẽr-ûr′băn.—Between cities, applied to electric railroads.

iodine, ī′o-dĭn.—A bluish-black, crystalline element, used externally as a medicine.

irrigate, ĭr′i-gāt.—To water land by artificial means.

isolated, ĭs′o-lāt″ed.—Separated from others. In a detached place.

Joule.—James Prescott Joule, an English physicist, 1818–1889.

Keokuk, kē′o-kŭk.—A city in Iowa on the Mississippi River.

kerosene, kẽr′o-sēn.—Common illuminating oil. A product of petroleum.

kilowatt, kĭl′o-wạt.—A unit of electrical energy equal to 1000 watts.

Kuwoshiwo, kụ″ro-shĭ′wo.—(Formerly Kuwo-Siwo).—Japanese Current in the Pacific Ocean.

lactose, lăk′tōs.—The sugar found in milk.

Langley, lăng′ly.—Samuel Pierpont Langley, American scientist, 1834–1906.

leaching, lēch′ing.—1. Dissolving mineral salts out of the soil. 2. Soaking of sewage into the soil.

lever, lē′vẽr or lĕv′ẽr.—One of the simple machines. A stiff, rigid bar.

levulose, lĕv′ụ-lōs.—The sugar found in fruits.

life process.—A process necessary to life.

lightning, līt′ning.—The flash of an electric discharge to or from a cloud.

liquefy, lĭk′wē-fy.—To convert into or to become a liquid.

loom, lōōm.—A flexible insulating tube used as a conduit for electric wires.

Los Angeles, lŏs ăn′ġē-lēz.—A city in southern California.

luminous, lū′mi-nŭs.—Giving off light.

luxurious, lŭg̅-zhū′ri-ŭs.—Pertaining to indulgence in pleasure of the senses which are unnecessary for health and comfort.

maltose, môl′tōs or ma̤lt′ōs.—A hard, white, crystalline sugar formed by the action of malt on starch.

manometer, mā-nŏm′e-tẽr.—An instrument for measuring pressure.

maximum, măx′i-mum.—Highest. The maximum thermometer indicates the highest temperature.

mean, mēn.—Average. The mean temperature is the average temperature.

mechanical advantage.—Advantage obtained by using a mechanical device.

mesophyte, mĕs′o-fīt.—A plant which requires a medium amount of moisture.

metabolism, mē-tăb′o-lĭzm or mē-tăb′o-lism.—Total process of obtaining nourishment from food.

microorganism, mī″ȼrō-ŏr′g̅ăn-ĭsm.—An organism that can be seen only by use of the microscope.

microscopic, mī″ȼrō-sȼŏp′iȼ.—Seen only by the aid of a microscope.

minimum, mĭn′i-mŭm.—Least, lowest. The minimum thermometer indicates the lowest temperature.

molecule, mŏl′e-ȼūl.—The smallest particle of matter that can exist as such.

monsoons, mŏn-sōōns′.—Winds along the coast, blowing toward the land in summer and toward the sea in winter.

mycelium, mȳ-çē′li-ŭm.—The plant body of a fungus.

naphtha, năf′tha.—A volatile distillate from petroleum.

neutralize, nū′tral-īz.—To destroy the power of, as acids neutralize alkalies.

Newcomen, nū-ȼŏm′en.—Thomas Newcomen, an English inventor, 1663–1729.

non-green plants.—Plants which lack chlorophyll and therefore are not green.

non-luminous, nŏn-lū′mi-nŭs.—Not giving off light.

nutation, nū-tā′shon.—A revolving motion, giving rise to a nodding motion.

nutrition, nū-trĭsh′ŏn.—The process by which growth is promoted and waste repaired in living organisms.

oleomargarine, ō″lē-ō-mär′ḡa-rĭn (not mar′jĕr-ēn).—A substitute for butter.

olla, ōl-ȧ (Spanish).—A porous, earthen water jar or container.

organic, ôr-ḡăn′iȼ.—1. Formed by or pertaining to an organism. 2. A chemical compound having carbon for its chief constituent.

organism, ôr′ḡăn-ism.—A living being having different organs performing special functions.

oscillating, ŏs′i-lāt″ing.—Swinging back and forth on its axis.

paraffin, păr′a-fĭn.—A translucent, waxy, solid substance derived from petroleum.

parasite, păr′a-sīt.—An organism that lives upon or within the body of another.

Pasteur, päs″tûr′.—Louis Pasteur, a celebrated French chemist and bacteriologist, 1822–1895.

pasteurization, päs″tûr-i-zā′shon.—Killing active organisms by heat.

pathogenic, păth″o-ġen′ic.—Disease causing.

percolation, pẽr″ȼō-lā′shon.—Passing slowly through small openings.

perforated, pẽr′fo-rāt″ed.—Pierced with small holes.

pinion, pĭn′yŏn.—A small toothed wheel driving or driven by a larger cog-wheel.

pitman, pĭt′man.—A rod connecting a moving lever with a rotating wheel.

platinum, plăt′i-nŭm.—A valuable, steel-gray, heavy, malleable metallic element.

plenum, plē′nŭm.—Applied to space full of matter, as plenum system of ventilation.

pneumatic, nū-măt′ic.—Pertaining to or containing compressed air.

Ponce de Leon, pōn′thē dē lē′ōn.—Juan Ponce de Leon, a Spanish explorer, 1460–1521.

porcelain, pûrç′lin, or pōr′çe-lān.—A translucent earthenware, usually glazed.

precipitation, prē-çĭp″i-tā′shon.—Water from the atmosphere falling to or toward the earth.

propulsion, prō-pŭl′shon.—Pushing; operation of propelling.

protein, prō′tē-ĭn.—One of the three food principles.

protractor, prō-trăȼ′tor.—An instrument for measuring angles.

radiation, rā″di-ā′shon.—The giving off of heat to or through space.

range, rānġ.—1. A stove with one side as a front. 2. Difference between the highest and the lowest, as the range of temperature.

relative humidity.—The humidity expressed in per cent. of saturation.

reservoir, rĕz′ẽr-vwor or rĕẓ′ẽr-vwor.—A huge tank or receptacle for storing water.

residue, rĕs′i-du.—The portion remaining after part is removed.

revolution, rĕv″o-lū′shon.—Complete circuit made by a body around a center.

Roquefort, rōk″fōr′ or rōk′fōrt.—A commune in France famed for its goats and cheese.

rotary, rō′tā-ry.—Turning around completely on its axis.

sanitary, săn′i-tā-ry.—Relating to the preservation of health.

saturation, săch″ụ-rā′shon.—State of being filled with (wạter) vapor.

sedentary, sĕd′en-tā-ry.—Pertaining to inactivity, as a sedentary life.

semi-transparent, sĕm″i-trăns-păr′ent.—Partly admitting of the passage of light.

septic, sĕp′tĭc.—Productive of putrefaction, rotting or decaying.

serum, sē′rŭm.—Blood with the corpuscles removed. A part of the blood.

sewage, sū′āġ.—Waste matter carried off in sewers.

shower, shŏw′ẽr.—A brief fall of rain, sometimes of hail or snow.

Sierra Nevada, si-ĕr′a ne-vä′da.—A mountain range in eastern California.

silicon, sĭl′i-kon.—One of the chemical elements found in sand.

siphon, sī′ fon.—A bent tube through which liquid flows.

sleet, slēt.—Frozen or partly frozen rain.

sludge, slŭdġ.—Soft, muddy, pasty, refuse which forms in the bottom of a septic tank.

snow.—Falling water vapor condensed at a temperature below freezing.

solstice, sŏl′stiç.—Date upon which the sun seems to turn back north in the winter, December 22, or back south in the summer, June 21.

specific heat, spē-sĭf′ĭk.—Heat required to raise 1 gram of a substance 1°C.

spore, spōr.—A reproductive cell in higher fungi. A resting cell in bacteria.

squall cloud, skwạl.—A low, ragged, tumbling cloud often seen with the wind gust in front of a thunderstorm.

sterile, stĕr′ĭl.—Free from microörganisms.

sterilization, stĕr″ĭl-ī-zā′shon.—Act of making sterile.

stratus, strā′tŭs.—A flat layer cloud of rather uniform thickness.

strata, strā′ta (sing. stratum).—Layers, as of rock in the earth's crust.

substratum, sŭb-strā′tŭm.—Material through which the hyphae of a fungus grow.

sucrose, sū′krōs.—One of the sugars, as cane sugar, beet sugar, maple sugar.

susceptible, sŭs-cĕp′ti-ble.—Opposite of immune; liability to disease.

thermograph, ther′mō-ġrȧf.—An instrument for writing a continuous record of temperature.

thermostat, thẽr′mō-stăt.—A device for automatically regulating temperature.

threshing, thrĕsh′ing.—Separating grain or seed from straw or stalks.

thunderstorm, thŭn′dẽr-stôrm.—A shower accompanied by thunder and lightning.

tornado, tŏr-nā'dō.—A violent, whirling, twisting wind a few hundred yards or less in diameter, usually with a hanging funnel cloud at its core.

toxine, tŏks'ĭn.—A poison, often of bacterial origin.

treadle, trĕd'l.—A lever operated by the foot to run a machine, as a sewing machine.

tungsten, tŭng'stĕn.—A steel-gray, heavy, metallic metal, used for lamp filaments.

turbine, tûr'bĭn or tûr'bīn.—One form of water wheel.

typhoon, tȳ-fōōn'.—A violent cyclonic storm occurring over the China seas.

vaccinate, văɛ'çi-nāt.—To treat with a vaccine.

vaccine, văɛ'çĭn.—A substance which induces immunity in an organism.

vacuum, văɛ'yụ-ŭm.—Space without matter, especially space devoid of air.

vaporize, vā'pŏr-īz.—To change into gaseous form.

vernier, vẽr'ni-ẽr.—A sliding scale on a barometer for measuring to very small divisions.

vibrating, vī'brāt-ing.—Moving back and forth in a straight line or the arc of a circle.

virulence, vĭr'u-lĕnç.—The disease producing property of an organism.

virus, vī'rŭs.—The substance used in vaccination.

vitality, vī-tăl'i-ty.—Life; power; surplus energy.

vitiated, vĭsh'i-āt"ed.—Polluted; impure.

volatile, vŏl'ā-tĭl.—Easily evaporated.

waterspout.—A tornado occurring over water.

Welsbach, wĕls̱' băc.—Carl Auer Freiherr Welsbach, an Austrian scientist, 1858–

westerlies.—The belt or zone of winds blowing from the west in both temperate zones.

xerophyte, zē'rō-fīte.—A plant which thrives in dry soil and dry air.

yucca, yŭɛ'a.—Lily-like plant, a native of southwestern United States and Mexico.

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