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PHYSICS AND CHEMISTRY FOR THE AUTOMOTIVE TRADES.

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NEW JERSEY STATE DEPT. OF EDUCATION, TRENTON

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DESIGNED FOR STUDENT USE, THIS MANUAL PRESENTS RELATED INFORMATION AND LABORATORY EXPERIMENTS FOR A 1-YEAR COURSE IN APPLIED PHYSICS AND CHEMISTRY. IT WAS DEVELOPED BY ESSEX COUNTY AUTOMOTIVE TEACHERS. CONTENT HEADINGS ARE -- (1) MATTER AND ITS PROPERTIES (15 EXPERIMENTS), (2) MECHANICS (4 EXPERIMENTS), (3) HEAT (3 EXPERIMENTS), (4) ELECTRICITY (8 EXPERIMENTS), (5) SOUND, AND (6) LIGHT. EACH EXPERIMENT LISTS THE NECESSARY MATERIALS, PROCEDURES, AND CONCLUSIONS. NUMEROUS ILLUSTRATIONS ARE PROVIDED, MOST OF WHICH ARE PHOTOGRAPHS OR LINE DRAWINGS. STUDENTS MAY BE EITHER HIGH SCHOOL OR POST-SECONDARY LEVEL. THE TEACHER SHOULD BE CERTIFIED AND HAVE A SCIENCE-AUTOMOTIVE BACKGROUND. THIS DOCUMENT IS AVAILABLE FOR $2.00 FROM THE VOCATIONAL-TECHNICAL CURRICULUM LABORATORY, RUTGERS UNIVERSITY, 10 SEMINARY PLACE, NEW BRUNSWICK, NEW JERSEY 08903. (EM)

STATE OF NEW JERSEY
DEPARTMENT OF EDUCATION
VOCATIONAL DIVISION

PHYSICS AND CHEMISTRY

FOR THE

AUTOMOTIVE TRADES

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State Of New Jersey
Department of Education
Vocational Division

PHYSICS AND CHEMISTRY FOR THE AUTOMOTIVE TRADES

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Robert Worthing

PREFACE

The automobile is our country's leading manufactured product. It is a complex, precise machine using principles from the whole range of physics and chemistry.

The large numbers of young men who are trained to work at the service and repair of automobiles need to have an understanding of these principles. This book sets them forth briefly, with examples and applications from the auto field. The treatment is kept at a simple level of mathematics.

Many of the findings of science cannot be correctly explained in a simple way. For example, the picture of the atom like a sun with planetary electrons whirling around it in circular orbits is inadequate even for today's high school chemistry courses. Yet it does illustrate some important facts very simply, and will continue in wide use even though the picture it gives is not strictly true. Compromises of this kind have been necessary at various points in this book, in order to offer the student a simple concept with which he could work.

Robert Worthing

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UNIT I. INTRODUCTION TO PHYSICAL SCIENCE

1. WHAT IS THE COURSE ABOUT?

Some men learn to become auto mechanics by working on cars. This is one of the best ways, especially if the man who is showing you how, knows his business. This is the method used in your shop class.

If you lived in a country with just one make of car, and it never changed, this system might be quite good. But with dozens of makes and new models coming out every year, the changes come faster than one can keep up with by simply working on the cars. Even one model has so many parts and features you couldn't learn about it quickly enough by experience. So you learn systematically about the various kinds of parts--carburetors, generators, valves, etc.--and how they work, in your related science class. This knowledge can then be applied to any make or model.

The part of your related science that you are now going into takes up the basic "whys" of cars such as:

What makes an engine "knock"?

How does a generator work?

What is the difference between a lacquer solvent and a thinner?

You may know some of the answers to these questions. The point of the course is to give you a basic knowledge that will have the answers, not only to today's questions, but to some that will only be asked 10 or 20 years from now.

2. METHOD OF SCIENCE

It is part of human nature to try to understand things. For several thousand years some men have studied things around them systematically to try to find out the rules or laws that they followed.

Newton, for example is supposed to have seen an apple fall, and to have wondered how its speed change as it fell. But he was not satisfied to look and wonder.

He studied the problem and developed a theory.

He did experiments, measuring the time, speed, and distance of falling objects. He also collected data about moving objects of all kinds, including the moon and planets to check his theory.

When he found it to be correct in all situations, he stated it as a scientific law, which he expected would describe how the speed of objects changes as they speed up or slow down.

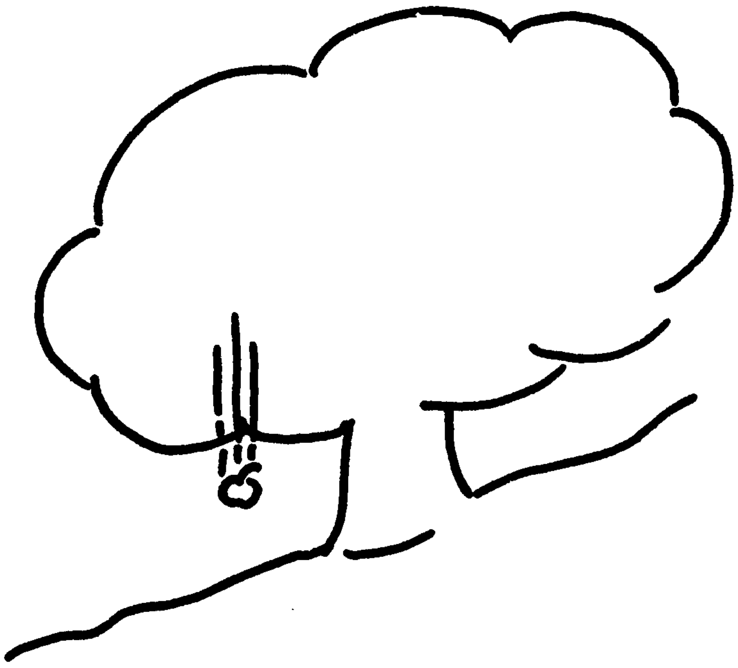


Fig. 1-1

Although Newton never saw an automobile, his law tells us the distance needed to stop cars traveling at various speeds. We see that, once a scientific principle is worked out, it can be used for many things. Most of the parts of a car--engine, fuel system, tires, brakes, etc.--work on principles that were known before the first automobile was built. If you know them you will understand why the parts of a car work as they do.

These principles of systematic knowledge form what we call science. The part of science dealing with nonliving things is called physical science. Automobiles are built and operate according to the laws of physical science.

3. MEASUREMENT

The automechanic does not always know it, but everything he does is controlled by numbers: parts are made to exact size; pistons are matched in weight; ignition is timed to thousandths of a second. At every point, correct operation demands exact measurement.

You know that 12 inches make a foot, 3 feet make a yard, 1760 yards (5280 ft.) make a mile, and so forth. You also have heard that there is a different system of measuring things--the metric system. Here 10 millimeters make a centimeter, 10 centimeters make a decimeter, 10 decimeters (or 100 centimeters) make a meter, and so forth.

The system we use is compared with the metric system in a few sample instances in the illustrations below.

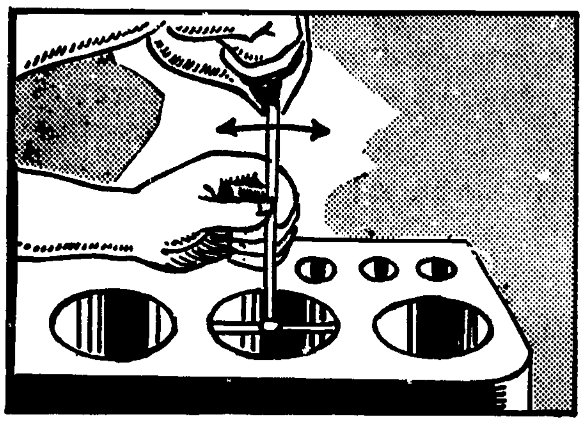


Fig. 1-2

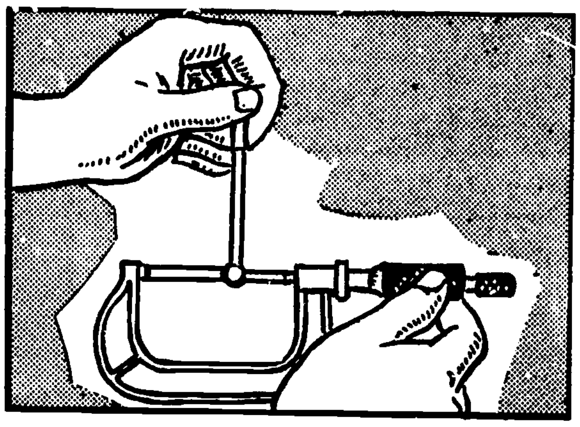
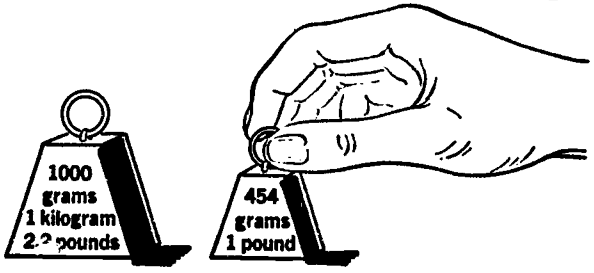
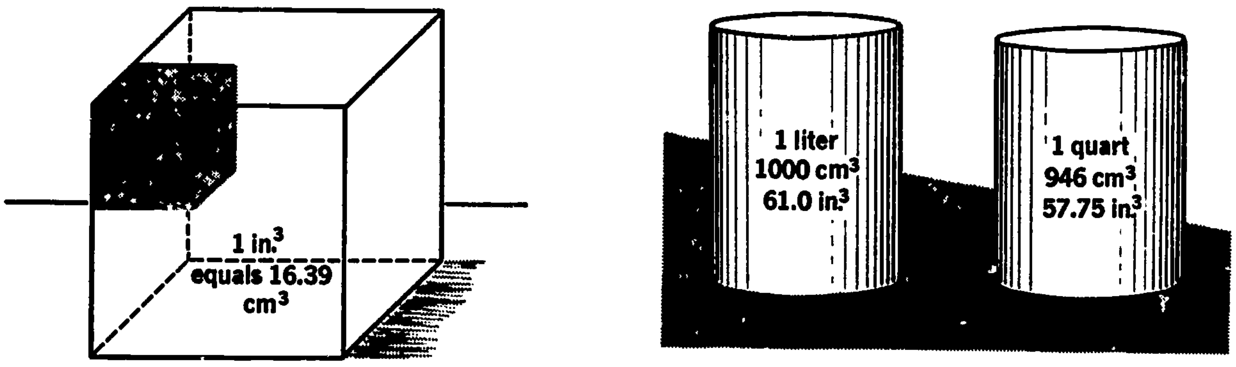


Fig. 1-3



The weight of a kilogram mass is more than twice that of the avoirdupois pound.

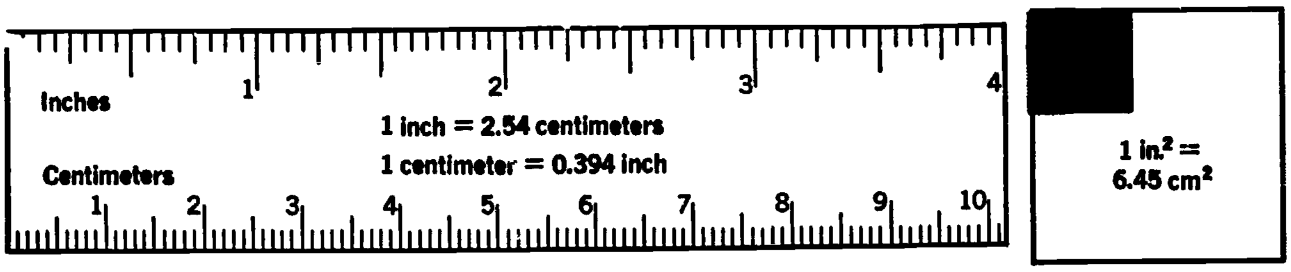
Fig. 1-4



Comparison of one cubic centimeter and one cubic inch.

The liter is slightly larger than the U.S. liquid quart.

Fig. 1-5



A comparison of (left) centimeters and inches, and (right) a square centimeter and a square inch.

Fig. 1-6

You can see that the metric system has a great advantage. For example, you can change meters to centimeters just by moving the decimal point. But to change feet to inches, you have to multiply by 12. Because of this advantage, most countries except the English-speaking ones now use the metric system. The United States is not likely to switch over soon, but you will note that the common fractions have been replaced by decimals in auto work.

UNIT 2. MATTER AND ITS PROPERTIES

1. ATOMS AND MOLECULES

Why does steel rust? Where does the water come from in the exhaust of a car? How does motor oil go bad? These questions are part of chemistry, the science of matter.

Matter is anything that has weight and takes up space. Fig. 2-1 shows some of the different forms of matter that are used in making an automobile. Each one used has certain characteristics or properties--steel is strong, rubber bends, copper carries electricity.

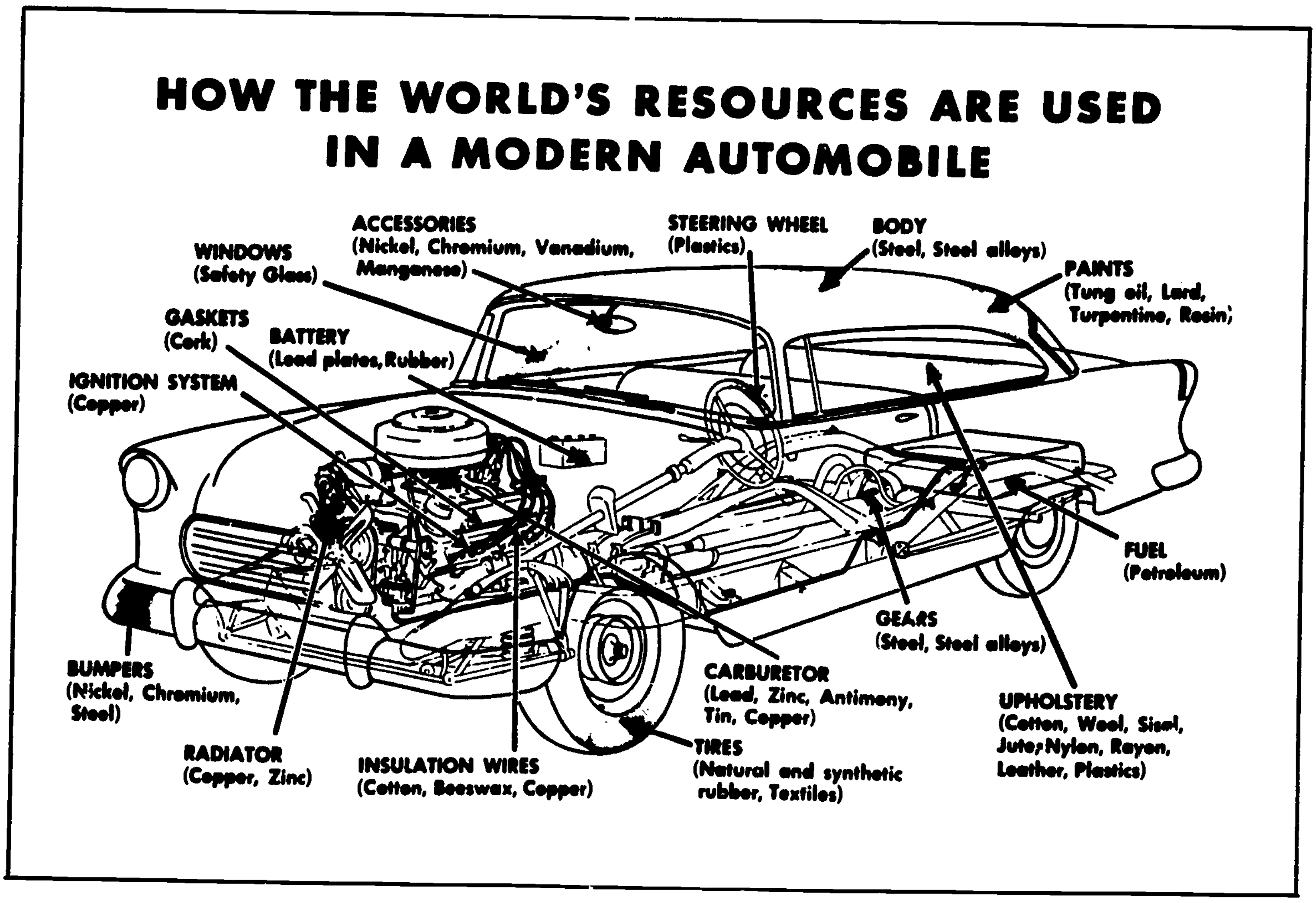
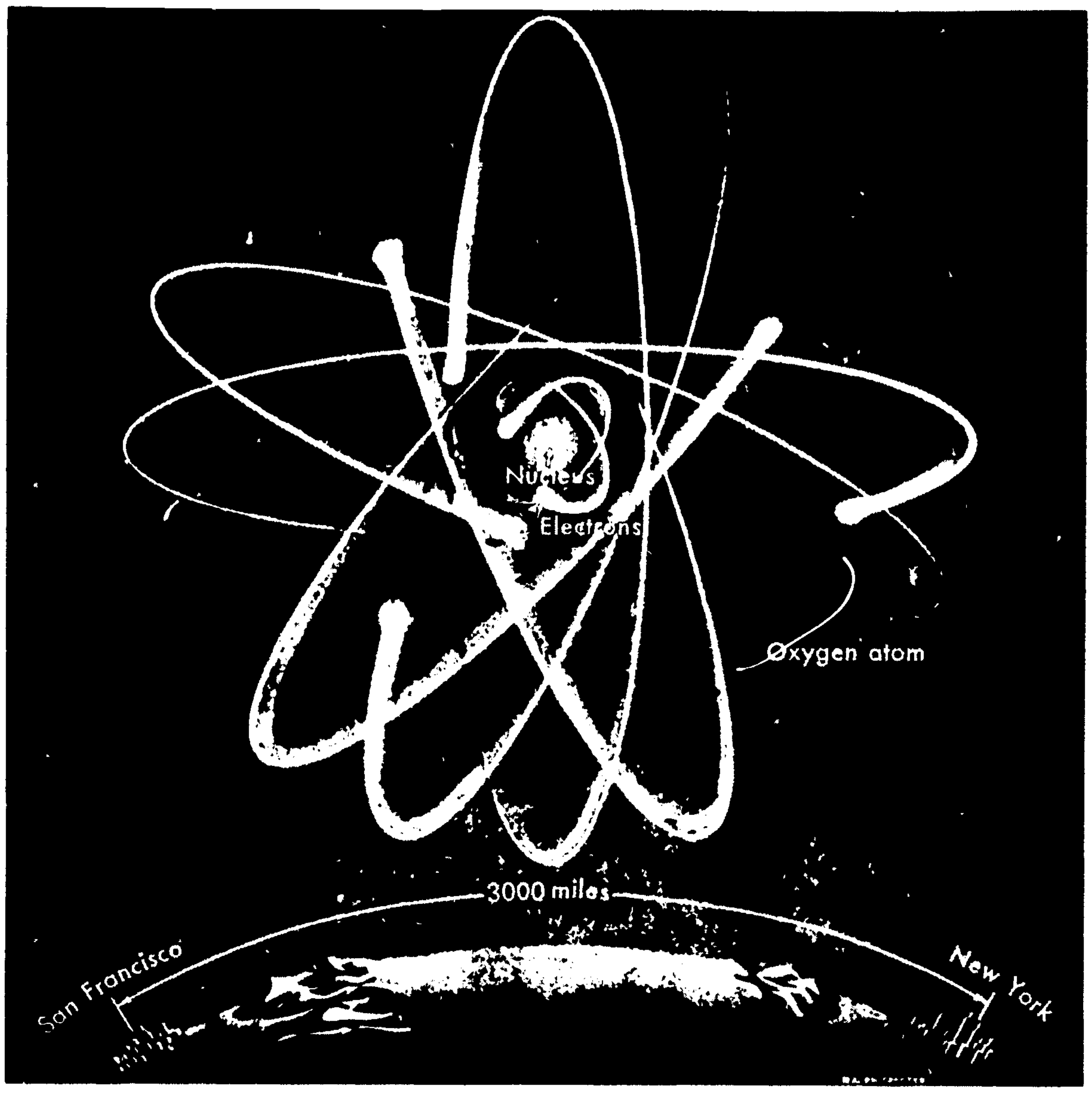


Fig. 2-1

Atoms. The properties of matter are due to the nature of the tiny atoms of which all matter is made. To understand matter we must study atoms.

Nucleus. Every atom has, in the middle, a tiny nucleus. See Fig. 2-2. (The plural form of the word "nucleus" is "nucleii".) The nucleus is very small compared to the whole atom, but it has most of the weight. About half of the weight of the nucleus is due to its protons, tiny particles which carry a positive (+) electrical charge and are quite heavy for their size.



Artist's Concept of an Oxygen Atom · The nucleus is very small as compared with the diameter of the atom. If the atom were expanded until the diameter of the outer electron shell equalled the distance between New York and San Francisco, the nucleus would be about the size of a city block

Fig. 2-2

The number of the protons in a nucleus is called the atomic number.

The charge on every proton is the same. So if an atom has an atomic number of one, its nucleus must have a charge of one. With an atomic number of two, it has a 2+ charge. The highest charge on any nucleus found in nature is 92+. In a little while you will see how important the atomic number is.

All atoms (except those of hydrogen) also have in the nucleus neutrons, particles which have no electrical charge and are about as heavy as protons.

Elements. Atoms which have the same number behave the same in most respects. Thus, if all the atoms in the universe could be sorted out, there would be only about 92 different kinds. (A few more have been made in nuclear reactors, but they are unstable and come apart into simpler ones in a while.)

These different kinds of atoms makeup the simple <u>elements</u>. Normally atoms do not change; an element cannot change into a different element except by a rare <u>nuclear reaction</u>.

So you see there are less than 100 basic kinds of matter in nature; however, most materials are combinations of several elements,as we shall see. A list of the elements is given in Table 1.

<u>Electrons</u>. Besides protons and neutrons, atoms contain <u>electrons</u>, tiny, light-weight particles having a negative (-) electric charge. The number of electrons in an atom is the same as the number of protons in the nucleus. Each electron has the same amount of charge as a proton, but is opposite in type. Since opposite charges attract one another, an atom tends to be electrically <u>neutral</u> by having the same number of electrons as it has protons. That is, the negative charge of the electrons neutralizes the positive charge of the nucleus.

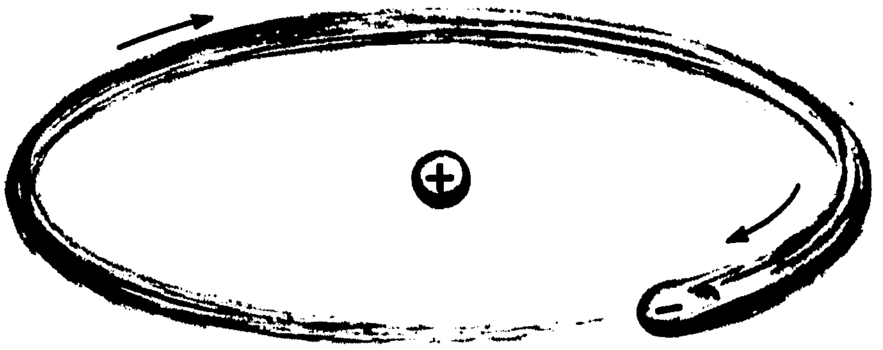
From a great many scientific experiments, it seems that the tiny electrons in an atom arrange themselves around the nucleus, as close as they can, moving along certain paths. No artist's picture of electrons can be correct, but they do give you some idea of their motion.

THE ELEMENTS

(Arranged in order of atomic numbers)

Atomic Number	Element	Symbol
1	Hydrogen	H
2	Helium	He
3	Lithium	Li
4	Beryllium	Be
5	Boron	B
6	Carbon	C
7	Nitrogen	N
8	Oxygen	O
9	Fluorine	F
10	Neon	Ne
11	Sodium	Na
12	Magnesium	Mg
13	Aluminum	Al
14	Silicon	Si
15	Phosphorus	P
16	Sulfur	S
17	Chlorine	Cl
18	Argon	A
19	Potassium	K
20	Calcium	Ca
21	Scandium	Sc
22	Titanium	Ti
23	Vanadium	V
24	Chromium	Cr
25	Manganese	Mn
26	Iron	Fe
27	Cobalt	Co
28	Nickel	Ni
29	Copper	Cu
30	Zinc	Zn
31	Gallium	Ga
32	Germanium	Ge
33	Arsenic	As
34	Selenium	Se
35	Bromine	Br
36	Krypton	Kr
37	Rubidium	Rb
38	Strontium	Sr
39	Yttrium	Y
40	Zirconium	Zr
41	Niobium	Nb
42	Molybdenum	Mo
43	Technetium	Tc
44	Ruthenium	Ru
45	Rhodium	Rh
46	Palladium	Pd
47	Silver	Ag
48	Cadmium	Cd
49	Indium	In
50	Tin	Sn
51	Antimony	Sb
52	Tellurium	Te
53	Iodine	I
54	Xenon	Xe
55	Cesium	Cs
56	Barium	Ba
57	Lanthanum	La
58	Cerium	Ce
59	Praseodymium	Pr
60	Neodymium	Nd
61	Promethium	Pm
62	Samarium	Sm
63	Europium	Eu
64	Gadolinium	Gd
65	Terbium	Tb
66	Dysprosium	Dy
67	Holmium	Ho
68	Erbium	Er
69	Thulium	Tm
70	Ytterbium	Yb
71	Lutetium	Lu
72	Hafnium	Hf
73	Tantalum	Ta
74	Wolfram	W
75	Rhenium	Re
76	Osmium	Os
77	Iridium	Ir
78	Platinum	Pt
79	Gold	Au
80	Mercury	Hg
81	Thallium	Tl
82	Lead	Pb
83	Bismuth	Bi
84	Polonium	Po
85	Astatine	At
86	Radon	Rn
87	Francium	Fr
88	Radium	Ra
89	Actinium	Ac
90	Thorium	Th
91	Protactinium	Pa
92	Uranium	U
93	Neptunium	Np
94	Plutonium	Pu
95	Americium	Am
96	Curium	Cm
97	Berkelium	Bk
98	Californium	Cf

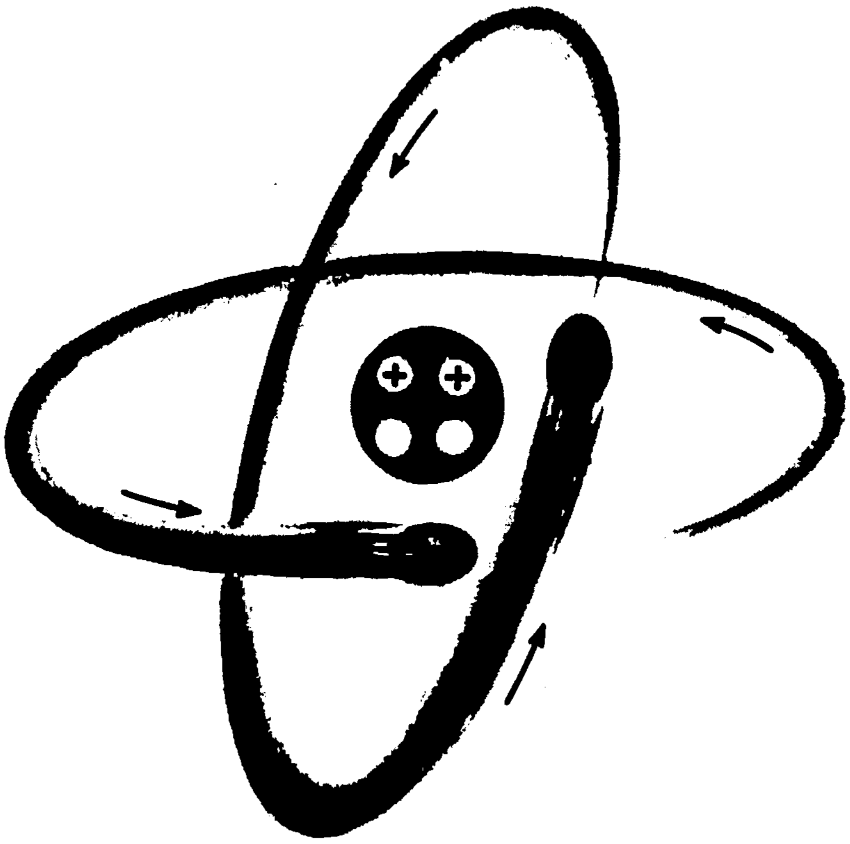
Table 1



A Hydrogen Atom
Fig. 2-3

The hydrogen atom, with one proton in the nucleus, has one electron.

The helium atom has two electrons. Their orbits are equal but different.



A Helium Atom
Fig. 2-4

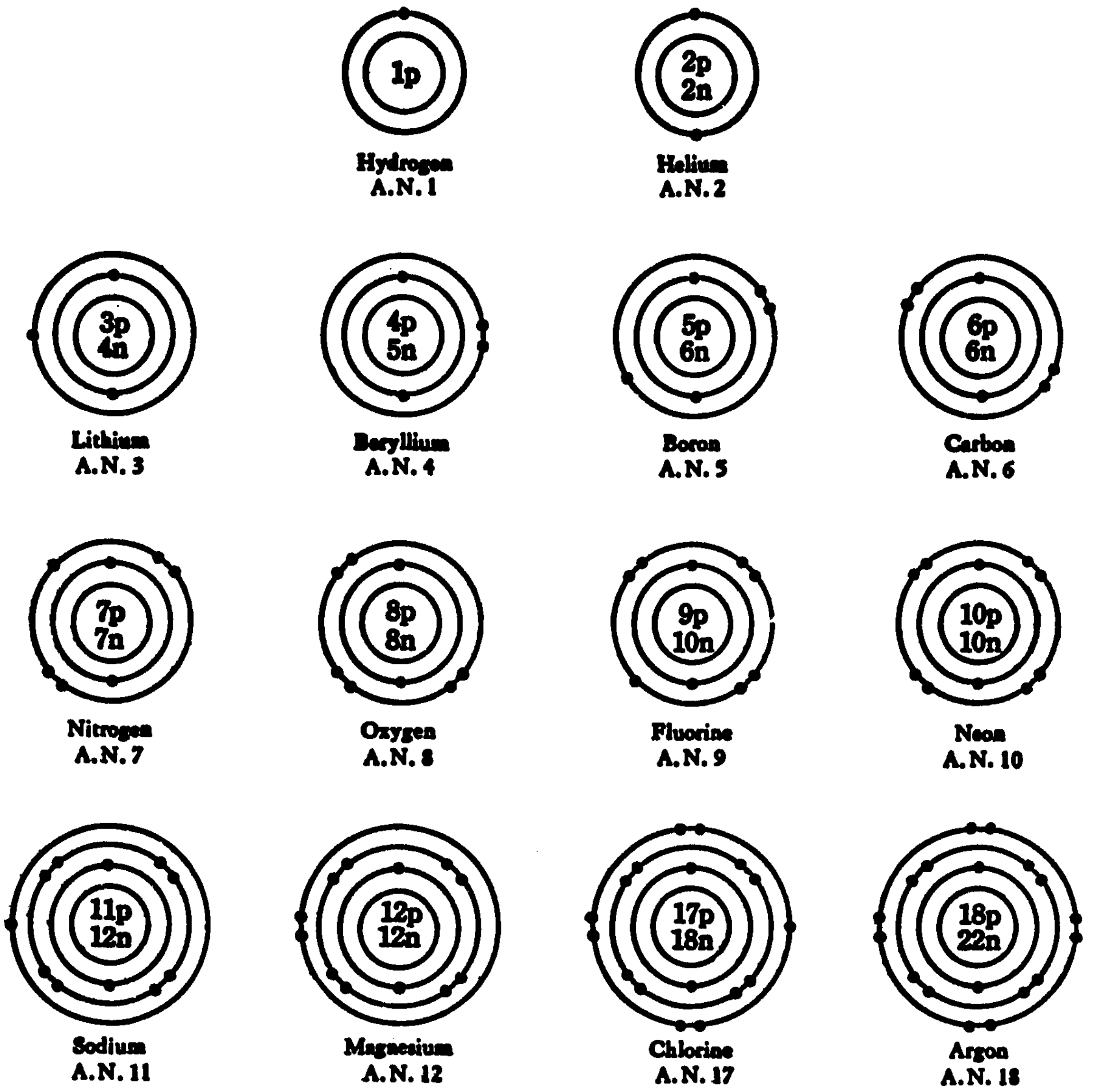
A lithium atom has two electrons close to the nucleus. A third electron is in a more distant orbit.

Fig. 2-5

From experiments in which electrons are taken out of atoms (by high-voltage sparks) and allowed to fall back in, it has been found that the electrons arrange themselves around the nucleus in a series of energy levels, usually called shells. Each shell has room for an exact number of electrons. The first, or K shell, has room for just two electrons; the second, or L shell, holds eight, etc. The inner shells tend to fill up before the outer ones, as shown in Fig. 2-6.

Molecules. Most kinds of atoms tend to join together with others. Of the ones shown in Fig. 2-6, only helium, neon and argon atoms are found by themselves. The electron shells in these atoms are complete.

Atoms with incomplete electron shells tend to join with other atoms so that in the end every electron will be part of a complete shell.



Simplified Representation of Several Atoms · In the inner circle the nuclear composition is given in terms of protons (*p*) and neutrons (*n*). The first circle outside the nucleus represents the *K* shell, the second one the *L* shell, and the third one the *M* shell.

Fig. 2-6

Schematic diagrams of a few common molecules. First Row. Helium, neon, hydrogen, nitrogen, oxygen, carbon monoxide, hydrochloric acid. Second Row. Ozone, carbon dioxide, water, hydrocyanic acid. Third Row. Methane, acetylene, benzine, methyl alcohol, ethyl alcohol.

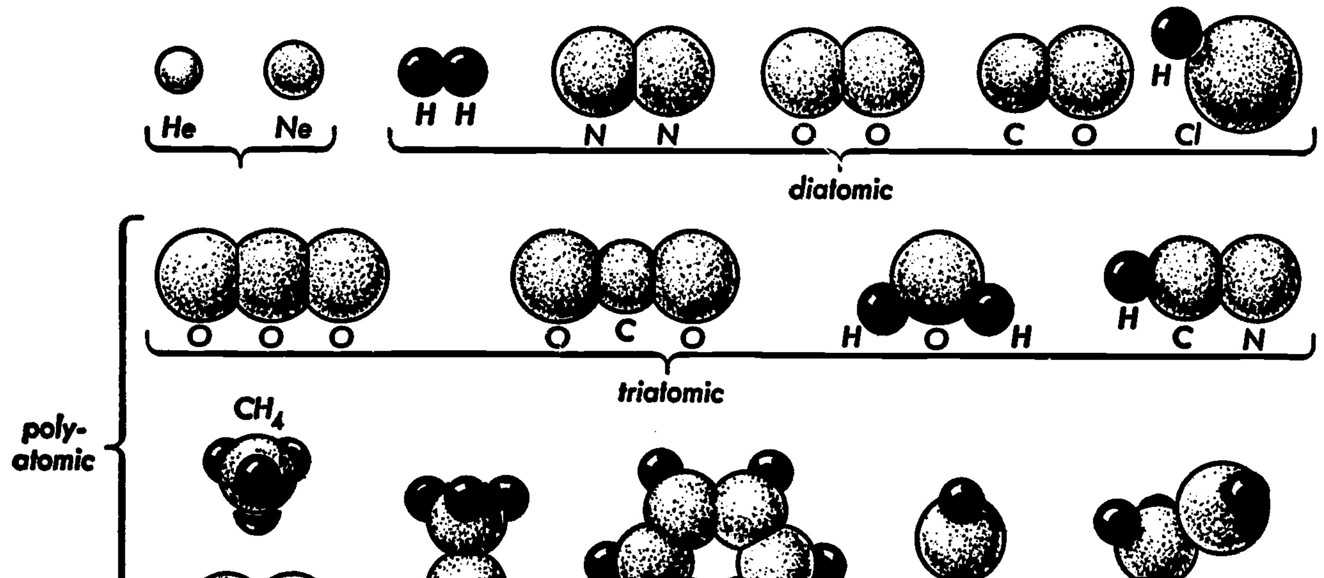


Fig. 2-7

Atoms can join together in several ways. The first is by sharing electrons.

Two hydrogen atoms share their two electrons to form a complete K shell which holds both nucleii. The result is a molecule of hydrogen gas.

A molecule is a group of atoms joined together. Fig. 2-7 shows diagrams of several common types of molecules.

The molecule of hydrogen can be described by the simple formula H_2. H is the symbol for hydrogen. (Table 1 gives the symbols or abbreviations that stand for the various elements.) The little subscript 2 after and below the H shows that two atoms of hydrogen make up the molecule.

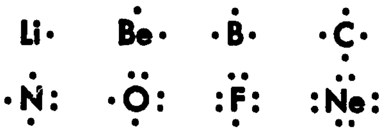
Two atoms of hydrogen and one of oxygen join to form a molecule of water, H_2O. This joining up of different atoms is called a chemical reaction. Fig. 2-8 is an artist's idea of the reaction between hydrogen and oxygen.

The oxygen's outer shell, with its six electrons, is the part of the atom that reacts with the hydrogen atom. It lacks two electrons to make a complete L shell of 8, so it shares two with two hydrogen atoms. Electrons in the outer, incomplete shell of an atom are called valence electrons.

Compounds. Water, because it is made from different elements joined together, is called a compound. Wherever it is found, water is made up of exactly two times as many atoms of hydrogen as of oxygen.

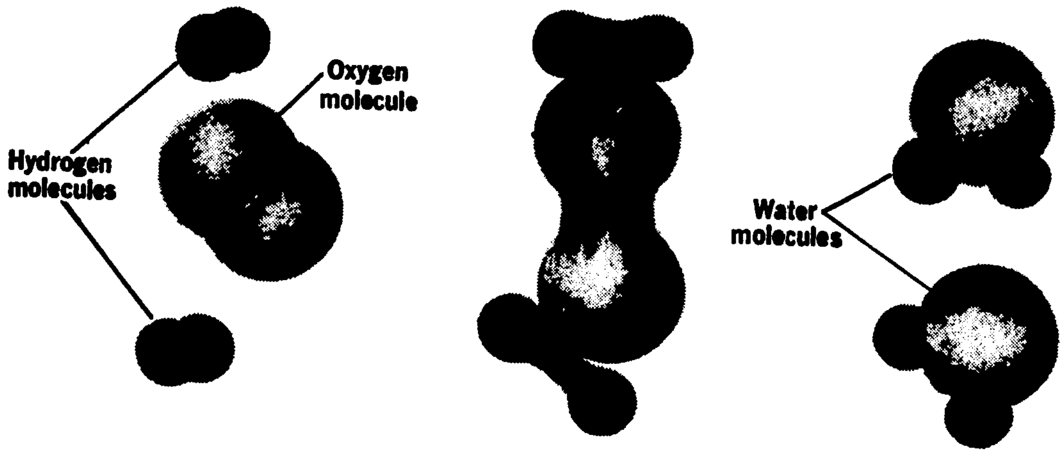
The chemical bond which comes from sharing electrons is quite strong.

Seeing that only the electrons in the incomplete outer shell of an atom are involved in chemical reactions, it is sometimes enough to show just the symbol and the proper number of valence electrons, like this: H· He:



Li· Be· ·B· ·C·

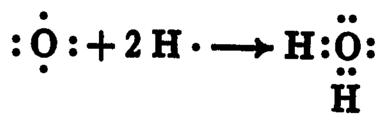
·N: ·O: :F: :Ne:



In the water molecules which result from the reaction of hydrogen and oxygen, the oxygen atom shares an outer shell electron with each of two hydrogen atoms, while each of the hydrogen atoms shares its single electron with the oxygen atom. This is an example of covalent bonding.

Fig. 2-8

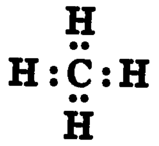
Now we can show the reaction between hydrogen and oxygen this way:



$$:\overset{\cdot}{\underset{\cdot}{O}}: + 2H\cdot \longrightarrow \begin{array}{c} H:\overset{\cdot\cdot}{\underset{\cdot\cdot}{O}}: \\ H \end{array}$$

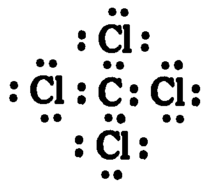
The element carbon forms more compounds than any other. Here are a few different ones:

Methane, the natural gas used as a fuel:



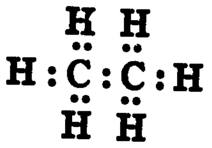
$$\begin{array}{c} H \\ H:\overset{\cdot\cdot}{\underset{\cdot\cdot}{C}}:H \\ H \end{array}$$

Carbon tetrachloride, a dry cleaning solvent:



$$\begin{array}{c} :\overset{\cdot\cdot}{Cl}: \\ :\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}:\overset{\cdot\cdot}{\underset{\cdot\cdot}{C}}:\overset{\cdot\cdot}{\underset{\cdot\cdot}{Cl}}: \\ :\underset{\cdot\cdot}{Cl}: \end{array}$$

Ethane, also found in natural gas. Notice the bond forming a "chain" between the two carbon atoms:



$$\begin{array}{c} H\ \ H \\ H:\overset{\cdot\cdot}{\underset{\cdot\cdot}{C}}:\overset{\cdot\cdot}{\underset{\cdot\cdot}{C}}:H \\ H\ \ H \end{array}$$

These compounds, in which carbon is joined to elements other than oxygen, are called organic compounds. Most of them come from animals or plants in some way.

Polar bonds. Carbon dioxide (CO_2) is the gas that is used in some fire extinguishers. It is made by burning wood, coal, or other organic fuels, and collecting the gas that is formed. $:\ddot{O}::C::\ddot{O}:$

Since oxygen atoms use two electrons to complete their outer shells, they become a little more negative than the carbon atoms. The molecule then has ends, or poles, which are electrically different. We call the bonds in this kind of molecule polar.

Many kinds of molecules are not polar, but have a uniform electrical field around them. The H_2 molecule, for instance, has two atoms that are the same. Neither has more attraction for electrons than the other.

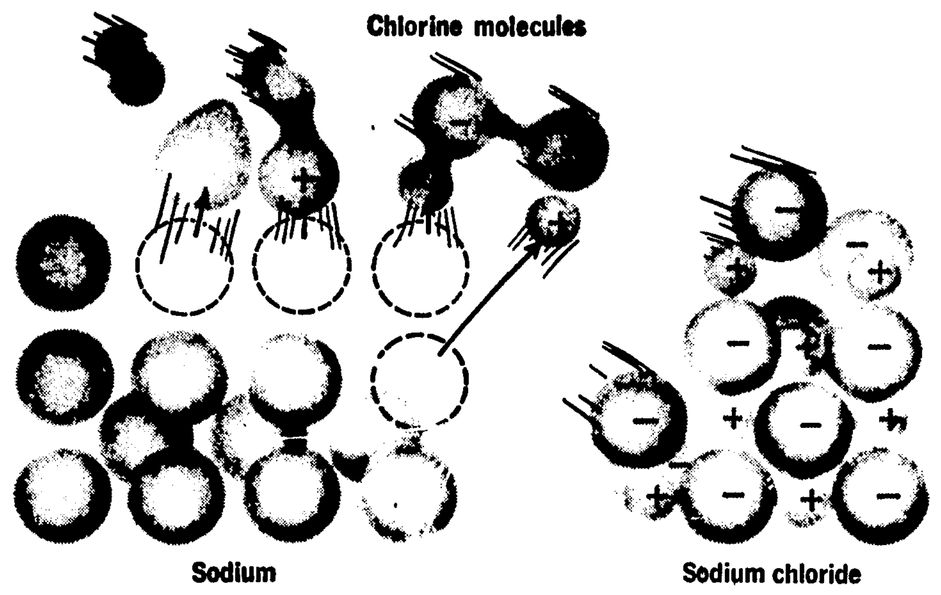
In ethane, likewise, the two carbon atoms are the same electrically. Bonds between identical atoms are usually nonpolar. Bonds between carbon and hydrogen are also nonpolar.

Ions. Extremely polar bonds are found in compounds between atoms that need to borrow just one electron to complete a shell and those that can lend just one. In fact, the lender atom may let go of the electron completely. Fig. 2-9 shows the reaction of sodium and chlorine atoms into table salt, or sodium chloride.

The sodium chloride is a compound quite different from the other compounds we have looked at so far. Each sodium atom is the same distance from six chlorine atoms; no molecules made of just one sodium and one chlorine atom can be found.

The sodium atom, having lent away completely the one electron in its M shell, now has 11 protons and 10 electrons. Having one more proton than electrons, it is a charged atom, which we call an ion. The sodium ion is written Na^+.

The chlorine atom now has 17 protons and 18 electrons. It is also an ion, Cl^-.



When sodium reacts with chlorine to form common salt, an electron is transferred from the outer shell of each sodium atom to the outer shell of each chlorine atom. The particles composing the salt are sodium ions and chloride ions.

Fig. 2-9

When ionic compounds such as salt dissolve in water, the ions separate. If electricity is applied to the solution, each ion moves toward the electrode having a charge opposite its own. This makes a solution such as salt water a good conductor of electricity.

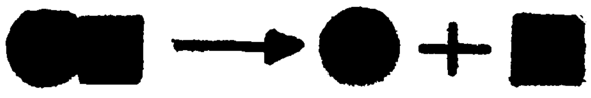
Chemical Reactions. We have seen that there are, in nature, about 92 different kinds of atoms, making up the elements; that they combine with one another to form molecules by shifting electrons; that, when different elements combine, compounds are formed; and that compounds have different kinds of bonds or electron structures that hold them together.

Any change in bonds between atoms is a chemical reaction. If we use marks of various shapes to stand for different kinds of atoms, here are a few different kinds of reactions:

Atoms can join together:

Molecules can join together:

Molecules can come apart:



An atom can replace another atom in a molecule:

The atoms in two different molecules can swap places.

Fig. 2-10

Equations. A chemical reaction can be given exactly by an equation, which is made up of the correct formulas for the compounds and elements that react. The ratio in which the molecules react is shown by numbers in front of the formulas. Equations like the following tell about important reactions:

Corrosion of metals is usually a combining with oxygen.

Iron and oxygen give iron oxide (rust)

$$4\ Fe + 3O_2 \longrightarrow 2\ Fe_2O_3$$

Fuels burn.

Methane and oxygen give carbon dioxide and water

$$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$$

At high temperature carbon monoxide (CO) forms:

$$2\ CH_4 + 3\ O_2 \longrightarrow 2\ CO + 4\ H_2O$$

Acids contain hydrogen, which can be replaced in a chemical reaction by some metals:

Iron and sulfuric acid give hydrogen and iron sulfate

$$Fe + H_2SO_4 \longrightarrow H_2 + FeSO_4$$

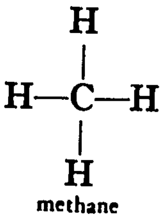
2. HYDROCARBONS

Because of their importance to the automotive industry, we should take some time to consider the group of compounds known as hydrocarbons. They consist of carbon and hydrogen.

The main source of hydrocarbons is petroleum, or crude oil, which is taken from the ground in many parts of the world. Petroleum is separated into various products by distillation, as shown in Fig. 2-11.

Thousands of different hydrocarbons are present in each petroleum deposit. The simplest is methane, which is the main constituent of natural gas. Natural gas is usually, but not always, found together with deposits of crude oil. Each molecule of methane has one carbon atom and four hydrogen atoms. As we already know, we write the formula CH_4. This can be written also with a pair of dots between the atoms to show a bond, as we did before, or with a line, like this:

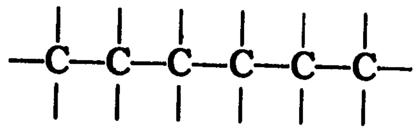
Because methane has a boiling point of -256°F., it is a gas at ordinary temperature and pressure.

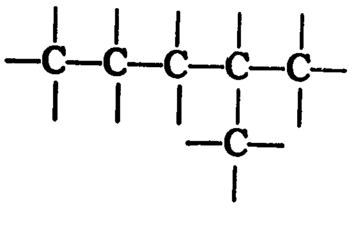


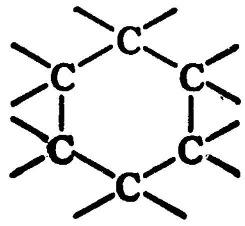
$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array}$$

methane

Carbon atoms can hook up to other carbon atoms, forming a sort of skeleton for chain and ring compounds:







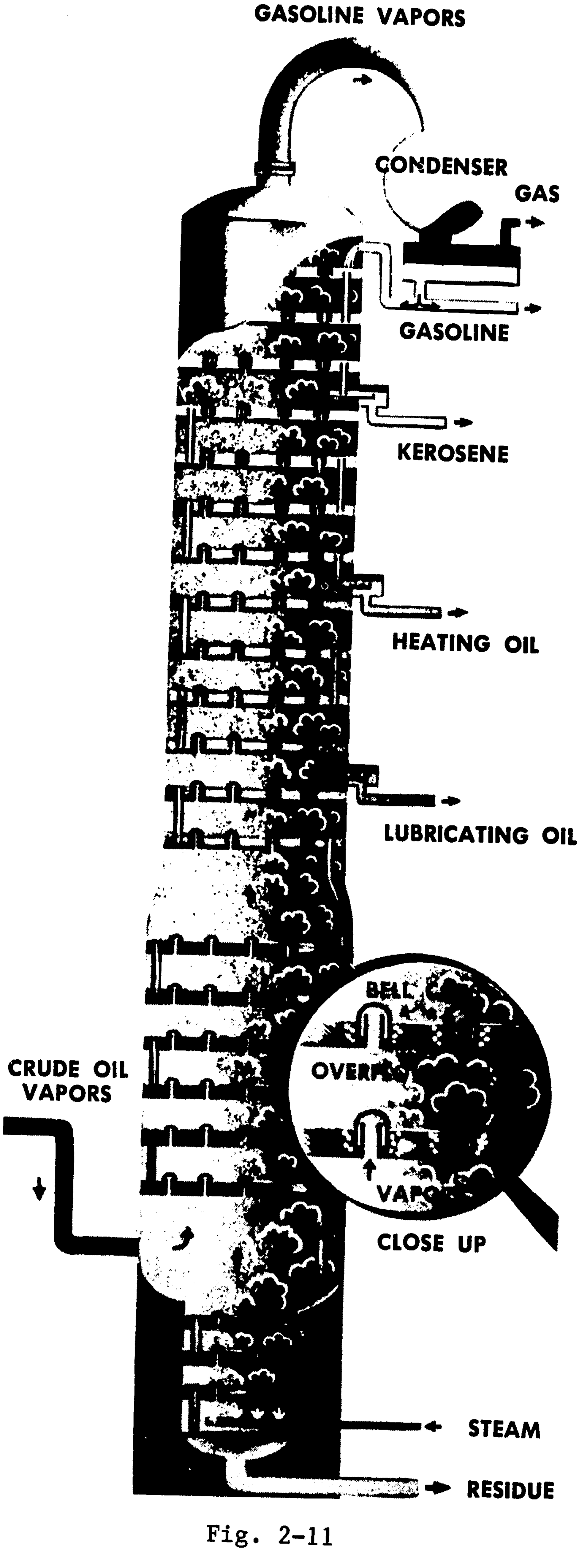


Fig. 2-11

EXPERIMENT 1. ELEMENTS, COMPOUNDS, AND MIXTURES

Matter of any kind is made of one or more simple substances called elements. There are about 100 of these, such as iron, copper, oxygen, and sulfur.

Elements can exist by themselves, pure. The copper in wire, for example, is so pure that it may have less than 0.1% of other elements in it. The sulfur you will use in this experiment will be even purer.

Most materials are not just one pure element. They may be mixtures of elements. In a mixture several materials are held together loosely and can be taken apart by gentle methods.

Elements are more often joined together in compounds. Here they are held together by strong electron bonds between the atoms. Only strong methods--electrical, chemical, or great heat--can take compounds apart.

When compounds are made or taken apart, this is a chemical change. The simple changes of form that can be used to take mixtures apart are physical changes.

In this experiment you will see how mixtures differ from compounds.

One thing to keep in mind is that we have air all around us all the time. When things burn, this is usually a combining with oxygen in the air.

MATERIALS: iron filings, sulfur flowers, magnesium ribbon, dilute hydrochloric acid, 2 semimicro test tubes, forceps, magnet.

PROCEDURE:

1. Examine a piece of magnesium ribbon. Pull or bend it-is it strong? Scrape it--is it shiny?

2. Holding the ribbon with a pair of forceps, put one end in a hot flame until it begins to burn. When it finishes, what is left? Is it like the magnesium ribbon you started with?

3. (Windows should be open for this part). Examine some powdered sulfur (flowers). Feel it. Smell it.

5. Add four more drops of acid to each tube and shake. Again record the results after two minutes.

6. Add ten more drops to each tube, shake, and note the results after two minutes.

7. Put the tubes into the beaker of hot water. After five minutes record which metals are reacting.

8. Empty the tubes. Rinse them several times with water. Wash off the metal samples thoroughly and put them back. Then repeat the same series of tests using acetic acid.

9. Do the same series of tests using sulfuric acid.

DATA:

	Iron	Zinc	Copper	Aluminum	Stainless Steel
Water					
+ 1 dr. HCl					
+ 5 dr. HCl					
+ 15 dr. HCl					
Above, heated					

CONCLUSIONS:

1. How much is corrosion rate affected by the kind of acid used.
2. How important is the concentration (strength) of the acid?
3. Which metals are acid-resistant?
4. What difference does temperature make?

EXPERIMENT 3. ACIDS AND BASES

When a base is added to an acid it neutralizes it, tying up the loose hydrogen tightly. In this experiment you will see how this affects the reaction of acids with metals, as well as their taste and their effect on indicators--chemicals that change color in acid or base.

MATERIALS: Zinc strips or iron nails; glass rod; dropping bottles of dilute (3N) sulfuric, hydrochloric, and acetic acids and sodium hydroxide; litmus paper; methyl red solution; five semimicro test tubes.

PROCEDURE:

1. Put the test tubes in a rack and fill them half full of water. Add 20 drops of dilute sulfuric acid to the first four of them.

2. To one of the test tubes of acid add 5 drops of sodium hydroxide; to the next, 10 drops; to the third, 20 drops.

3. Put a paper towel on the desk and on it put a strip of litmus paper. With a glass rod touch a drop of water on the litmus paper. What color is it? Take each test tube in turn, stirring with the rod and touching the liquid to the litmus paper. A second strip may be used if necessary. Record the results of each test. If the tube with 20 drops of base is the same as the rest, add base a drop at a time and test repeatedly until a new color is seen.

4. Add a drop of methyl red to each tube and record the color.

5. Into each tube put a strip of zinc or a small iron nail. Estimate the bubble rate after two minutes and write it down (none, slow, moderate, fast, etc.)

6. Rinse the test tubes well. Repeat steps 1-5, using the dilute hydrochloric acid. Record the results.

7. Rinse the test tubes well. Repeat steps 1-5, using the dilute acetic acid. Record the results.

8. Rinse the tubes again. Fill them one-fourth full of water. In each of the first three, put one drop of a different acid. In the fourth, a drop of sodium hydroxide. In the fifth, a drop of hydrochloric acid and a drop of sodium hydroxide.

9. With the glass rod stir one tube at a time and taste a drop of the liquid. Record the taste of each.

10. Add a drop of methyl red to each tube and record the color.

11. Clean up all the equipment and return it to your instructor.

DATA:

Acid	Sulfuric				Hydrochloric	Acetic
No. of drops acid	20	20	20	20		
No. of drops base	0	5	10	20		
Litmus - color						
Methyl red - color						
Corrosion rate						

	Taste	Color with methyl red
Sulfuric acid		
Hydrochloric acid		
Acetic acid		
Sodium hydroxide		
HCl and 2 NaOH		

CONCLUSIONS:

1. How can acid corrosion be stopped?

2. What effect should water taken from a car radiator have on litmus paper?

3. What compound is formed when hydrochloric acid and sodium hydroxide mix?

EXPERIMENT 4. CORROSION

You know that iron rusts in water, even without acid being needed. In this experiment you will study some of the factors in corrosion: moisture, chemicals, and contact with other metals.

MATERIALS: Semimicro (10 x 75 mm) test tubes, small finishing nails, pieces of 14 and 18 gauge copper wire, small strips of zinc and aluminum; water and dilute (10%) solutions of salt, sulfuric acid and sodium hydroxide; test tube rack or small jar; steel wool.

PROCEDURE:

1. In your notebook prepare a page to record the experiment. Your teacher will divide the work so that you will set up only a part of it, but you will record the data for all the different tests. Set up a table like this:

Liquid	Water	Salt Solution	Sulfuric Acid Solution	Sodium Hydroxide
Iron				
Zinc				
Copper				
Aluminum				
Iron + copper				
Zinc + copper				
Aluminum + copper				

2. Clean all the metal samples with steel wool. Make the last three kinds by wrapping 18 gauge copper wire around the other metal. Put each metal sample in a different test tube and line them up in a rack or stand them in a jar.

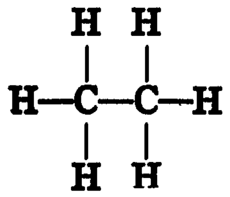
3. Whichever liquid is assigned to you, put enough in each of your test tubes to cover the lower half of the metal sample. Observe the samples over a period of time: some changes can be seen in a minute, some in 5 or 15, some only the next day. Look for dissolving, bubbling, change in color, or the formation of visible corrosion products, which may be colored or almost transparent and jelly-like. Record

any such observations and the time they took to appear. Record the corrosion effects in your classmates' experiments, too.

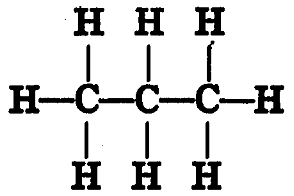
CONCLUSIONS:

1. What metals does water affect?
2. Which metals are affected by salt solutions?
3. Which metals corrode faster when in contact with a second metal?
4. Which metal is the best for all-around corrosion resistance?

There is no limit to the variety of carbon compounds that can be made. A skeleton with two carbon atoms gives us ethane:


$$\begin{array}{cccc} & H & H & \\ & | & | & \\ H- & C- & C & -H \\ & | & | & \\ & H & H & \end{array}$$

Three carbon atoms give propane:


$$\begin{array}{ccccc} & H & H & H & \\ & | & | & | & \\ H- & C- & C- & C & -H \\ & | & | & | & \\ & H & H & H & \end{array}$$

This same formula can be written a little more simply:

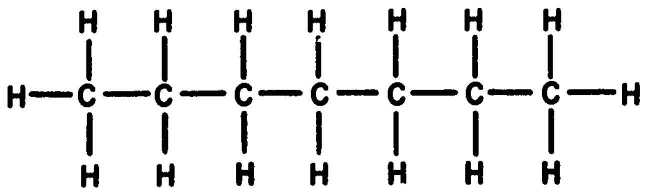
Propane boils at -44°F., so it can be liquified by pressure. It is sold in pressure tanks as a handy fuel. $CH_3—CH_2—CH_3$

A fourth hydrocarbon is butane. It boils at 31°, near the freezing point of water. It is added to gasoline in the winter, because it turns into a vapor so easily. This makes for good starting. $CH_3—CH_2—CH_2—CH_3$

Isomers and branched chains. The four carbon atoms in butane can be arranged into a slightly different chain, with one carbon atom branching off from another. This gives a substance called isobutane. Such a variation of a compound is called an isomer. Two isomers of a compound may be quite different, even though their general formulas are the same (in this case, C_4H_{10}).


$$\begin{array}{ccc} CH_3— & CH & —CH_3 \\ & | & \\ & CH_3 & \end{array}$$

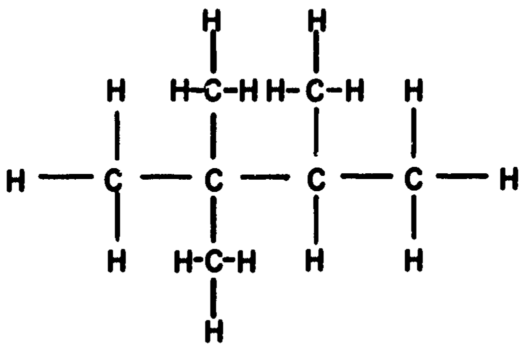
Branched-chain isomers are valuable in gasoline because they "knock" much less in an engine than straight-chain types. N-heptane, for example, knocks very badly.



n-HEPTANE (C_7H_{16})

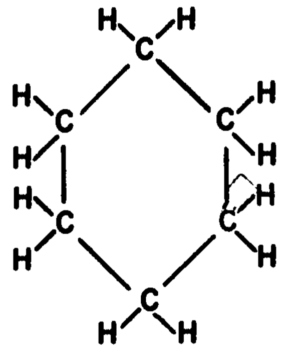
Triptane, an isomer with the same number of carbon and hydrogen atoms, knocks very little.

All the hydrocarbons we have studied so far are part of the paraffin family.



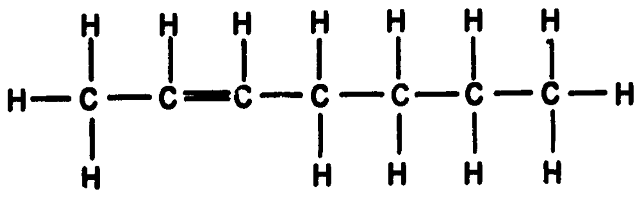
TRIPTANE (C_7H_{16})

Ring compounds. Another kind of carbon skeleton is shown in the naphthenes, such as cyclohexane. It behaves like an open-chain or paraffin compound in most ways.



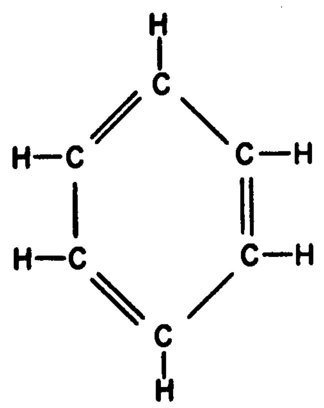
CYCLOHEXANE (C_6H_{12})

NAPHTHENE



2-HEPTENE (C_7H_{14})

Unsaturated hydrocarbons, like 2-heptene, have two bonds between a pair of carbon atoms. The carbon atoms are not combined with as many hydrogen atoms as possible--hence the term "unsaturated". They make up the olefin family (sometimes called the ethylene family). Most gasolines contain this kind of compound also. As we shall see further on, they tend to form gum and sludges in the engine.



BENZENE (C_6H_6)

AROMATIC

Aromatic hydrocarbons, like benzene, have a ring structure and fewer hydrogen atoms than the others. They have high antiknock value but tend to form carbon in an engine. Toluene and xylene are aromatic solvents used in painting.

Hydrocarbons as gases, liquids, solids. There is significant relationship between the number of carbon atoms and the physical state of the hydrocarbon compound. As the number of carbon and hydrogen atoms in hydrocarbons increases, their boiling points increase.

Molecules with one to four carbon atoms are gases at normal temperatures and pressures. Those with five carbon atoms (pentane, C_5H_{12}, which boils at 97°F.) and more are usually liquids. Finally, those molecules with 18 or more carbon atoms are usually semisolids and solids. This rule applies generally whether the hydrocarbons are paraffin or olefin, straight-or branch-chain.

EXPERIMENT 5. BOILING RANGE OF PETROLEUM FRACTIONS

Petroleum, or crude oil, is distilled into parts (or fractions) of various boiling ranges: gasoline, naphtha, kerosene, heavy fuel oil, lubricating oil, and so forth. In the distilling process, the boiling ranges are chosen so as to give the desired evaporation, fast or slow, needed in the product. (Remember that boiling is just a special kind of vaporization.)

Gasoline is a product that has to begin vaporizing very easily so it will ignite even when cold. Naphtha (a solvent used for dry cleaning and for thinning paints) must not vaporize enough at room temperature to form an explosive mixture; on the other hand it must evaporate completely in a reasonable time. Kerosene, for safety reasons, must vaporize enough to catch fire only when heated quite warm.

In this experiment your class will distill these three fractions.

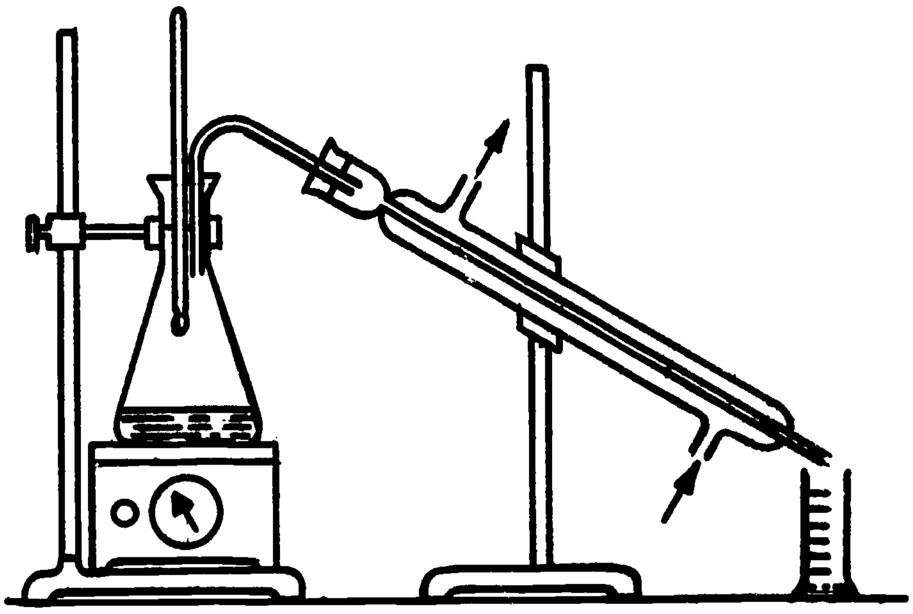
MATERIALS: Gasoline, kerosene, naphtha, 125 ml. Erlenmeyer flask, stoppers, 75° glass bend, condenser, 50 ml. graduated cylinder, 600°F. thermometer, hot plate, 2 ring stands, clamps, water hose.

PROCEDURE:

1. In your notebook prepare a table like this, allowing for all three materials:

Sample	Time	Temp., °F.	Vol., ml.	Vol. %	Remarks
			0	0	
			IBP	0	
			10	20	
			20	40	
			30	60	
			40	80	

2. Assemble the apparatus as shown. Be sure it is straight and firm. Tighten all clamps gently. Your instructor will help you. Do not use stronger force than three fingers on any glass connection, as the glass may break and cut you.



3. When the apparatus is all together and checked by your instructor, measure 50 ml. of the liquid to be tested. Open the flask and pour it in. Then replace the stopper with the thermometer and reconnect the condenser. Run water through the condenser, in at the bottom and out at the top. Keep the water running--a slow trickle is enough.

If working with gasoline, have no flames around.

Turn the hot plate on under the flask, recording the time you do this. The liquid will boil, forcing vapors into the condenser. When the first drop falls into the graduate, record the temperature in the IBP (initial boiling point) line of the data table, as well as the time. Continue heating so the distillation gives about two drops per second. Record time and temperature when you have 10, 20, 30, and 40 mls. Then turn off the heat.

4. Compare the distillation ranges for the three petroleum fractions.

5. Optional: Distill water, ethyl alcohol, and water-alcohol mixtures.

CONCLUSIONS:

1. Which figures in the data table show how flammable a petroleum fraction will be?

2. How will a liquid distill which is made so it will evaporate easily and completely?

3. GASES

The states of matter. Matter exists in three states: gas, liquid, and solid. A substance that has no particular shape or volume is called a gas.

Air is a typical gas. The same air can be pumped from a square room into a cylindrical tank, and from it into a doughnut-shaped tire. It has no special shape. A large volume in the room becomes a smaller volume in the tank when it is compressed. It fills whatever container it is in.

Air is our most important gas. We need it for our bodies; cars use it to burn fuel for power. It is light, but it does have weight. Our earth is surrounded by a layer of air. Just over the one square foot on which you may be standing, there is about a ton of air. At the surface, it is compressed by the weight of air above it. At higher altitudes there is less air, and the pressure is lower. When you go up a high mountain, both you and your car suffer from the low air pressure.

At sea level, the pressure of the atmosphere is about 15 pounds per square inch of surface.

Air is a mixture of molecules, mostly of nitrogen and oxygen, but with some carbon dioxide, water, and other materials also. The atoms within each molecule are held together by strong bonds, but a molecule of nitrogen or oxygen is not strongly attracted to other molecules.

Illustration of the air surrounding the earth. The height is exaggerated to bring out the decrease in density with altitude. (If drawn to scale, the earth's atmosphere would form a layer much thinner than the line shown here representing the earth's surface.)

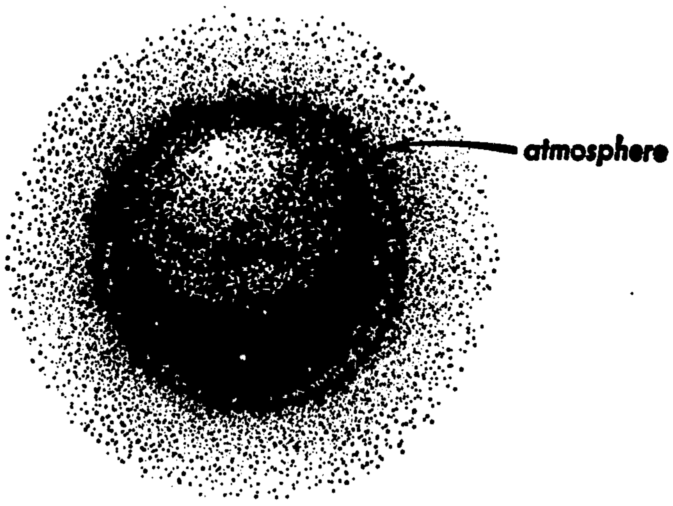
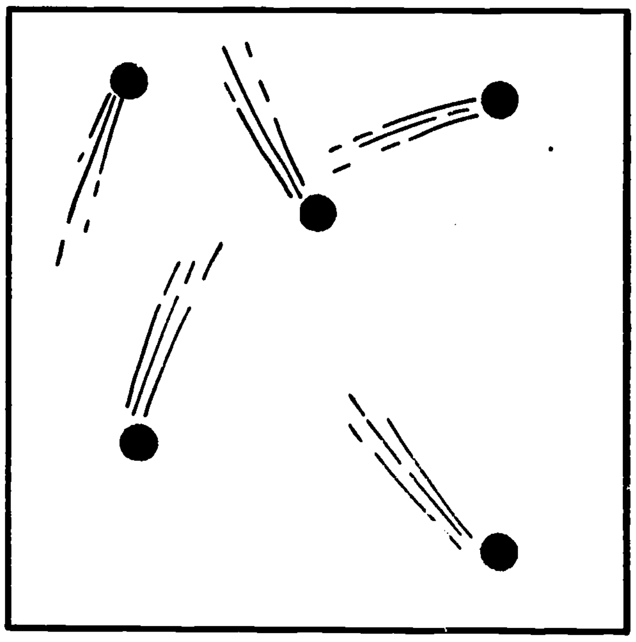


Fig. 2-12

Motion of atoms in gases. If a cup of water is boiled and turned into steam, it will take up about 50 gallons of space. Obviously the molecules of steam, which is water in gas form, must have a good deal of empty space between them.

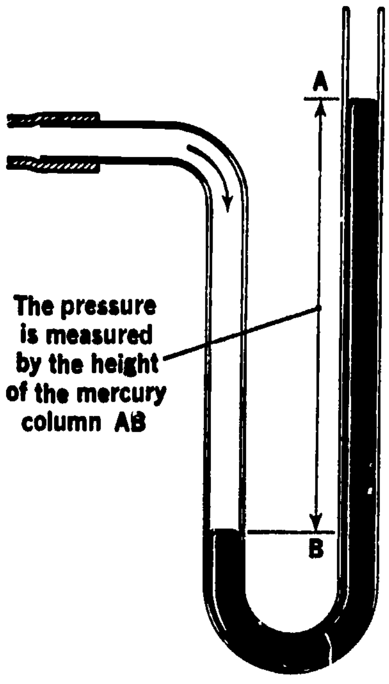
If you open a gas burner, you can smell the gas yards away in a short time. The molecules of gas are in rapid and continuous motion. Their speed in ordinary air is around ¼ of a mile a second. However, they travel short distances before hitting other molecules or the walls of the container; on the average, an air molecule has 5 million collisions per second. The molecules hitting the wall of the container give what we call pressure. Molecular collisions do not usually lead to a change in a molecule's structure or energy.



Molecules of a gas are widely separated and move rapidly.

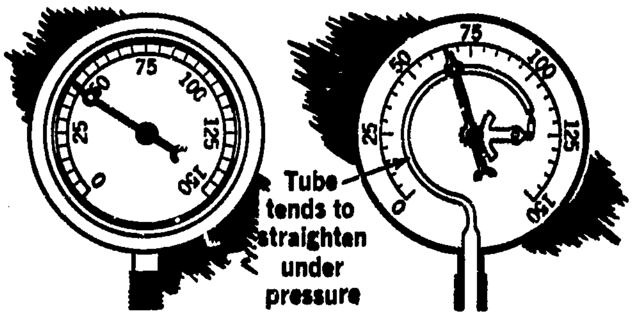
Fig. 2-13

Pressure of a gas can be very useful. It keeps tires inflated, giving a smooth ride over bumps. It leads to flow from points of high pressure to where it is lower, as in the fuel system of the car, in operating a floor lift, or in a paint sprayer. Pressure of air and other gases can be measured with a simple open manometer (Fig. 2-14) or a Bourdon gauge (Fig. 2-15).



An open manometer is used to measure pressure.

Fig. 2-14



The Bourdon pressure gauge. The internal mechanism is shown at the right.

Fig. 2-15

The average energy of motion, or kinetic energy of the molecules in a gas, is what we call its temperature. If the gas is heated up, its molecules speed up and have more energy.

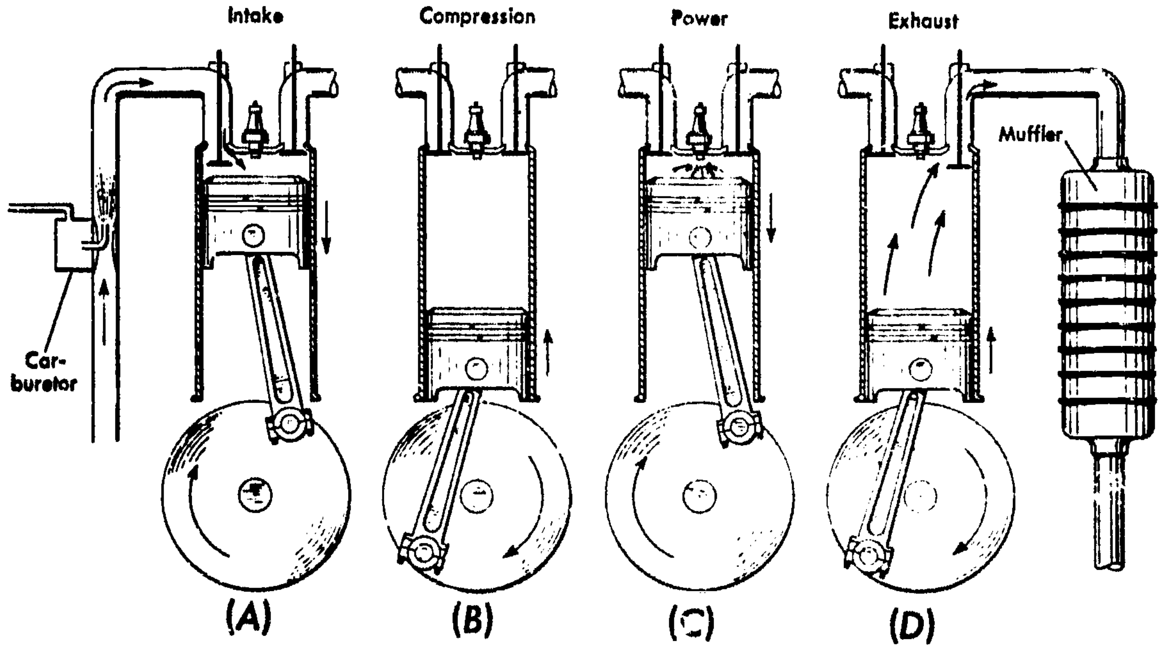
Temperature changes volume (Charles' Law). If a gas is heated, its pressure or volume go up in proportion. On the power stroke of an engine, for instance, the burning of the gasoline--air mixture produces a great amount of heat. As the temperature of the gas mixture shoots up, its pressure does the same. This great rise in pressure pushes on the piston and delivers power. As the piston goes down, the pressure drops but the volume of the gas increases.

These changes are described by the following equation for Charles' Law:

$$\frac{P_1 x V_1}{T_1} = \frac{P_2 x V_2}{T_2}$$

In using this formula, temperature must be put on an absolute scale. Add 492^o to the Fahrenheit temperature or 273^o to the Centigrade temperature to convert to an absolute basis.

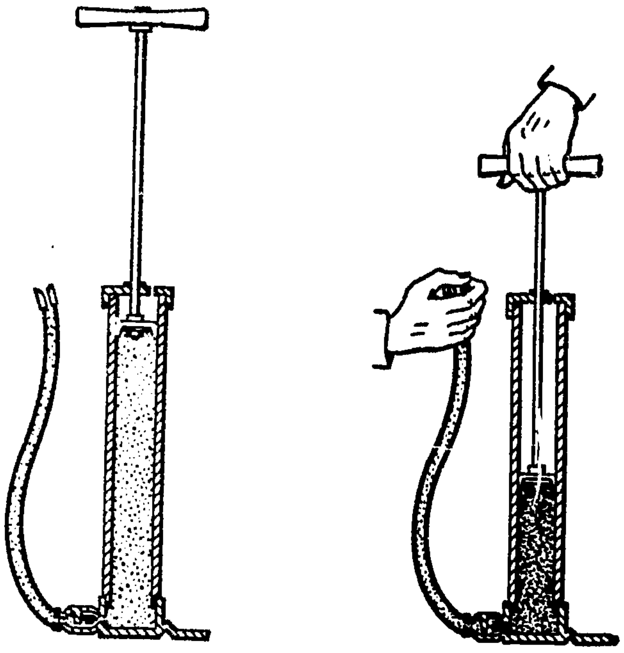
The temperature of a gas changes when its pressure changes. For example, compressing air will heat it. In diesel engines the 20:1 compression



The Four Strokes of a Gasoline Engine · (*A*) Intake; (*B*) compression; (*C*) power; (*D*) exhaust

Fig. 2-16

ratio heats the air so much that, when fuel is injected into it, no spark is needed for ignition.



The density of the air is doubled by doubling the pressure and compressing the air to one-half the original volume.

Fig. 2-17

Pressure changes volume (Boyle's Law). If you have ever worked a tire pump, as in Fig. 2-17, you know that you force the air into a small space to increase its pressure. Suppose you had 50 cubic inches of air in the pump to begin with, at the ordinary pressure of 15 pounds per square inch (psi). Then, with the piston halfway down, you would have only half the volume, or 25 cubic inches. But the pressure would be double, or 30 psi, if no air got out. The equation which shows how the pressure and volume of a given amount of gas are related is

$$P_1 x V_1 = P_2 x V_2$$

In this equation P stands for pressure and V stands for volume. The numbers after and below the letters tell whether we are talking about the first measurement (at the beginning) or the second (at the end).

During the compression stroke of an internal combustion engine, the volume of the air-fuel mixture goes down and its pressure goes up as the piston moves from bottom dead center to top dead center. The ratio of these volumes is called the compression ratio. Fig. 2-18 shows how an engine with a compression ratio of 8 to 1 compresses 80 cubic inches of air-fuel mixture into 10 cubic inches.

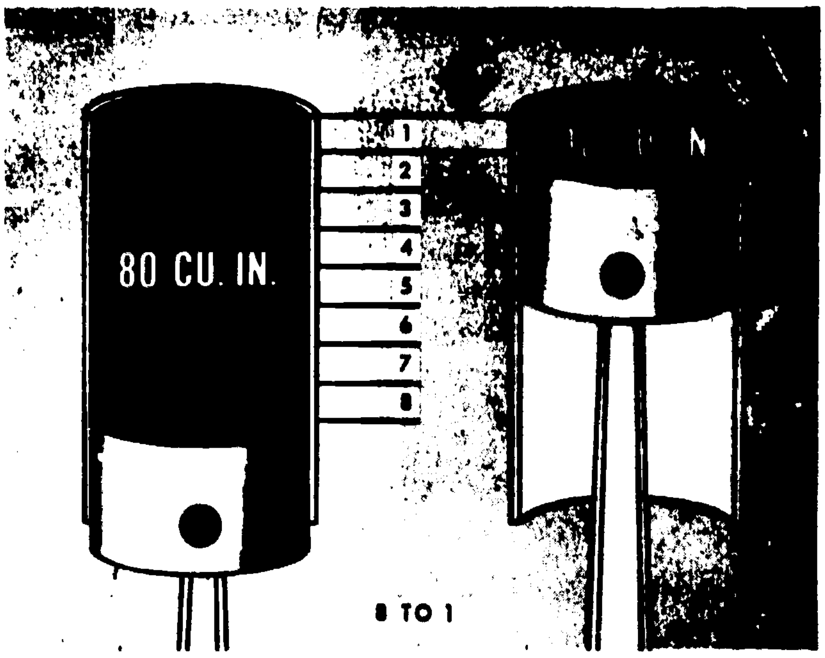
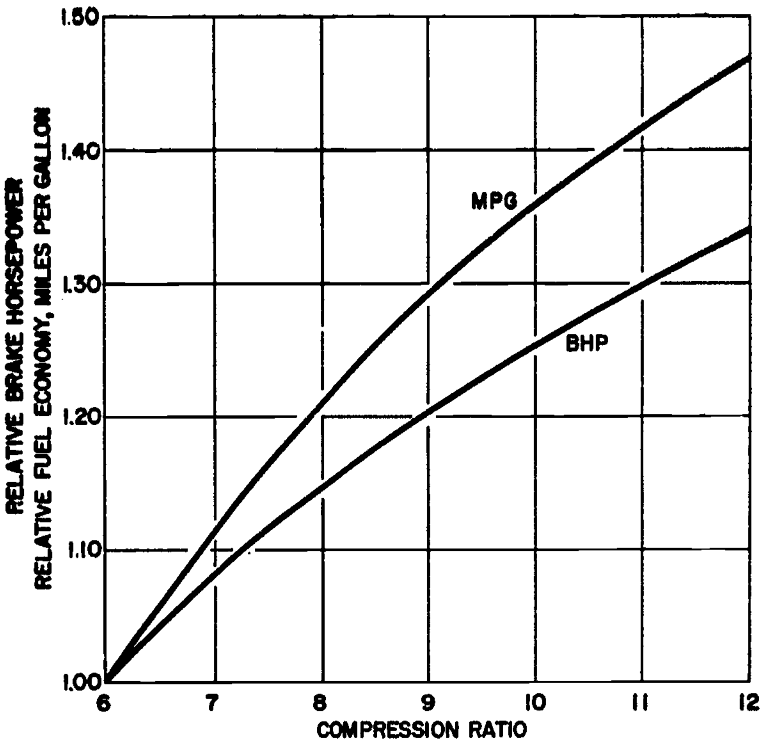


Fig. 2-18

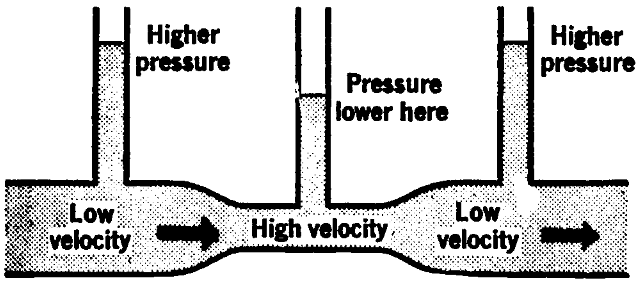
High compression ratios give higher pressures on the power stroke, leading to more power and miles per gallon.



Effect of Compression Ratio on Horsepower and Fuel Economy

Fig. 2-19

Pressure and velocity (Bernoulli's Law). When a portion of a gas or liquid is set in motion, its pressure decreases, and the faster the motion, the lower the pressure.



As the water flows more rapidly through the narrow portion of the tube, the pressure is lowered.

Fig. 2-20

Unlike the scientific laws mentioned above, this law seems to contradict common sense. But it can be shown to be true by using a venturi tube with water flowing through it, as shown in Fig. 2-20.

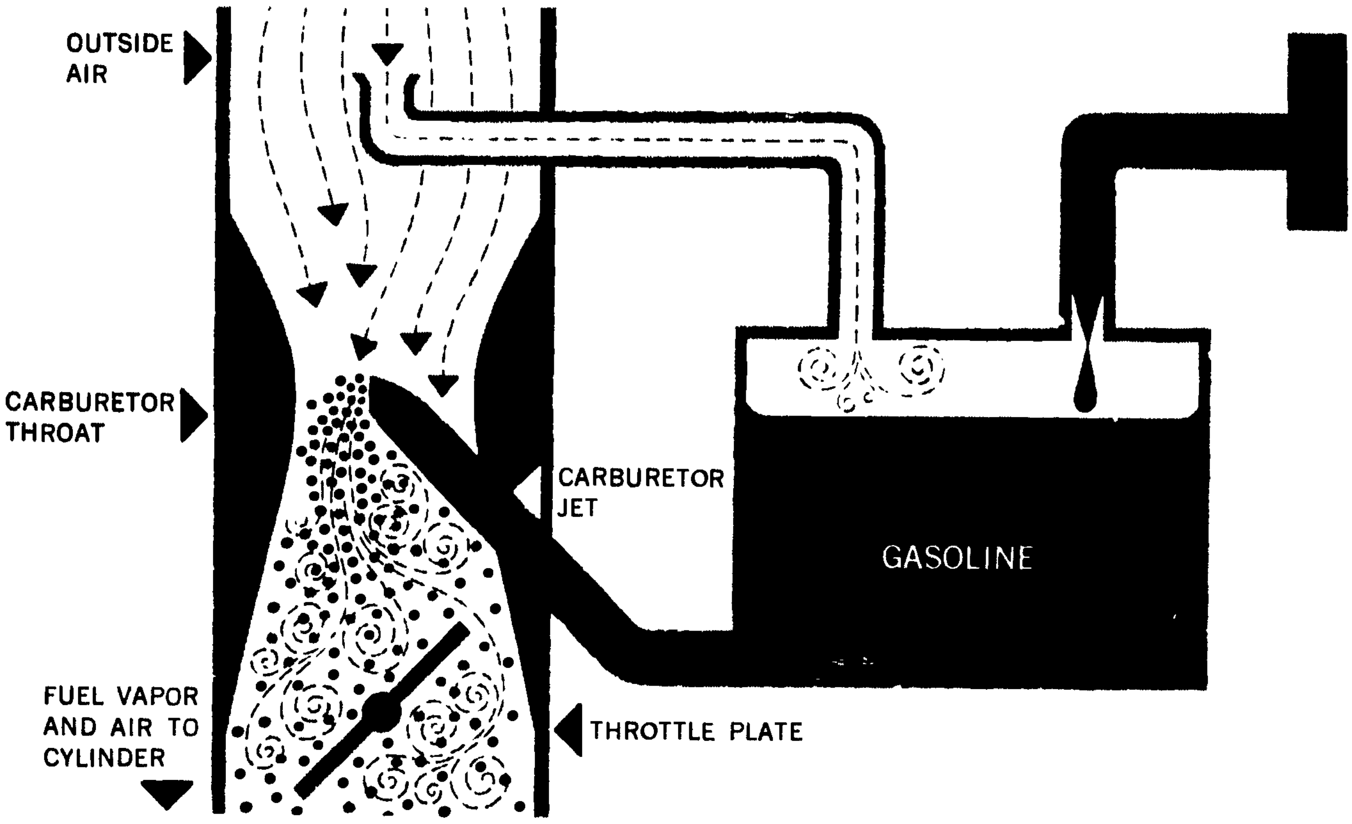


Fig. 2-21

Fig. 2-21 shows how this law works in the carburetor of a car. First, as the pistons go down in the cylinders, they draw air through the carburetor. The carburetor has a throat, or narrow place (a venturi tube). As the air goes through here, it has to speed up. Since the air has to move faster, a low-pressure spot is created, according to Bernoulli's Law. This partial vacuum draws gasoline through the tiny carburetor jet. The faster the engine goes, the more suction at the jet, and the more gasoline is drawn into the engine.

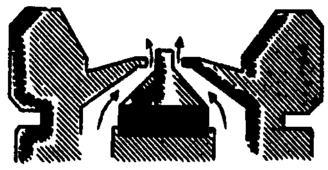
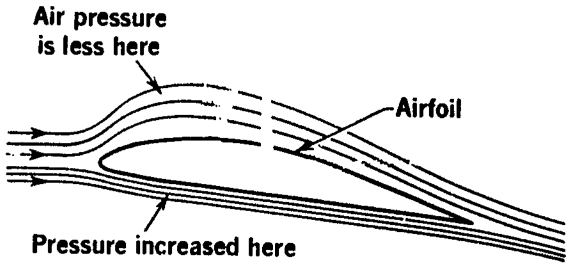


Fig. 2-22

Small spray guns used in paint shops also work on Bernoulli's principle. Air goes through a narrow passage. It speeds up at the narrow place, creating enough vacuum to pull paint up from the can through the fluid nozzle. This type of gun is called a suction feed gun.



The movement of air over the wing produces a difference in pressure between the upper and lower surfaces.

Fig. 2-23

The lifting power of an airplane wing is due to the airfoil shape, that is, curved on top and flat on the bottom. Air passing over the wing has to go faster than air passing underneath. This decreases the pressure on the top, and the greater pressure below lifts the plane.

Force and pressure. Force is a push or pull; it tends to cause motion. Pressure is the force on a unit of area, usually the number of pounds on one square inch (psi). The relationship between them is shown by the equation

$$P = \frac{F}{A} \qquad \text{or} \qquad F = PxA$$

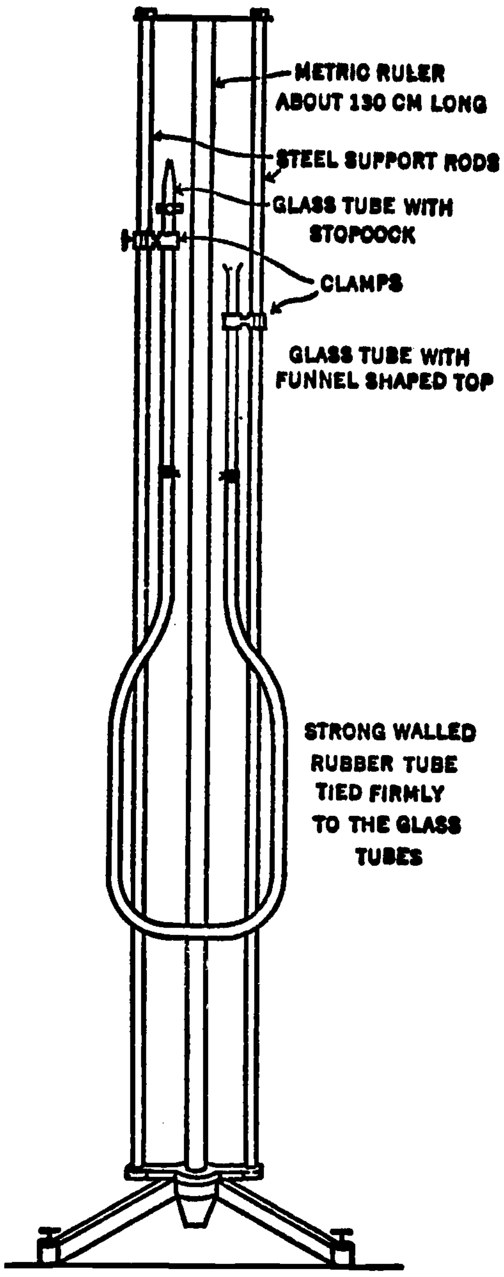
This equation applies to gases and also to liquids. As an example, suppose a 4000-pound car touches the ground with 40 square inches of tire surface on each wheel. As each wheel puts 1000 pounds of force to the ground (one-fourth of the weight of the car) the pressure on the ground under each tire must be

$$\frac{1000}{40} = 25 \text{ psi.}$$

Therefore, the pressure within each tire must also be 25 psi if the tire is not to flatten.

EXPERIMENT 6. COMPRESSION OF A GAS

At sea level, the air above the earth presses down upon everything with a pressure of about 15 pounds per square inch. This is enough to support a column of mercury (in a tube) 76 cm. high.



When pressure is put on a gas it is squeezed smaller--its volume becomes less. The aim of this experiment is to see how the amount of volume changes with the amount of pressure.

You will use apparatus like the one shown in the picture. The gas you will work with is air, trapped in a tube by some mercury. The pressure will come from the mercury in the glass tube, and you will be able to change the pressure at will. Pressure will be measured directly, as height in centimeters of mercury. The volume of gas will be proportional to the length of the trapped air in the tube, and will be measured in centimeters also. (Of course you realize this is not the actual volume; that would be calculated from the length times the cross-sectional area of the tube.)

Keep in mind that the total pressure on the trapped gas is the mercury pressure plus that of the atmosphere on top of the mercury. This is about 76 cm. all the time, or can be read more exactly from a barometer.

MATERIALS: Boyle's Law apparatus, metric ruler.

PROCEDURE:

1. Prepare a page in your notebook for recording data. Use a table like this:

Test Number	1	2	3	4	5
V (length of air section)					
Mercury height difference, cm.					
Atmospheric pressure, cm. Hg					
P, total pressure, cm. Hg					
P x V					

2. Obtain the apparatus from your instructor. CAUTION: Do not take mercury out of it. Mercury is not a toy to play with; if spilled, it gives off vapors that are gradually poisonous if breathed over a long time. It also ruins metal objects such as gold rings, coins, etc.

3. Open the stopcock and adjust the tubes so the mercury comes up to about the middle of both. Close the stopcock. Test it by raising the open tube several inches and leaving it at the new height. The mercury should take a new position and stay; if it slowly drifts down and becomes equal in the two tubes, the apparatus leaks and your instructor should check it.

4. When the apparatus checks out tight, adjust it back so the mercury is at the same height in both tubes.

5. Measure the length of the air section, from the stopcock to the top of the mercury. Use the metric (centimeter)scale of your ruler. Record this length as V in the first column of your table.

6. Write a zero (0) for the mercury height difference, as the mercury is the same height in both tubes.

7. Record the barometric pressure in cm. of mercury. If there is a barometer in the room, read it; otherwise, use 76 cm.

8. Add up the two pressures. This sum is P in the first column.

9. Multiply V times P and record the product in the last line.

10. Change the height of one of the tubes on the apparatus. Take a new set of readings. If the mercury in the open tube is higher than in the close one, the difference is to be added to atmospheric; if it is lower, subtract the difference. Measure the length of the trapped air and do the calculations as in the first test.

11. Repeat the test at five or six different positions, covering total pressures from 60 cm. to 90 cm. of mercury. When all the calculations are finished, show the results to your instructor.

CONCLUSIONS:

1. What happens to the volume of a gas when the pressure is decreased?

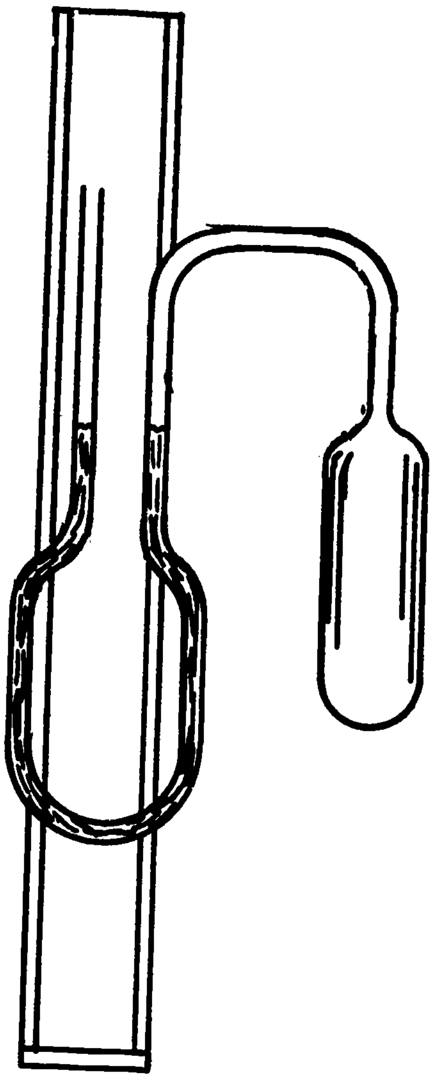
2. What formula shows how the pressure and volume of a certain quantity of a gas are related as one or the other changes?

3. When a truck is loaded up, what happens to the volume of air in the tires?

4. Why is it hard to crank a good engine?

EXPERIMENT 7. EFFECT OF HEAT ON A GAS

When a gas is heated, its pressure or its volume--or both--increase; if it is cooled, they decrease. In this experiment you will keep the volume of a gas the same, and see its pressure change as you cool and heat it, and will locate absolute zero from the data you collect.



MATERIALS: Air thermometer (Charles' Law apparatus) complete with mercury, glass marker, Fahrenheit thermometer, stainless-steel 2000 ml. beaker, heavy ring stand with large ring, water, ice if possible, gas burner or electric heater, metric ruler, graph paper (5 x 5 or 10 x 10 to the inch).

PROCEDURE:

1. Prepare a page in your notebook with a data table like the one shown here, on this page.

2. Obtain the Charles' Law apparatus, thermometer, metal beaker and other materials listed above. **CAUTION**: Do not take mercury out of the apparatus or play with it. Spilled mercury gives off a very unhealthful vapor.

3. Set up the apparatus and adjust the open tube so that the mercury level is the same in both arms. Make a mark on the closed arm at the top of the mercury level. Then change the open arm so as to make a difference in the two levels, and see if they stay. If they drift toward each other, ask your teacher to help you find and fix the leak. Then get the two mercury levels even again.

Temperature, °F.						
Pressure difference, cm. Hg						
Atmospheric pressure, cm. Hg						
Total pressure, cm. Hg						

4. Read and record the temperature of the room in Fahrenheit degrees and the atmospheric pressure as shown by a barometer (or, if there is none, use 76 cm.). Record these figures in the first column of your data table. Put down 0 for "pressure difference".

5. Support the metal beaker around the glass bulb of the apparatus. Fill it with ice water or cold water to cover the bulb. What happens to the mercury levels?

6. Move the open tube up or down until the mercury in the closed tube is back on the mark you made. With a metric ruler measure the difference in mercury heights. If it is higher in the open tube, the difference is positive (+); if lower in the open tube, it is negative (-). Record the pressure with its sign. Find the total pressure by adding to, or subtracting from, atmospheric.

7. Measure and record the water temperature.

8. Change the temperature of the air in the bulb by heating the water in the metal beaker. Stop heating when it has changed about 20 or 30°F. and take a reading of the pressure difference. Record temperature and pressure difference. Take a series of temperature-pressure readings until the water is at the boiling point, recording the figures each time. Compute the <u>total</u> pressure for each temperature reading.

9. Prepare a piece of graph paper like the sample. Your instructor will show you how to graph your data.

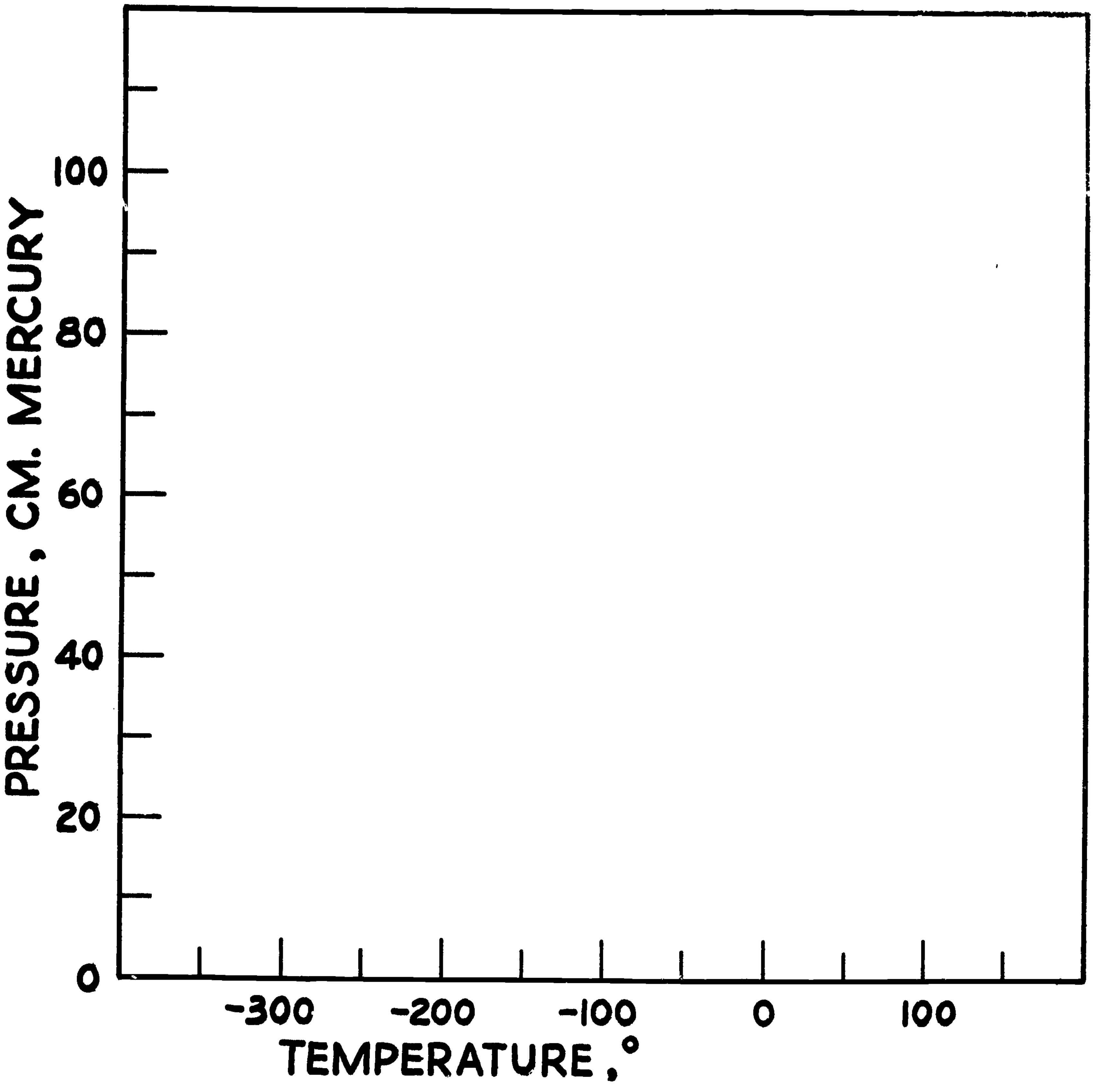
10. When you have made your graph, extend it with a ruler to find the temperature at which the gas would have <u>no</u> pressure (0 cm.). This is called absolute zero temperature.

<u>CONCLUSIONS</u>:

1. Is the change in pressure proportional to the change in (Fahrenheit) temperature?

2. If not, then what is it related to?

3. What do we mean by absolute zero?


PRESSURE, CM. MERCURY
100
80
60
40
20
0
-300
-200
-100
0
100
TEMPERATURE, °

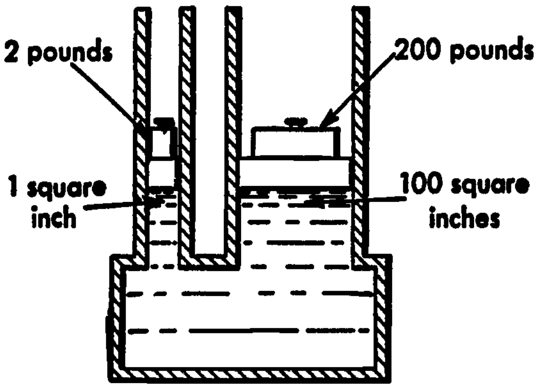
4. LIQUIDS

What are liquids? Substances which have a definite volume but no particular shape are called liquids. Water, oil, and gasoline are typical liquids.

Liquids flow under pressure but they can not be compressed. Compared to gases, they are much heavier.

Pressure in liquids (Pascal's Law). Have you ever wondered why it is so easy to stop a car weighing thousands of pounds with only the lightest pressure on the brake pedal? The principle involved is quite simple:

Liquids transmit pressure equally
in all directions.



Pascal's hydraulic press. The force on the larger piston exceeds the force on the smaller one.

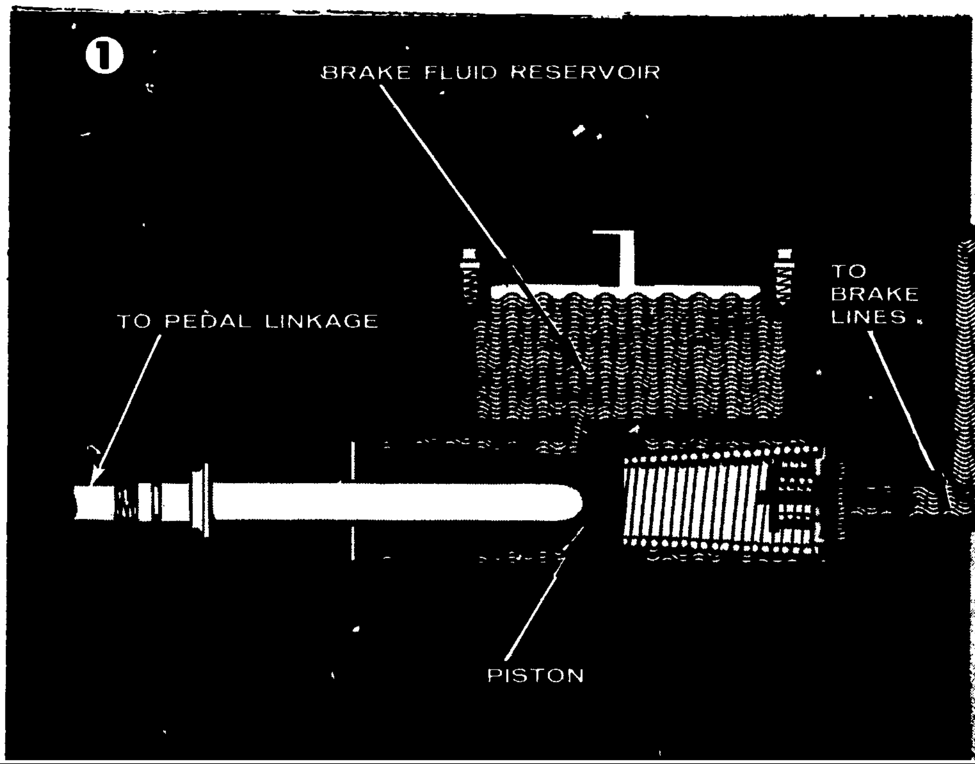
Fig. 2-24

Thus a force of two pounds on a small piston one square inch in area (see Fig. 2-24) gives a pressure of 2 psi in the whole system. When it pushes on 100 square inches of the large piston,

Force = Pressure x Area

a force of 2 x 100 = 200 pounds is available.

In a hydraulic brake system, pushing on the pedal forces the piston in the master cylinder against the brake fluid. The pressure is carried by metal tubes or brake lines to all four wheel cylinders. Here small pistons are pushed out by the pressure, forcing the shoes against the drums; only then is pressure in the whole system equal.



In a hydraulic lift the pressure on the oil comes from compressed air.

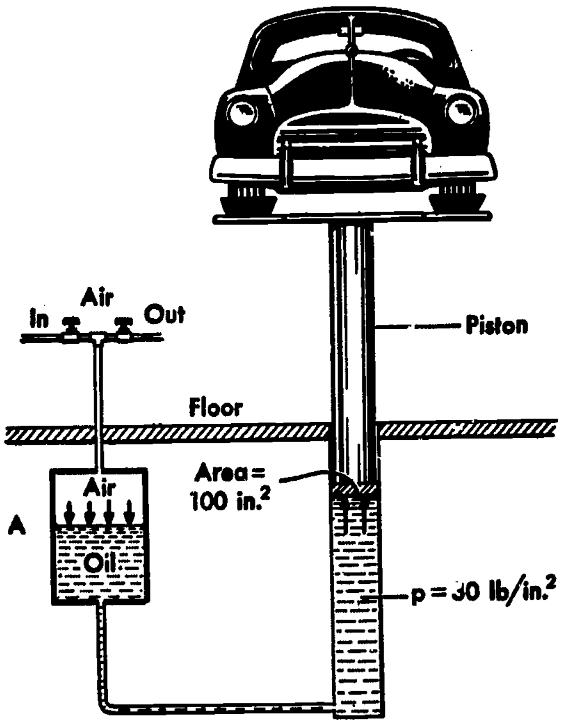


Fig. 2-26

Molecules in a liquid. The properties of liquids are due to the kinds of molecules they have. In general, the molecules are packed in close to each other about as tight as they can get, but in an uneven way. Liquids are weak materials, and this is due to the kinds of bonds between the molecules.

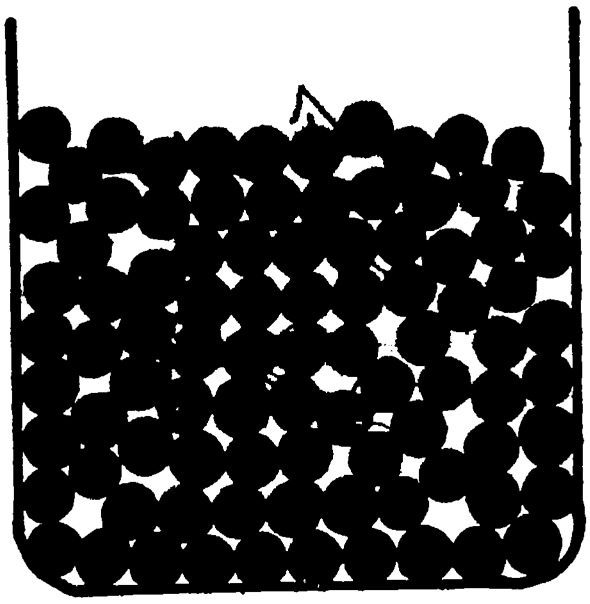


Fig. 2-27

Thinking back over the various kinds of bonds that attract atoms to each other to form molecules, the covalent bond, formed by sharing electrons in order to complete shells, is very strong. For example: rocks can be heated red hot without the molecules' coming apart.

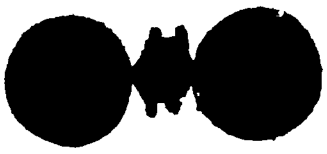


Fig. 2-28

Bonds of a strong electrical difference, ionic or polar bonds, are powerful and work over long distances. Salt, an ionic compound can also be heated red hot.

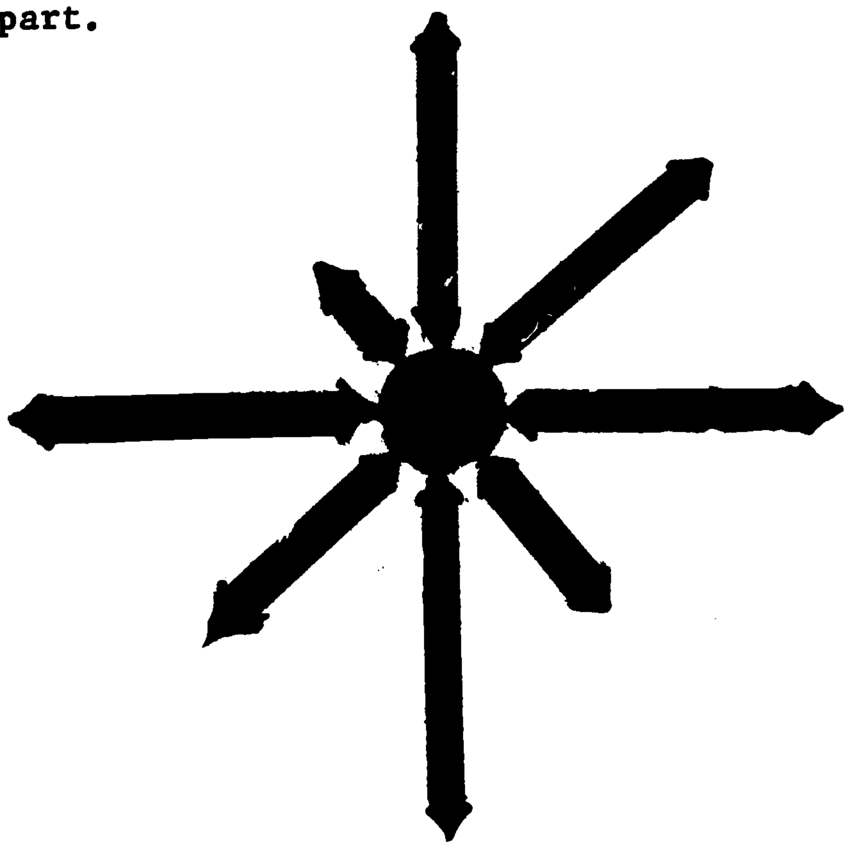


Fig. 2-29

This leaves compounds having only covalent bonds, such as the hydrocarbons in gasoline and oil. Within their molecules the valence bonds holding the atoms together may be quite strong, but have no electric fields around them except what is made by the movement of the tiny electrons in their orbits. The attraction of one molecule for another is weak and works over a short range. It is enough to hold the molecules together, but not to lock them rigidly solid.

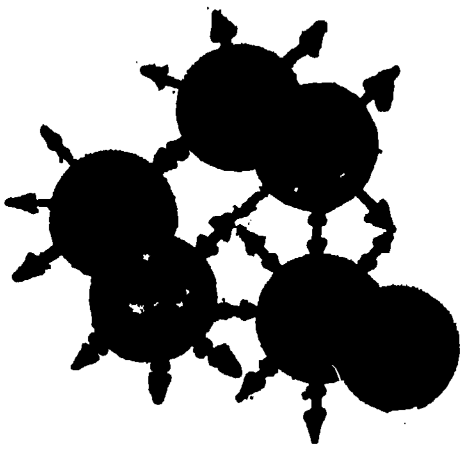


Fig. 2-30

The molecules of a liquid like those of a gas, are in constant motion. A drop of ink, placed gently in a glass of water, will soon have the water colored all over, as the water molecules bump into the ink and push it in all directions. The molecules in a liquid are in continual motion. At any time, some move faster than others.

The commonest and most important liquid is water. In a water molecule, the oxygen atom has two electron pairs that are not shared with hydrogen. They make one end more negative than the other. The water molecule therefore has a slightly positive end or pole near the hydrogen atoms, and a slightly negative pole at the oxygen end. Because of this electrical difference it is a polar compound.

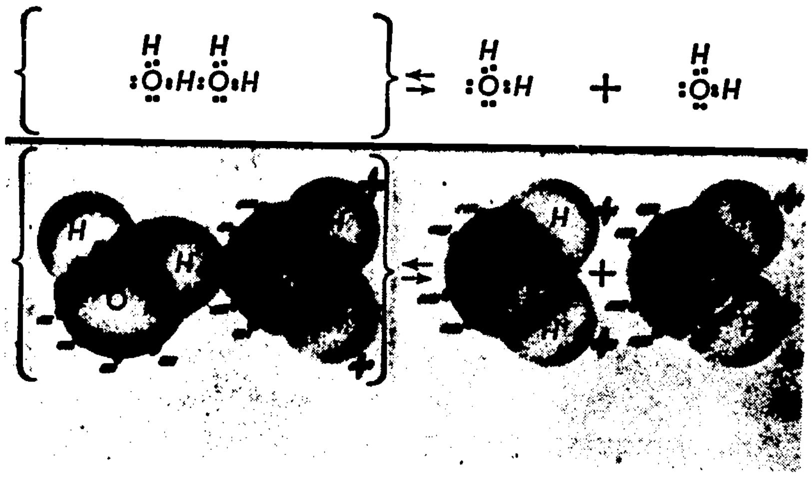


Fig. 2-31

Electrical attraction between oppositely charged poles of water molecules holds them together.

In fact, a hydrogen atom on one molecule tends to use an unshared electron pair on the next molecule as its electron shell. This ability of a hydrogen atom to hold two molecules together by attracting electron pairs on two molecules is called the hydrogen bond.

Freezing. In a liquid, the weak electrical poles on molecules tend to hold one to the next. The motion they have, proportional to temperature, keeps them from hooking to each other strongly. When they are cooled, the motion slows down. If they slow down until the motion is less than the electrical attraction, the molecules will freeze to one another, turning the liquid into a solid.

Ice crystals are formed by molecules of water joined by hydrogen bonds. Here the space between molecules is exaggerated to show how each hydrogen in each molecule is joined to an oxygen in a neighboring molecule.

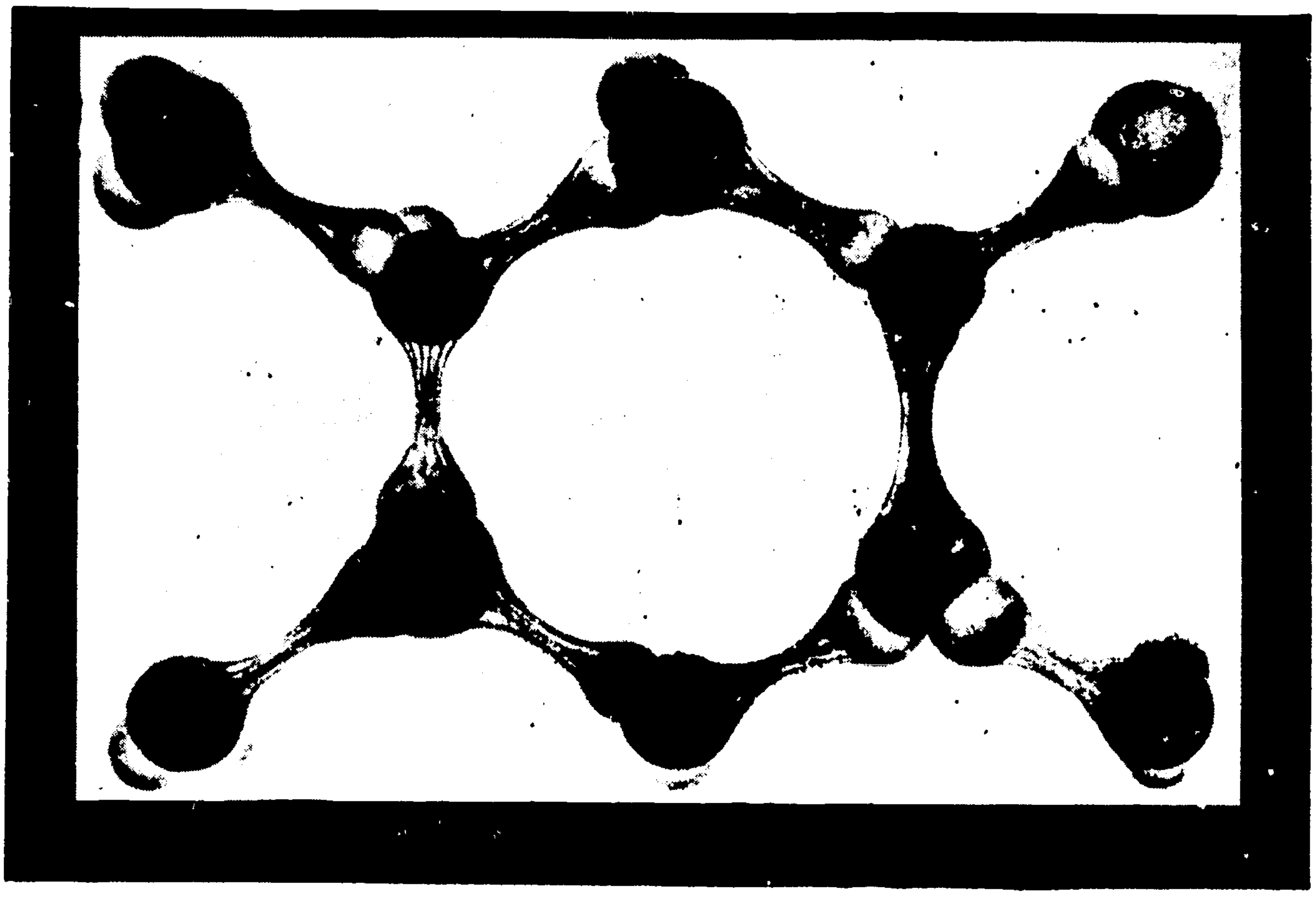


Fig. 2-32

Strong polar forces cause water molecules to freeze into six-sided crystals.

Molecules which are nonpolar, such as the hydrocarbons, do not freeze easily. Gasoline, for example, does not freeze even at the North Pole. But some hydrocarbon molecules with long, straight chains such as are found in lubricating oils, have so many weak attractions that they turn solid. Such hydrocarbons are called <u>waxes</u>. (See Fig. 2-33)

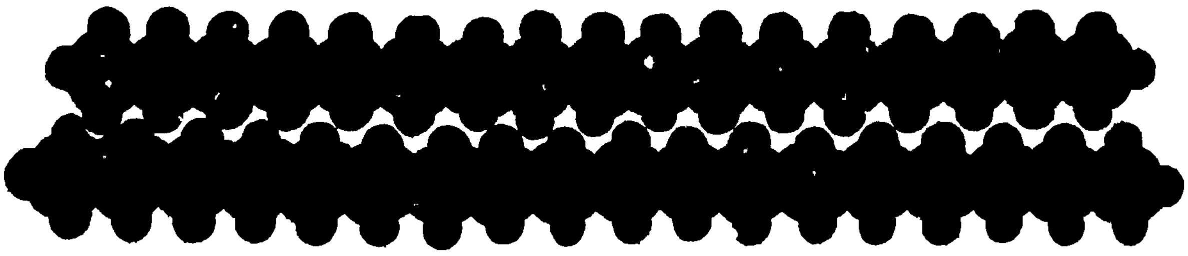


Fig. 2-33

If a large hydrocarbon molecule has even one small projection or bend in it, as in Figs. 2-34 and 2-35, it will not come close to the next one at enough places to freeze, as the weak attractions will not be lined up perfectly.

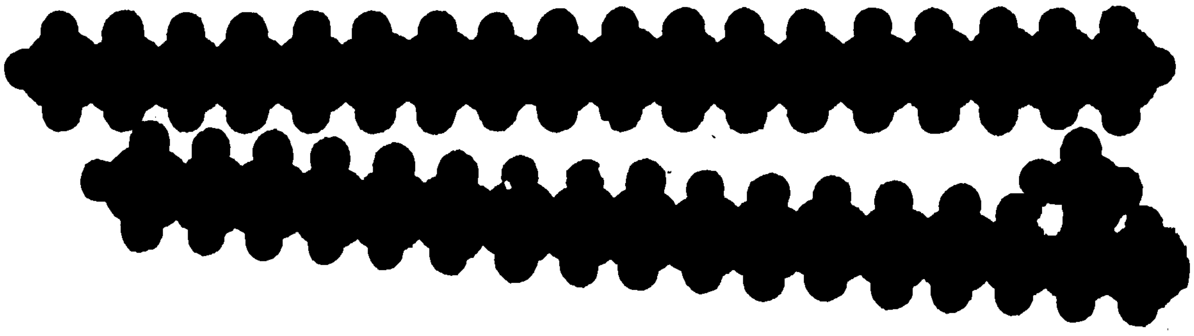


Fig. 2-34

Fig. 2-35

If the oil in an engine turned solid in the cold, it would be impossible to turn the engine over and start it. For this reason, oils are refined by a dewaxing process, in which the oil is chilled and the wax filtered out. The temperature at which an oil turns solid is its pour point. In cold weather, oils of low pour point are needed. The hydrocarbons in such oils have a branch or ring structure at some point.

Just as the motor oil of a car must remain liquid for operation at low temperatures, the liquid in the cooling system cannot be allowed to freeze, either. The usual liquid, water, is not only useless as a coolant when it cannot circulate, but it expands in freezing, as can be shown by experiment (Fig. 2-36).

To keep the coolant liquid and prevent damage to the engine, antifreeze chemicals are added. These are compounds whose molecules get between the water molecules, keeping them away from each other so they can't freeze.

When the water inside the bomb freezes, the expansion bursts the cast-iron walls.

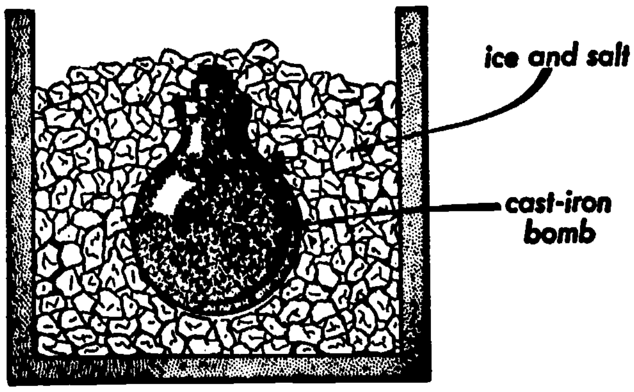


Fig. 2-36

The common antifreeze compounds are alcohols, which can be thought of as hydrocarbons with a hydroxyl (OH) group in place of one or more hydrogen atoms.

The OH group in these molecules is attracted to water molecules by hydrogen bonds. The ordinary alcohols boil off at temperatures well below the boiling point of water and can be lost by evaporation, leaving the engine unprotected against freezing. Ethylene glycol has two OH groups. They form so many hydrogen bonds that its boiling point is higher than that of water, making it a "permanent" antifreeze.

Viscosity. A liquid has the ability to flow. This is often the most important thing about it. The key to cooling the automobile engine, for example, is water circulating (flowing) between the block and the radiator (Fig. 2-37).

In the cooling system the liquid should flow as easily as possible.

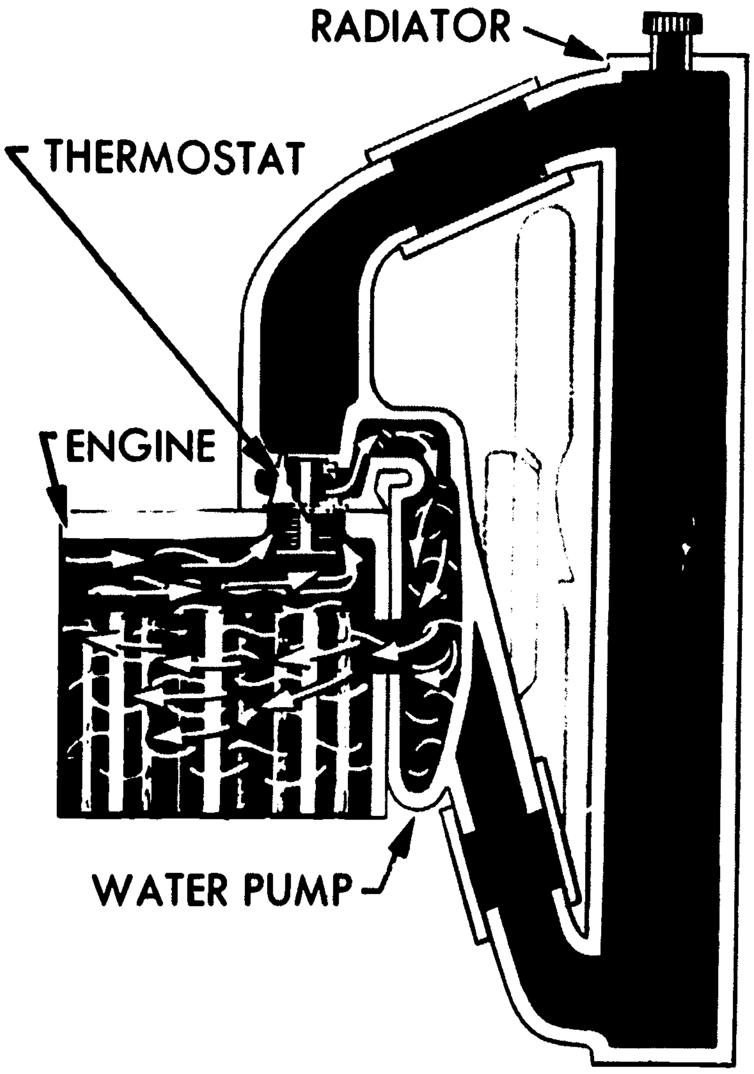


Fig. 2-37

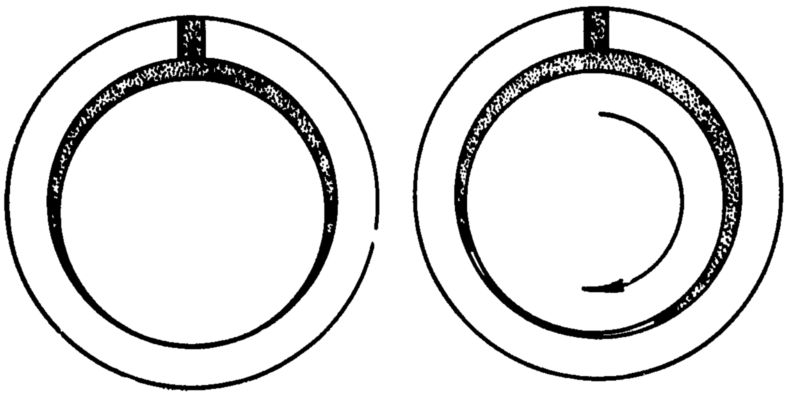


Fig. 2-38

In a bearing, on the other hand, the oil film between the two metal surfaces is what keeps them from wearing. The oil must not flow too easily; it must be viscous, that is, have a certain "body," or viscosity.

A simple way to measure viscosity is to see how long it takes a given amount of oil to run out of a certain size hole. This can be done in equipment like that shown in Fig. 2-39.

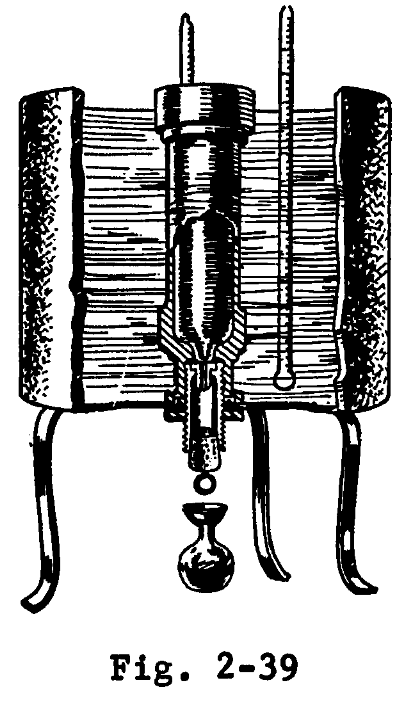


Fig. 2-39

The viscosity of lubricating oils is rated by SAE numbers.

Viscosity is caused by the attractions between molecules. Just how viscous a liquid will be is mainly a matter of:

1. Size of molecule: number of points of attraction. Gasoline is like lubricating oil, but it is less viscous because the molecule is smaller.

2. Strength of the molecular forces. In nonpolar hydrocarbon molecules, these are weak. Polar molecules containing oxygen, and particularly OH groups, have strong bonds. For example, glycols, having two OH groups, are more viscous than ordinary alcohols, with one; castor oil, with an OH group, is more viscous than similar oils without one.

SAE Viscosity Number	SAE VISCOSITY CLASSIFICATION			
	Viscosity Range, Saybolt Universal Seconds			
	At 0°F		At 210°F	
	Minimum	Maximum	Minimum	Maximum
5W	—	4,000	—	—
10W	6,000	12,000	—	—
20W	12,000	48,000	—	—
20	—	—	45	58
30	—	—	58	70
40	—	—	70	85
50	—	—	85	110

Table 2

3. Shape of the molecule. Thin molecules slide about more easily than wide ones. Lubricating oils of the paraffinic type (Fig. 2-34) have open or branched chains; naphthenic ones (Fig. 2-35) have ring structures. For a given number of carbon atoms, the ring types give higher viscosity.

Temperature. Keep in mind that temperature is a way of telling about the speed of molecules. The higher the temperature, the faster they are moving in all directions, and the easier it is to move them where you want them.

Motor oils have to be fluid when an engine is cold, so it can turn over easily and so the oil will get to the bearings. Then, when the engine is hot, the oil must not be too thin, or it will run out of the bearings like water.

How much the viscosity of an oil changes as it is heated is shown by its viscosity index, or VI. Fig. 2-40 shows how different oils which all meet the SAE 10W specification of about 9000 seconds at 0^{o}F. may have viscosities of 38 to 58 seconds at 210^{o}. They would all give reasonably easy starting in the cold, but the 0 VI oil with its 38-second viscosity would be too thin for protection in a hot engine. As you see from Table 3, manufacturers favor oils of the multigrade type, such as 10W-30.

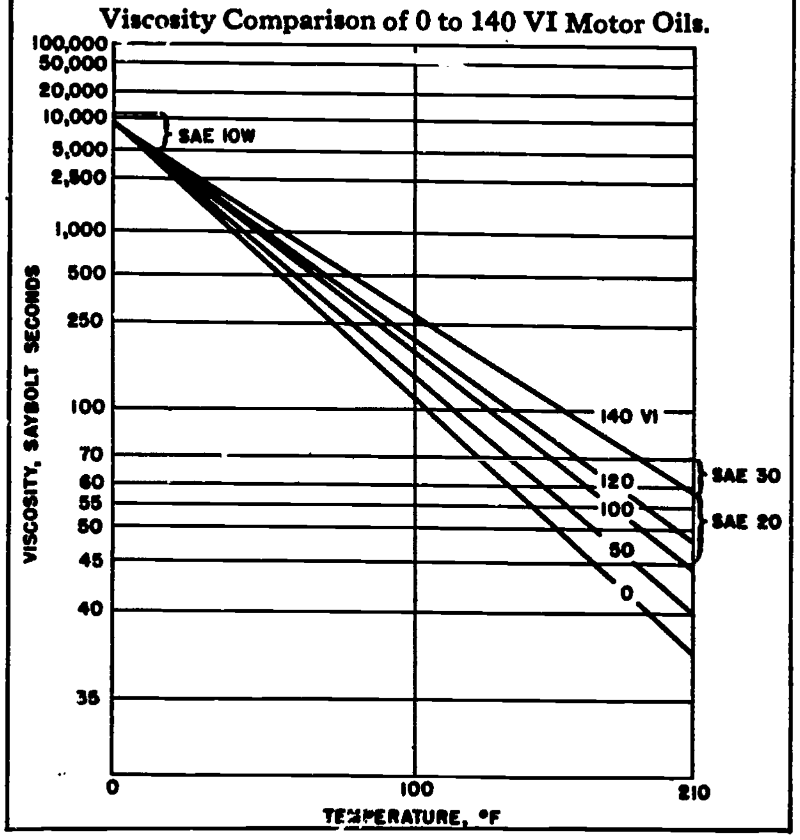


Fig. 2-40

COMPOSITE OF CAR MANUFACTURERS' RECOMMENDATIONS

Minimum Air Temperatures	SAE VISCOSITY NUMBER								
	30	20	20W	10W	5W	20W-40	10W-30	10W-20	5W-20
32°F	X	X	X			X	X	X	
10°F			X	X		X	X	X	
0°F				X			X	X	X
–10°F				X	X		X	X	X
below –10°F					X				X

Table 2

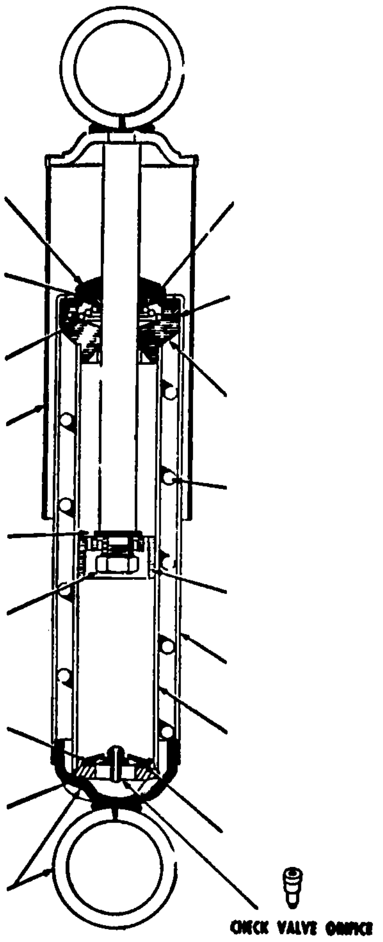


Fig. 2-41

In past years the best oils had to be made from Pennsylvania crudes. They has a VI of about 100. Today oils from many fields are improved by chemical additives. VI improvement can be made in any oil by adding a chemical that keeps it from thinning out under heat.

Viscosity is important in other places in a car, as well as in lubrication. For example, the action of a shock absorber comes from forcing oil up and down through a tiny orifice or hole.

Cohesion and Surface Tension. Attractions between molecules of the same kind make them hold together--this is called cohesion. Fig. 2-42 shows how cohesion makes oil form into spherical (round) drops when it floats between alcohol and water.

The forces between molecules are balanced within a liquid but not on its surface. At the surface the pull is sidewards and toward the inside; this produces a condition called surface tension--almost as if the surface molecules formed a sort of skin over the liquid. At some time you have probably filled a cup or spoon with a liquid up above the rim. It was this surface tension that prevented the liquid from overflowing.

Demonstration of the spheroidal state.

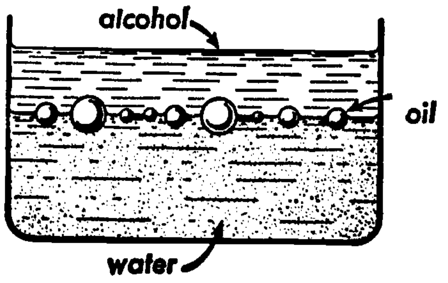
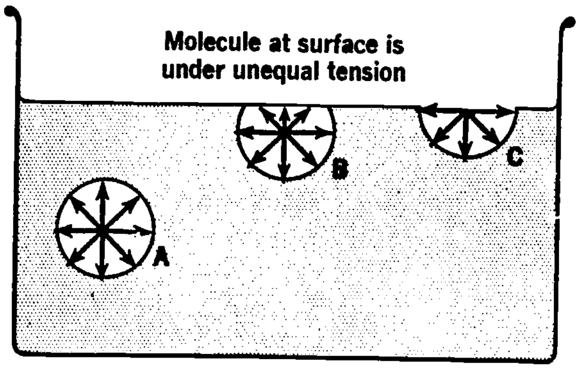


Fig. 2-42



The unbalanced downward force on molecules near the surface of a liquid causes surface tension.

Fig. 2-43

There are two main types of liquids, from a molecular point of view--polar and nonpolar. Water and alcohols are polar liquids, and the hydrocarbons, such as oil and gasoline, are nonpolar. No one has to be reminded that these two types do not mix.

Wetting. When a solid surface is touched by liquid of a similar type (for example--glass by water), the molecules of the liquid are attracted to the molecules of the solid. The liquid therefore has no surface tension where it touches, so it can spread out, and we say the surface is wet. In the case of glass, water wets clean glass because the surface of the glass includes oxygen atoms, to which the water is attracted.

Fig. 2-44 shows how water creeps into narrow spaces between surfaces that it wets. This is called capillary attraction or capillarity. Capillarity explains the action of a towel or sponge in drawing up water. But if you put water on a waxed surface, it is not attracted to the nonpolar coating, and it stands in drops rather than wetting the surface. Water cannot go through small holes if it does not wet the material.

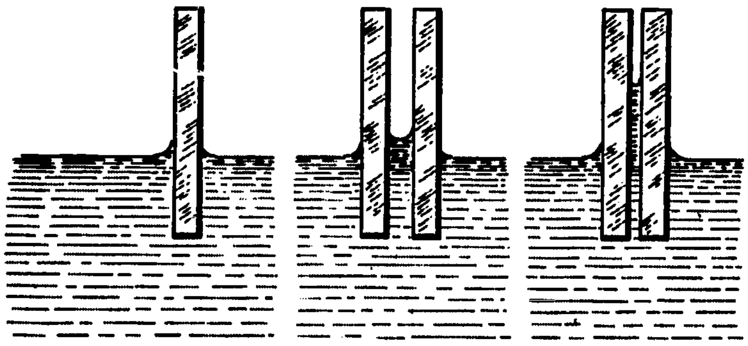


Fig. 2-44

A Plastic Strainer Floats on Water • Surface films keep water from entering

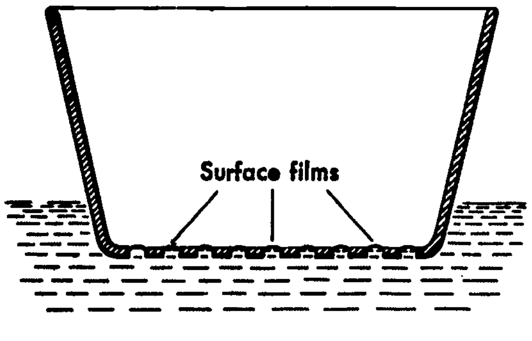


Fig. 2-45

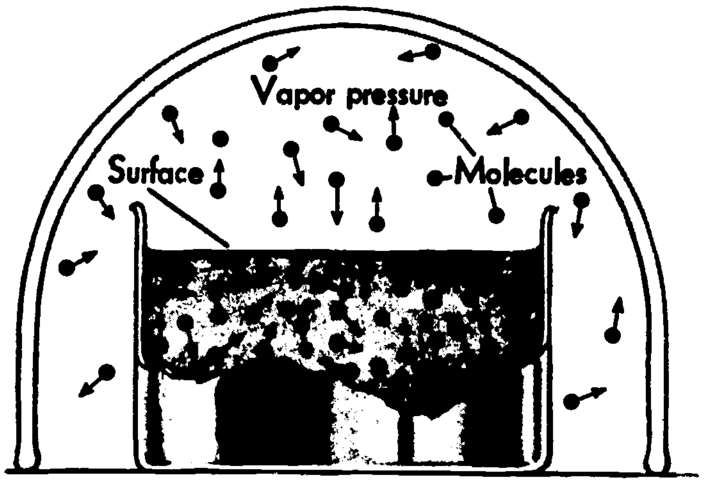


Fig. 2-46

Vaporization. If the molecules in a beaker of water could be magnified enough to be visible, we would see them travel in all directions--some fast, some slow, some moving fast enough to escape through the surface or evaporate.

The tendency of a liquid to vaporize (evaporate) is called its volatility and is measured as its vapor pressure. Vapor pressure increases as the temperature increases.

When a liquid is heated to the point where its vapor pressure is equal to atmospheric pressure, it boils.

The vapor pressure of a gasoline at low temperatures must be high enough to form an explosive vapor--mixture in the cylinders. For easy starting, winter grades of gasoline have butane added to them. It boils at 31°F.

The vapor pressure of a gasoline is measured by putting some in a bomb (Fig. 2-47) at an exact temperature, and then reading the pressure on the gauge.

While a good vapor pressure is needed, it must not be so high that the gasoline will boil when the engine gets hot. As shown in Fig. 2-48, when gasoline boils in the fuel pump, it sends only vapors to the carburetor; the engine starves for gas and dies. This condition, when the carburetor is filled with vapors, is called vapor lock.

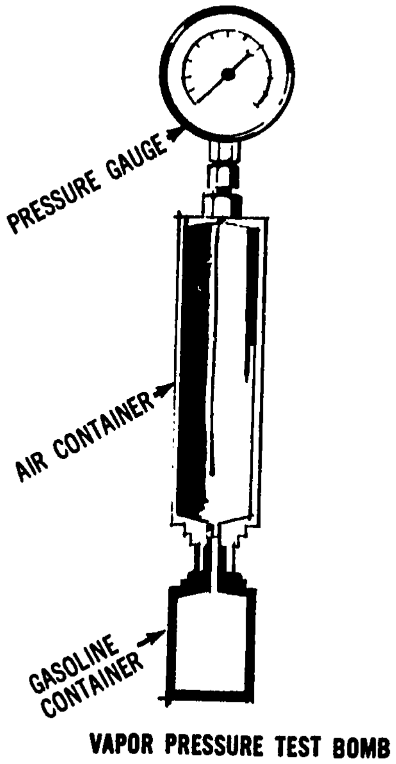


Fig. 2-47

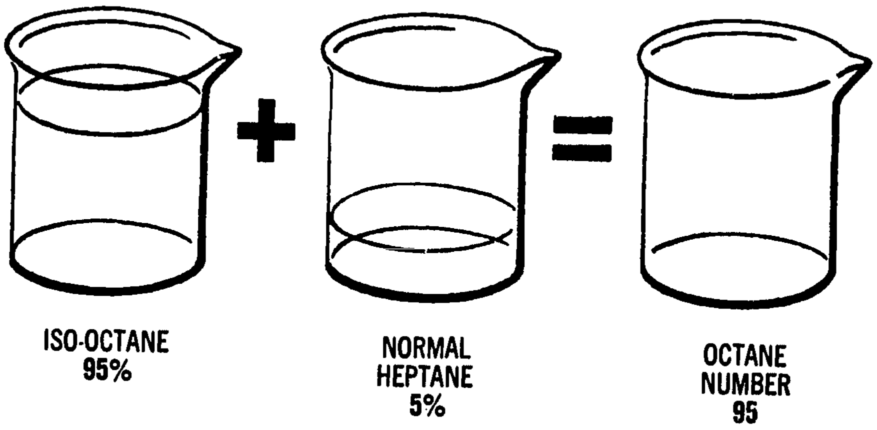
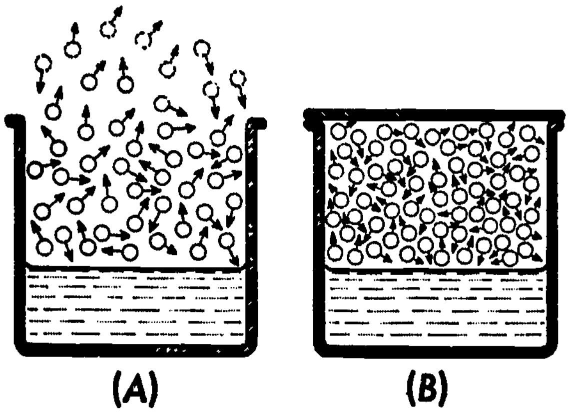


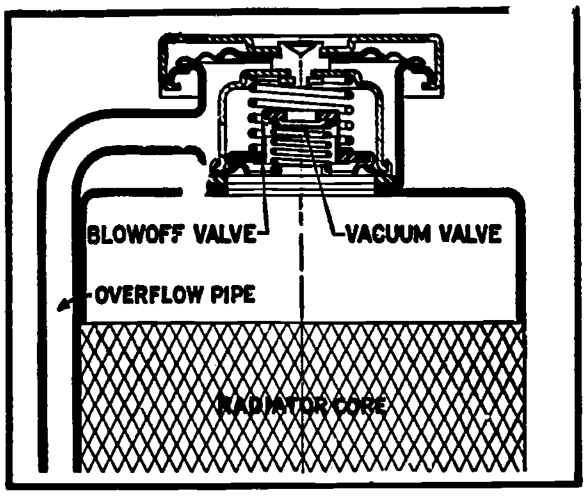
Fig. 2-48

The vapor pressure of water and alcohols in the cooling system must also be controlled to keep them from boiling away. This is done by closing the system. (See Fig. 2-49).



Evaporation · *(A)* Water molecules break through the water film and escape. *(B)* In a closed vessel the vapor molecules accumulate till they condense and evaporate at the same rate. Then the space is saturated

Fig. 2-49



Radiator pressure cap.

Fig. 2-50

Modern radiator caps (Fig. 2-50) are built to keep the system closed, but have a spring which opens them when the pressure gets too high.

Even motor oils have a vapor pressure. It is normally very low, but on the hot cylinder wall (Fig. 2-51) when an engine is running, the vapor pressure of some oils is quite high. Evaporation takes place; the exhaust shows white smoke; and the gases which blow by the rings carry oil vapors out the breather pipe.

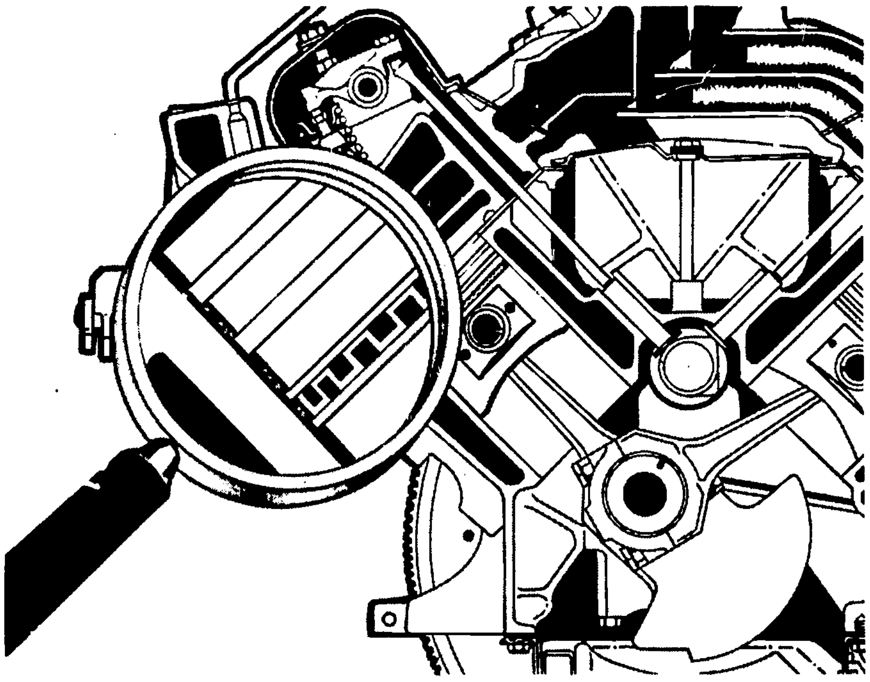
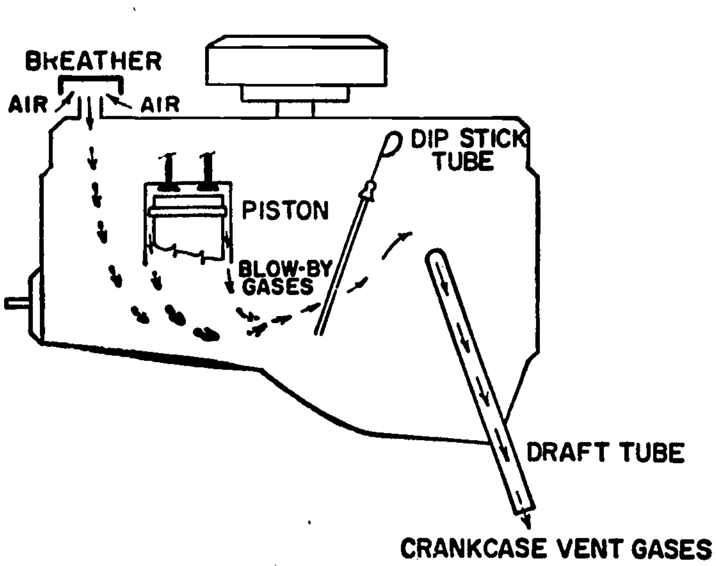


Fig. 2-51



Schematic showing crankcase ventilation and blow-by gases.

Fig. 2-52

Evaporative cooling. When a liquid vaporizes, the fastest-moving molecules escape and leave the slower ones behind. As a result, the material that is left will be colder. You have felt this cooling effect of evaporation (of sweat) when you felt chilled as the wind blew on your skin.

In the automobile carburetor, the cooling effect may be so great that the gasoline is cooled below 32°F. This can lead to icing--the freezing of tiny drops of water in the carburetor jets (Fig. 2-53).

Condensation. We see from Fig. 2-54 how much vapor pressure liquids can develop at various temperatures. (The chart gives temperatures in centigrade degrees, and pressures in millimeters of mercury. Normal atmosphere pressure corresponds to 760mm.)

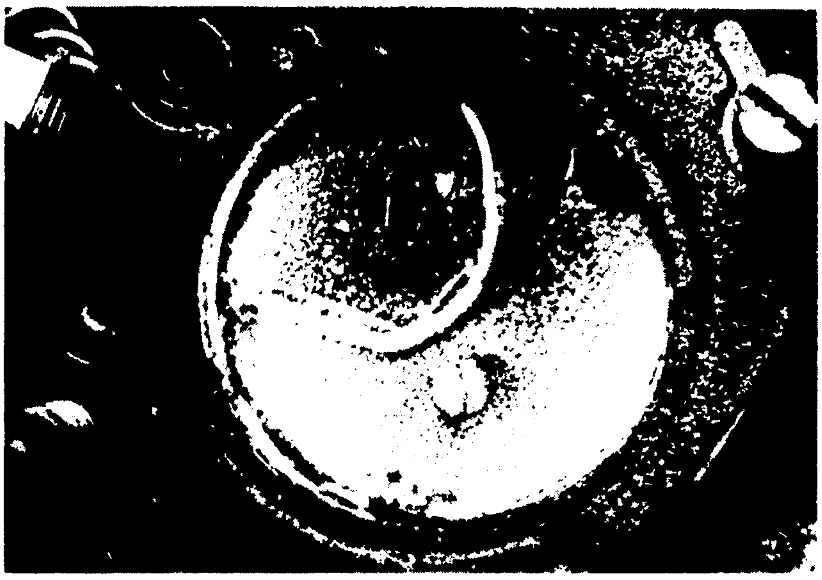


Fig. 2-53

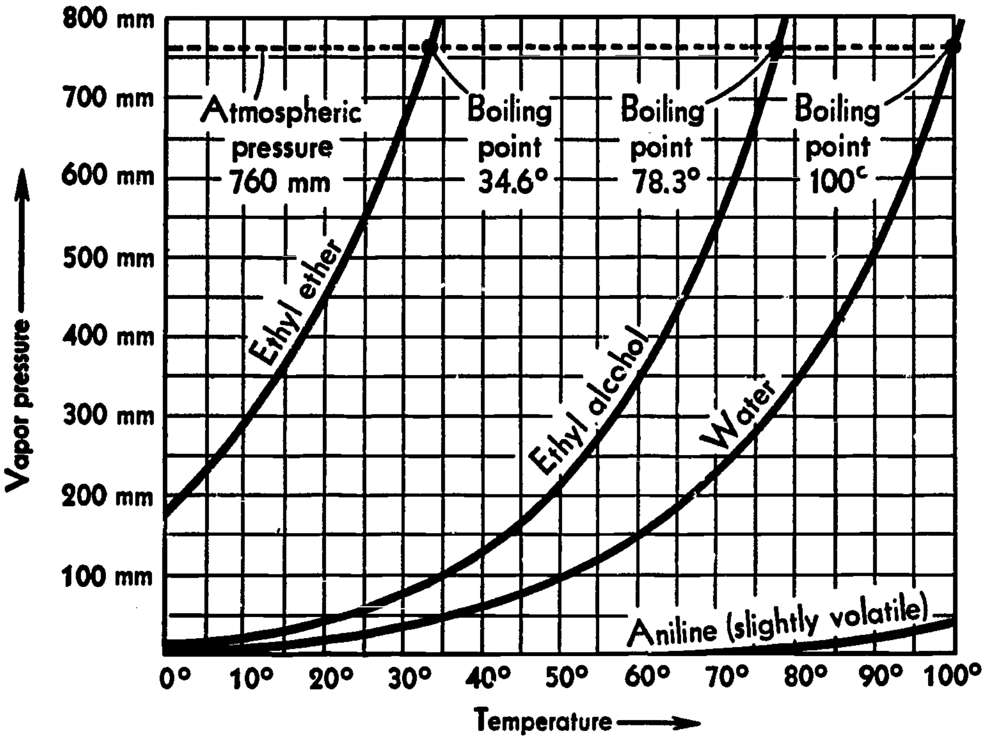


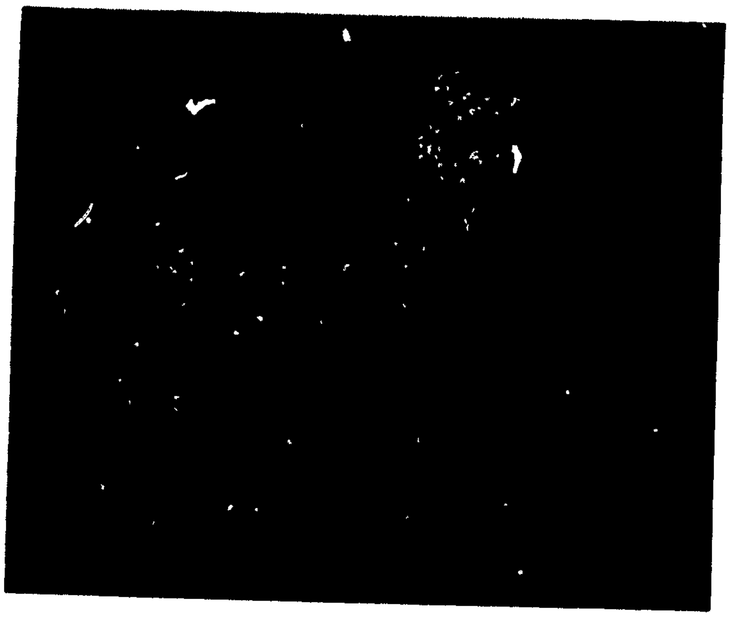
Fig. 2-54

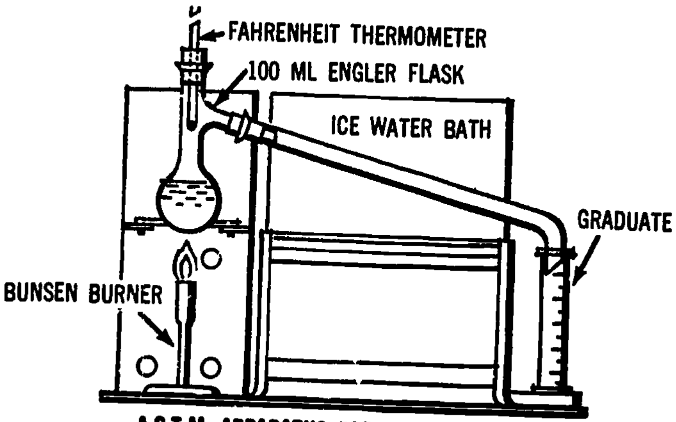
Warm air can hold a lot of water vapor. But when it is cooled, the vapor pressure of water drops. At the dew point, the temperature at which the air can no longer hold the amount of water vapor it has, the water vapor must condense out as liquid water.

Water from your breath condenses to fog or frost on a cold windshield; we get rid of it with lots of warm air, which can hold the water vapor easily. Water vapor, produced during the burning of gasoline, condenses in the crankcase, and so does part of the gasoline that is fed into the engine. The effects of these materials in forming sludge and varnish deposits and in corroding the engine are discussed under Oxidation of Hydrocarbons.

When paint is sprayed, it cools down. On humid days it may cool below the dew point and collect water on the paint either during or just after the spraying. This water dissolves in the solvent and ruins its ability to dissolve the organic binder. The paint bodies clump, giving the finish a milky or dull blush. To avoid blushing, the painter avoids spraying on humid or rainy days, uses high-grade thinners, uses a retarder, and reduces the air pressure to his spray gun.

BLUSHING





A.S.T.M. APPARATUS FOR DISTILLATION TEST

Fig. 2-55

Distillation. The process of boiling a liquid and then condensing the vapors is called distillation. In the laboratory it can be done as shown in Fig. 2-56.

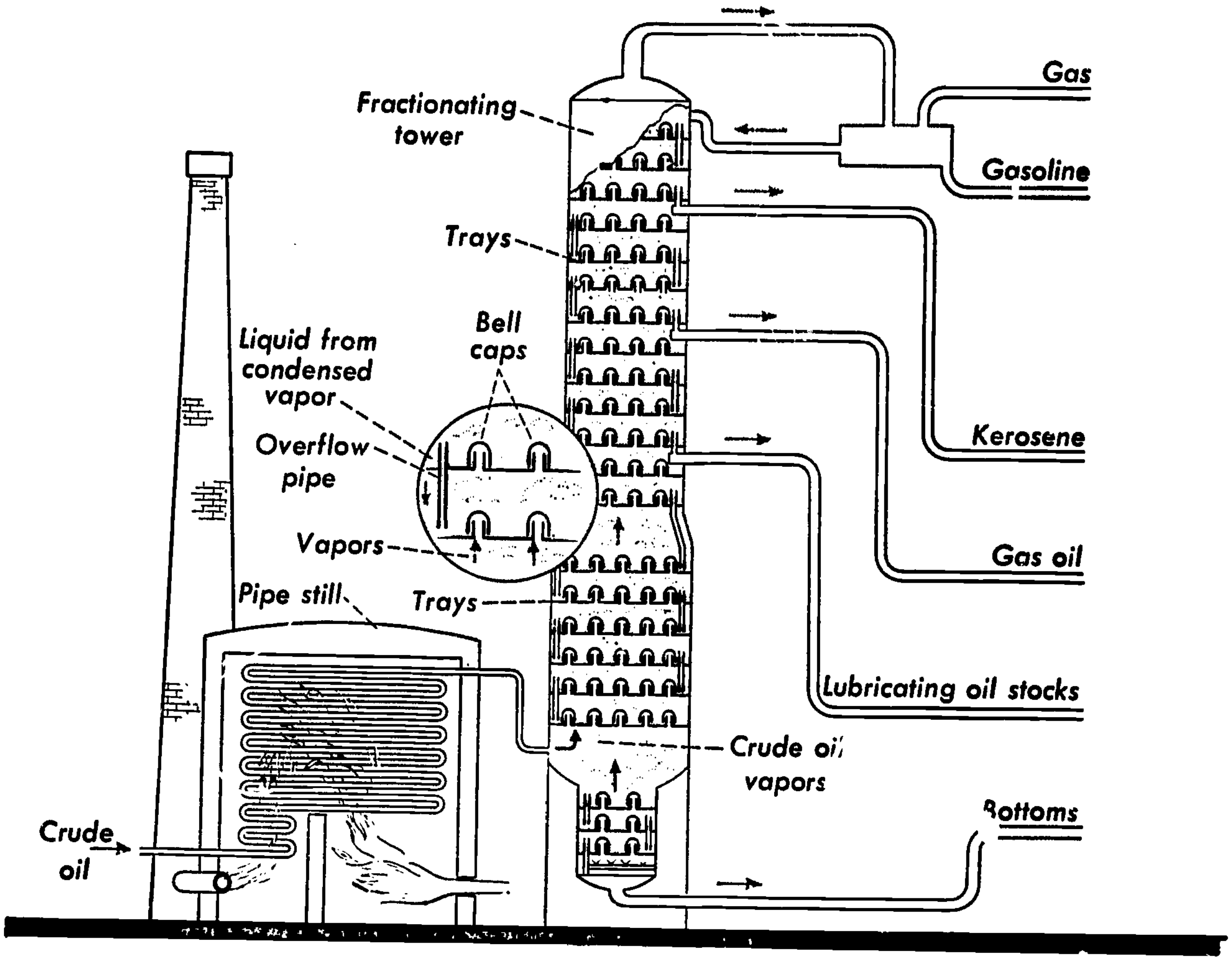
If we distill a solution of water and nonvolatile impurities, as in tap water, the impurities stay in the flask, and the condensate--or distilled water--will be very pure.

When a solution or mixture of different liquids is distilled, the more volatile ones (that is, those that boil at lower temperatures) go off first, leaving the less volatile ones behind. This can be a way of separating the mixture into its different parts.

Distilling mixtures in this or similar ways is called fractional distillation. It is called this because the amount obtained at each boiling temperature (or condensing temperature, as in Fig. 2-57) is a fraction of the original amount of liquid.

Petroleum, or crude oil, is a mixture of hydrocarbons of various boiling points. It is separated into its main products by fractional distillation as shown in Fig. 2-57.

The oil is heated to about 800°F. in a pipe still and run into the bottom of the fractionating tower. Vapors rise up through the tower, bubbling through a flow of liquid (condensate) that runs from one tray to the next. The vapors gradually cool as they rise. The fraction with the highest boiling point--lubricating oil--condenses first, at 600° - 700°F., and is drawn off, as shown. Other fractions condense higher up and are drawn off. The final product, which condenses at about 100°F., is gasoline. Later, these fractions, which are still mixtures, are further processed and refined.



Cross-section of a pipe still and fractionating tower used in refining petroleum.

Fig. 2-57

Solvents used in refinishing are mixtures of organic compounds that evaporate at different rates. In paint spraying, part of the solvent goes off at once, and part goes later. Such mixtures must be balanced so that they will evaporate fast enough for rapid drying but not so fast that condensation of water will lead to blushing. This means that there must not only be enough active solvents (ketones, esters, etc.) to dissolve the lacquer or enamel, but there must be enough left after spraying so that the wet finish will have some tolerance for water. These solvents are expensive.

Flash point. Most organic compounds (hydrocarbons, alcohols, solvents, etc.) burn in the vapor form. The temperature at which the material produces enough vapors so that a flame will start them burning, (Fig. 2-58) is called the flash point. Gasoline and some lacquer solvents have a flash point below room temperature. They vaporize without heating to form explosive mixtures. Kerosene and higher-boiling oils flash only when heated. Chlorinated hydrocarbons such as carbon tetrachloride, perchloroethylene, etc., do not burn (although the vapors of some of them are quite poisonous.)

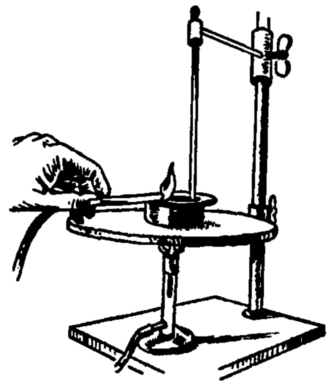


Fig. 2-58

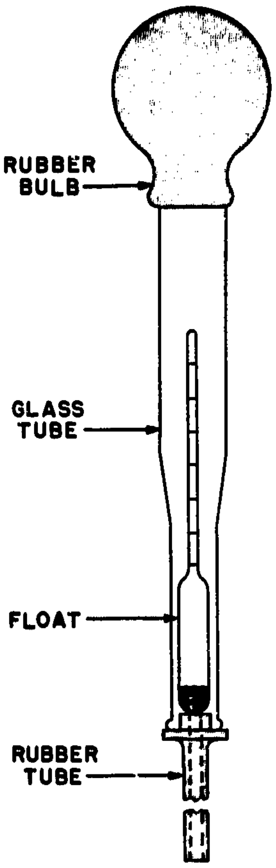


Diagram showing essential parts of a battery hydrometer for measuring specific gravity of battery electrolyte.

Fig. 2-59

Density and Specific Gravity. Oil floats on water. Why? Because it is lighter--its density (weight per unit of volume) is less than that of water. The ratio

$$\frac{\text{density of a material}}{\text{density of water}}$$

is called specific gravity of a material.

The concept of specific gravity has several uses in the auto field. For example, sulfuric acid, used in batteries, is heavier than water. Mixtures of the acid with water have a specific gravity which depends on the strength of the acid. We can tell if a battery is charged by measuring the acid with a hydrometer. (See Fig. 2-59). The float will rise higher when a heavy mixture is drawn into the tube than it will for a light mixture. Therefore the higher the float rises in the liquid, the stronger the acid, and the more change in the battery, as shown in Table 4.

State of Charge*	Specific Gravity
100%	1.260
75%	1.225
50%	1.190
25%	1.155
Discharged	1.110

* Based on cranking ability at 80° F.

Table 4

The strength of antifreeze solutions is checked the same way. Glycol (permanent) types are heavier than water; alcohol types are lighter. They require different hydrometers.

EXPERIMENT 8. VISCOSITY

Oil is valued for the drag inside it when it flows--its viscosity. This is the basis of the SAE grade numbers. Viscosity can be measured by how slowly the oil runs out of a hole. In this experiment you will compare the viscosity of different motor oils. You will also see what happens to the viscosity of an oil when it is heated or cooled. Is this important? Would you expect all oils to be the same? What kind of oil is best?

It is suggested that all students do a test on the same oil, SAE 20, and then each do another, different oil.

MATERIALS: Variable hot plate, beaker, 10 ml. pipet, 2-oz. rubber bulb, stopclock, Fahrenheit thermometer (-4° to +230°), oils of various qualities and grades --SAE 10, 20, 30, and multi-grade; glass marker.

PROCEDURE:

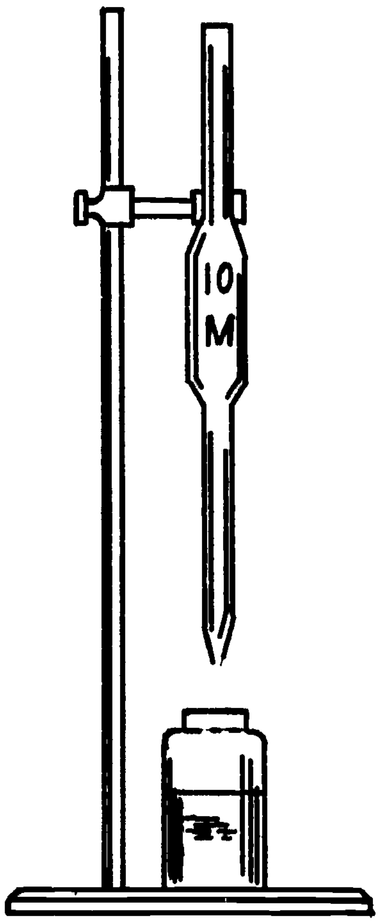
1. Prepare in your notebook a page to record the data with a table like this.

Pipet No.

Sample name						
Grade, SAE	20					
Price						
Temperature	100	210	100	210	100	210
Flow time, sec.						
1						
2						
3						
4						
5						
Average						
Relative Viscosity	1					

2. Write down the number or initial of the pipet that is given you. Every pipet is different, and should be marked. Work with the same one through the whole experiment. Mark a line on it about an inch under the bulb.

3. Clamp it on a ring stand as shown in the figure. Set the clock on zero.



4. Take the SAE 20 oil that your instructor set aside for all the students to do. Write down its name and price in the first column of your table.

5. Turn the hot plate to low heat. Fill a beaker about ½ to ¾ inch deep with the oil. Stir it gently with the thermometer. When the temperature reaches 100° to 102° take the beaker off the hot plate and put it under the pipet, on a couple of paper towels. Wipe the thermometer off and put it where it will be safe.

6. Your instructor will show you how to fill the pipet by use of the rubber bulb. Bring the oil up over the upper line on the pipet. Let it drain into the beaker. As it passes the first line, start the clock; when it passes the second line (that you put there) stop the clock. Repeat the test until the readings are not more than one second apart. Check the temperature of the oil between tests and heat it up if it cools below 98°.

7. When three tests give times within one second of each other, average those three and record this result.

8. Heat the oil to 210°-212° and do the test again. Work fast, as the oil tends to cool down. You may wish to flush the oil through the pipet once or twice to warm the glass before doing the time test. Reheat the oil if it drops below 208°. When you have three checks, average them as before. Then return the oil to its container. Drain the pipet and beaker well.

9. Clean the beaker and pipet (your instructor will tell you how) and do the same series of tests on a second oil that he gives you.

10. Divide the average flow times in the other tests by the flow time for the "standard" SAE 20 oil at 100°. This gives you a <u>relative viscosity</u> by which the oils can be compared.

11. Make a table showing the names and grades of all oils tested by the class, and the relative viscosities of each at 100° and 210°.

12. (Optional) Using 2-cycle semi-log paper, make a graph of the results. Put relative viscosity on the vertical scale with major divisions at 0.1, 1.0 and 10; put temperature along the horizontal scale.

CONCLUSIONS:

1. Are all oils of the same SAE grade equally viscous.

2. What is the main feature of "premium" oils?

5. OXIDATION OF HYDROCARBONS

You know that in the gasoline or diesel engine, power comes from burning hydrocarbon fuel vapors with air. In theory, the carbon and hydrogen should burn to carbon dioxide and water, and the amount of each material should be in a certain proportion, as shown in Table 5.

Heptane	+	Oxygen	=	Carbon Dioxide	+	Water
C_7H_{16}	+	$11\ O_2$	=	$7\ CO_2$	+	$8\ H_2O$
1.00 lb.	+	3.52 lbs.	=	3.08 lbs.	+	1.44 lbs.
Similarly—						
1 gal. gasoline	+	air*	=	carbon dioxide + water + nitrogen etc.		
6.2 lbs.	+	94 lbs.	=	19.1 lbs. + 8.9 lbs. + 72.2 lbs.		

From this equation, it is apparent that an automobile might theoretically require about 94 pounds of air (about 9000 gallons) to burn a gallon of gasoline. Slightly more than a gallon of water (8.9 lbs.) would be produced in the exhaust gases.

Dry air contains by weight about 23.2% oxygen, 75.5% nitrogen, and 1.3% of other gases (argon, carbon dioxide, etc.).

Table 5

You can see that 1 gallon (6.2 pounds) of gasoline needs 94 pounds of air for complete combustion. When a carburetor is adjusted to give these proportions (about 15 pounds of air for each pound of gasoline), the engine does not give its best power. A richer mixture is better, as shown in Fig. 2-60. The air-to-fuel ratios which are found in well-adjusted engines are shown in Table 6.

The two products of complete burning, carbon dioxide and water, are very mild. But when you go out on a busy highway your eyes start to burn and your nose hurts after a few minutes. The materials in the air that bother you are not carbon dioxide and water, but are the materials that are produced when gasoline and oil burn incompletely.

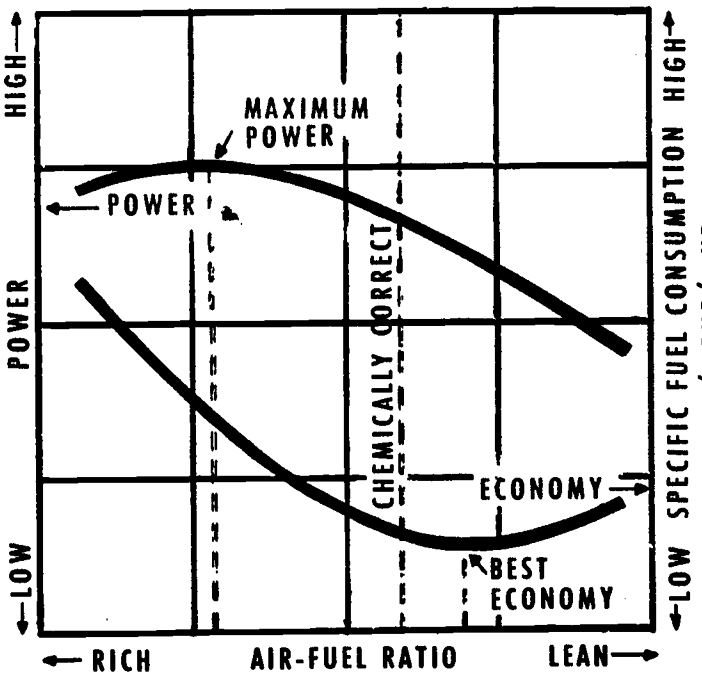


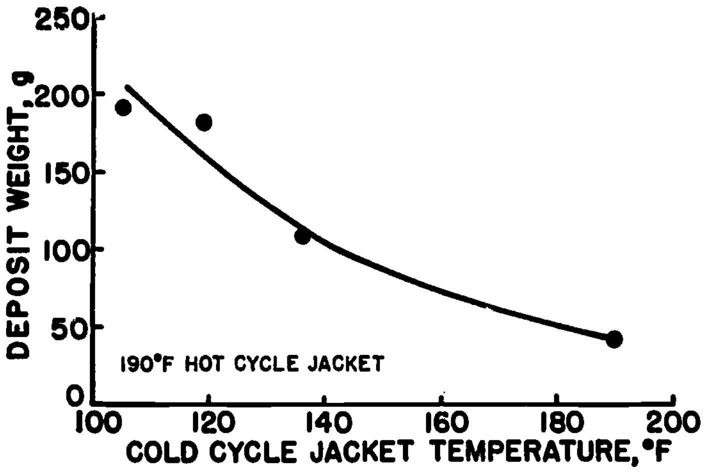
Fig. 2-60

OPERATING CONDITIONS	A/F RATIO
Idling	11-12.5
Cruising	13.5-17.0
Full load	12-13.5

Table 6

The products of combustion tend to blow by piston rings and collect in the crankcase. They must be got rid of. Water, for example, collects acids and then it rusts parts; it also mixes with oil, forming a thick, black sludge. Partially burned and raw gasoline form other sludges and gunks. To blow out these materials the crankcase must be ventilated.

Control of engine temperatures at about 180° is a help in chasing out these materials that form sludge deposits.



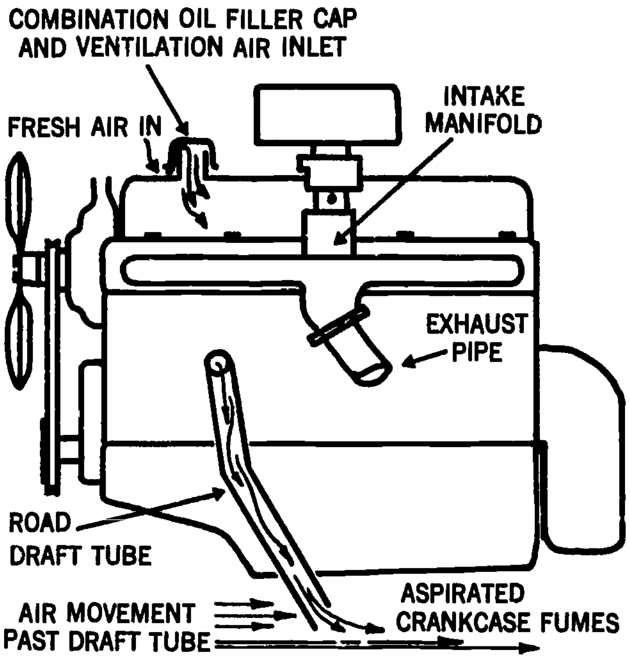
Effect of coolant temperature on sludge formation.

Fig. 2-62

Exhaust gas and blow-by pollute the air in some places badly. To control air pollution some cars have devices to bring back this blow-by gas into the air intake to be burned again.

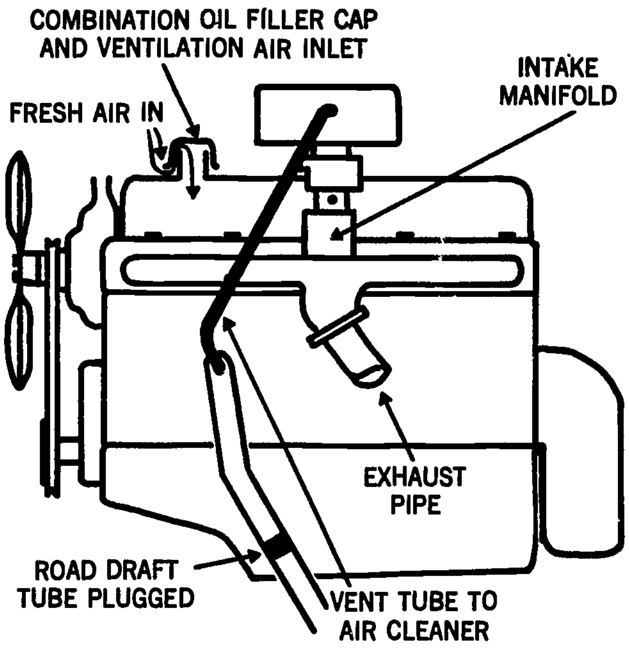
We see, then, in the engine of a car, many products of part-way reactions with oxygen: varnish, sludge, "carbon," etc. Oxidation of hydrocarbons can make a lot of different materials. Let's look at these one at a time.

First, let us review the formula for the complete burning reaction of heptane, C_7H_{16}. As we saw from Table 5, it is:



Conventional Crankcase Ventilation System Using Road Draft Tube

Fig. 2-61



Crankcase Ventilation System Using a Vent Tube to the Air Cleaner

Fig. 2-63

$$C_7H_{16} + 11\ O_2 \longrightarrow 7\ CO_2 + 8\ H_2O$$

align heptane + oxygen → carbon dioxide + water

Carbon monoxide forms when gasoline is burned at high temperatures with too little air. It is a very poisonous gas in the exhaust of every engine. It is particularly dangerous to man because it is odorless, so that a person may breathe it in and be poisoned without being aware of the danger.

$$C_7H_{16} + 9\ O_2 \longrightarrow 3\ CO_2 + \underline{4\ CO} + 8\ H_2O$$

Carbon forms when the amount of air is much too little, in other words, with very rich mixtures. Some of it goes out the exhaust as a black smoke; some stays in the engine.

$$C_7H_{16} + 7\ O_2 \longrightarrow \underline{6\ CO} + \underline{C} + 8\ H_2O$$

Alcohols are a class of organic compound in which one atom of oxygen has been added to a hydrocarbon molecule. Some alcohols form when gasoline reacts with oxygen in an engine.

$$2C_6H_{14} + O_2 \longrightarrow 2C_6\ H_{13}\ OH$$

Some Hydrocarbons and the Corresponding Alcohols

Hydrocarbon		Alcohol		
Name	**Formula**	**Name**	**Formula**	**Structural Formula**
Methane	CH_4	Methyl alcohol	CH_3OH	CH_3OH
Ethane	C_2H_6	Ethyl alcohol	C_2H_5OH	CH_3CH_2OH
Propane	C_3H_8	Propyl alcohol	C_3H_7OH	$CH_3CH_2CH_2OH$
Butane	C_4H_{10}	Butyl alcohol	C_4H_9OH	$CH_3CH_2CH_2CH_2OH$
Pentane	C_5H_{12}	Amyl alcohol	$C_5H_{11}OH$	$CH_3CH_2CH_2CH_2CH_2OH$
Hexane	C_6H_{14}	Hexyl alcohol	$C_6H_{13}OH$	$CH_3CH_2CH_2CH_2CH_2CH_2OH$

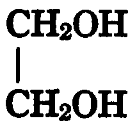
Table 7

The simplest alcohol is CH_3OH, methyl alcohol. It is poisonous. If drunk, it can lead to blindness.

If ethane oxidizes to an alcohol, we get C_2H_5OH, ethyl alcohol. This is the common alcohol that is made from fruits and grains for drinking and industrial uses. Both methyl and ethyl alcohol are used in antifreezes. When ethyl alcohol is used, bad-tasting and poisonous impurities are used to turn it into denatured alcohol, making it unfit to drink.

Alcohols with longer carbon chains, such as butyl alcohol, are important in making lacquer solvents.

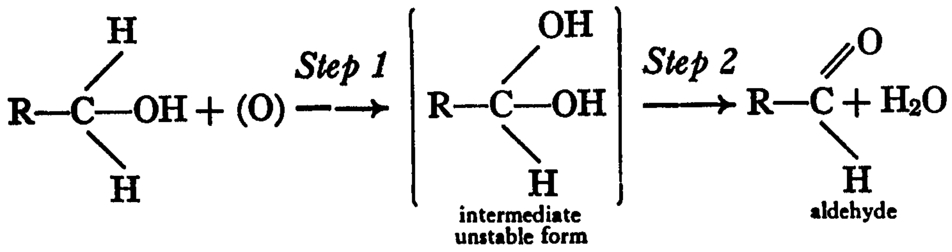
Permanent antifreeze usually contains an alcohol with two OH groups. The commonest one is ethylene glycol:



$$\begin{array}{c} CH_2OH \\ | \\ CH_2OH \end{array}$$

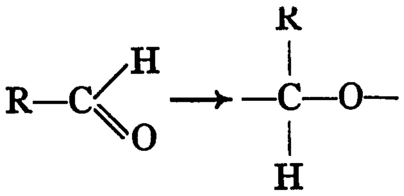
We have seen that alcohols are a class of compound that can form when any hydrocarbon, large or small, reacts with small amounts of oxygen. In practice this is not the way they are usually made. One reason is that once made, the alcohol will react with more oxygen and oxidize further.

Aldehydes are the next product formed when an alcohol reacts with another atom of oxygen. If we use R to stand for any hydrocarbon chain such as CH_3, C_2H_5, etc., then we get this general equation:

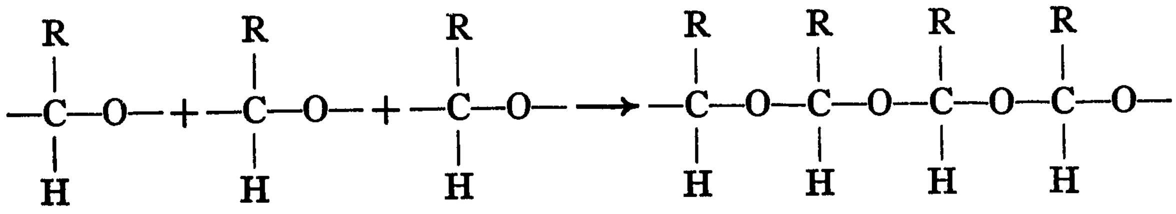


Aldehydes have the general formula R-CHO. They have sharp odors and make the eyes burn. They are the most irritating part of engine exhaust.

Aldehydes are very reactive. One of the bonds holding the oxygen can open up, giving two free valences.

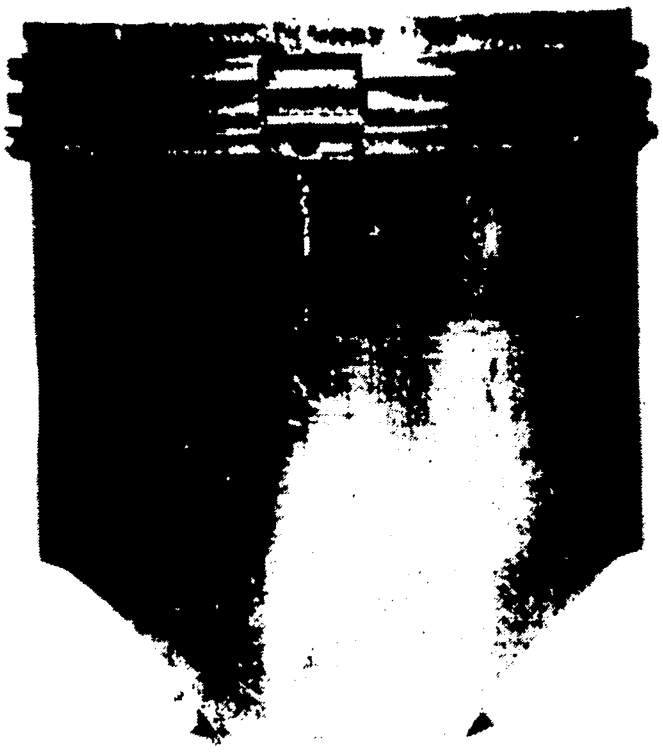


With these valences the molecule tends to join to another molecule, as shown here:



$$-\underset{H}{\overset{R}{C}}-O-+-\underset{H}{\overset{R}{C}}-O-+-\underset{H}{\overset{R}{C}}-O-\longrightarrow-\underset{H}{\overset{R}{C}}-O-\underset{H}{\overset{R}{C}}-O-\underset{H}{\overset{R}{C}}-O-\underset{H}{\overset{R}{C}}-O-$$

This process can go on, with hundreds of small molecules joining to make one giant molecule (the name given to this process -- where two molecules of the same kind combine to form a larger molecule--is polymerization.) The small molecules are soluble in lubricating oil. When large, polymer molecules form in an engine, they may be insoluble, forming a yellow "varnish" on cylinder walls and pistons (Fig. 2-64).



Varnish-coated Piston
Fig. 2-64

Acids are formed when aldehydes react with still more oxygen:

$$\underset{\text{hydrocarbon}}{R{-}CH_3} \xrightarrow{(O)} \underset{\text{primary alcohol}}{R{-}CH_2OH} \xrightarrow{(O)} \underset{\text{aldehyde}}{R{-}CHO} \xrightarrow{(O)} \underset{\text{carboxylic acid}}{RCOOH}$$

Acids from hydrocarbons have a COOH group in their molecule.

acid + metal → a salt + hydrogen

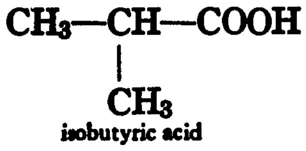
Acids can be made from hydrocarbons of all sizes:

$H{-}COOH$
formic acid

$CH_3{-}COOH$
acetic acid

$CH_3{-}CH_2{-}COOH$
propionic acid

$CH_3{-}CH_2{-}CH_2{-}COOH$
butyric acid



$$\begin{array}{c} CH_3{-}CH{-}COOH \\ | \\ CH_3 \end{array}$$

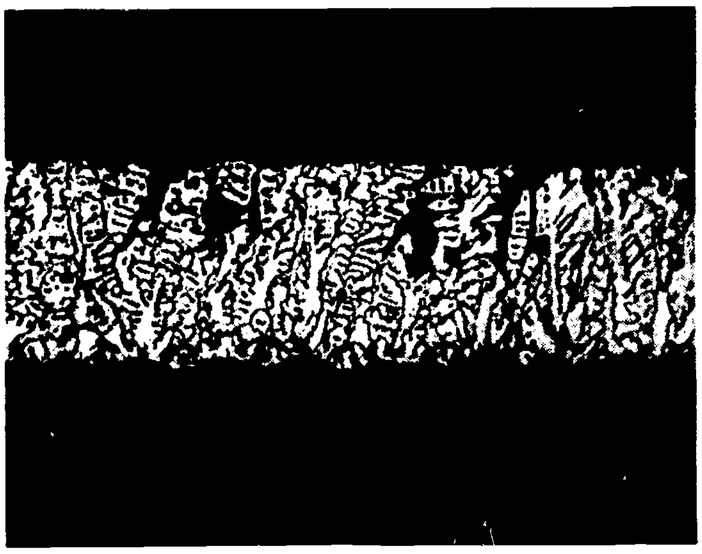
isobutyric acid

$CH_3(CH_2)_{14}COOH$
palmitic acid

$CH_3(CH_2)_{16}COOH$
stearic acid

Organic acids which form when gasoline or oil oxidize are weak, like vinegar (acetic acid). But they corrode bearings and other parts taking off metal in serious amounts. Fig. 2-65 is a picture of a section through a bearing made of copper-lead alloy. You can see how some of the lead has been dissolved away by acids in the oil.

To prevent formation of acids and corrosion of bearings, inhibitors are added to lubricating oils. Gasoline and antifreeze also contain inhibitors to control oxidation. Inhibitors last only a certain amount of time and then are used up. After that the oil or antifreeze can become acidic and corrosive.



– Photomicrograph showing lead corrosion in copper-lead bearing.

Fig. 2-65

Sulfuric acid is made when sulfur compounds in fuels burn. First sulfur oxide, a gas, forms:

$2S + 3O_2 \rightarrow 2SO_3$ (sulfur oxide)

This can combine with water to form sulfuric acid:

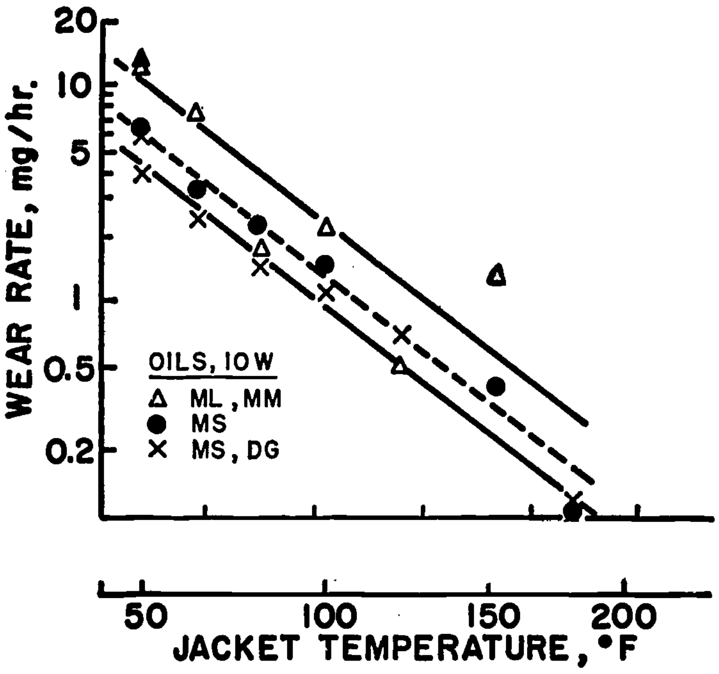
$SO_3 + H_2O \rightarrow H_2SO_4$ (sulfuric acid)

Sulfuric acid forms only in cool places, where water condenses and the sulfur oxide can dissolve in it. It is a minor problem in bearing corrosion,but it attacks pistons, rings, cylinders, and valve lifters. It is the main enemy of mufflers and tailpipes, especially in cold weather and when the engine is stopped and started many times.

Corrosion by sulfuric acid needs water. At higher engine-jacket temperatures, it drops to a very small amount.

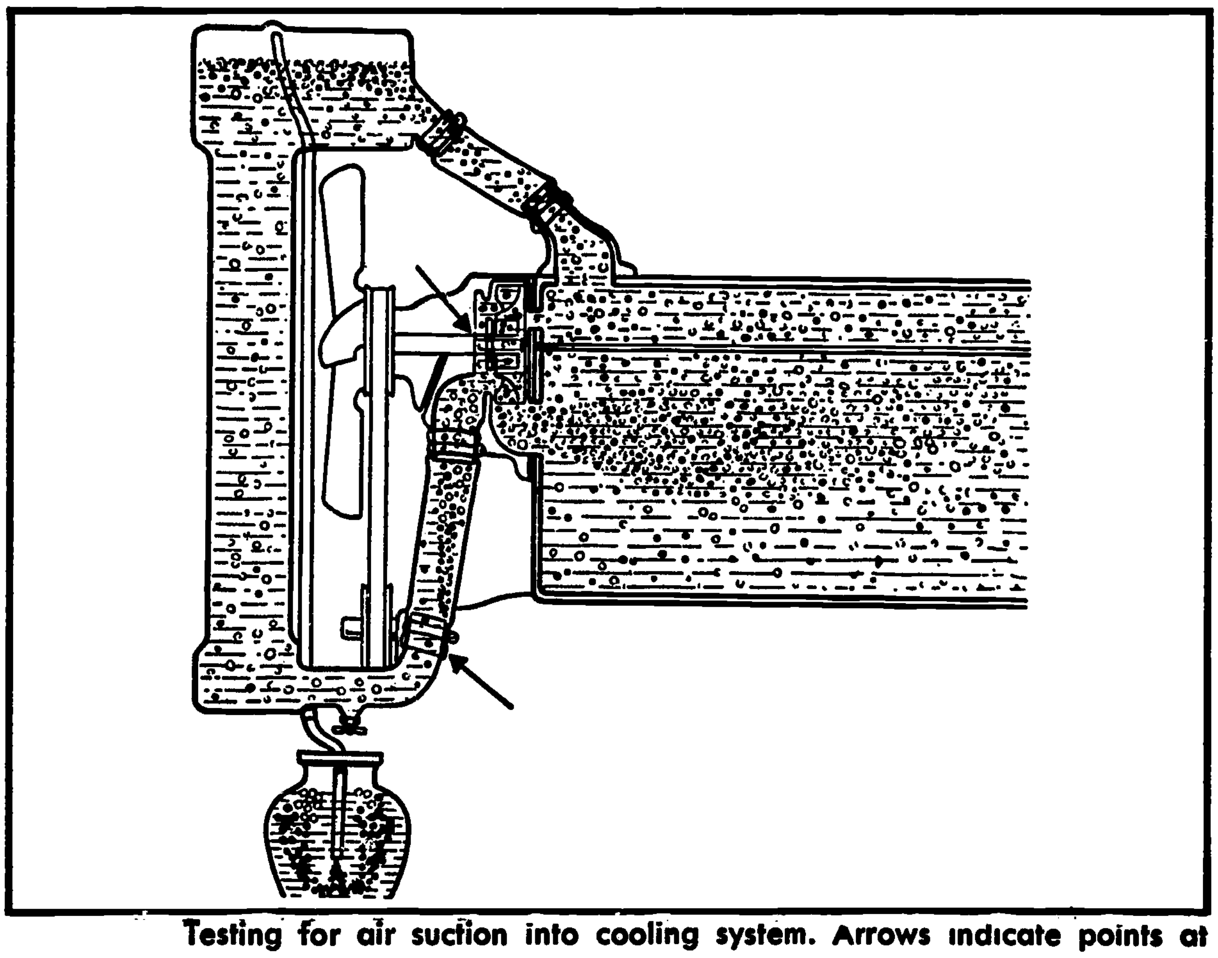
Antifreeze based on ethylene glycol oxidizes to form an acid also. In cooling systems which leak, drawing air into the coolant, the glycol can oxidize quite rapidly.

Leaking head gaskets, which let exhaust gas blow through, also lead to rapid oxidation of antifreeze.



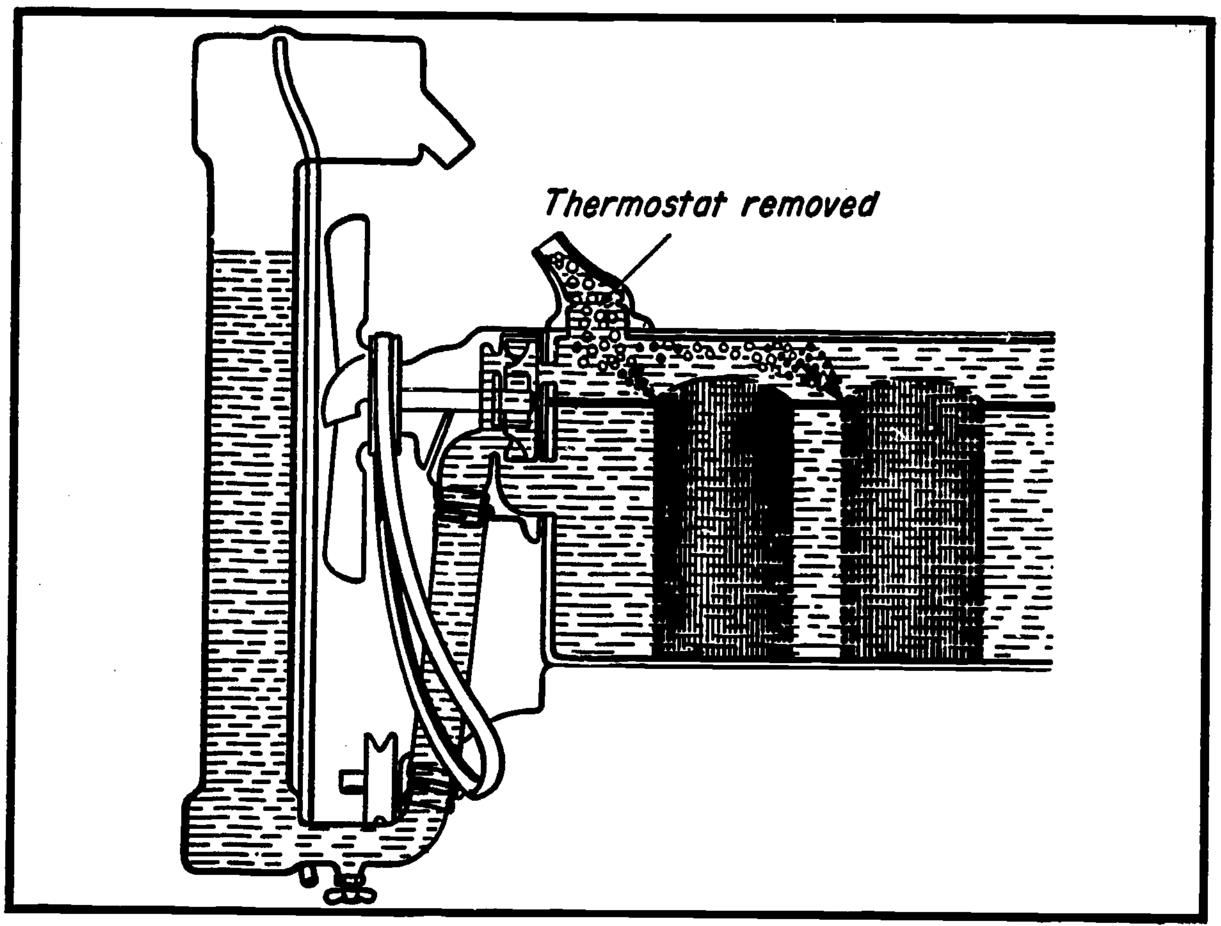
— Dependence of corrosive wear rate on jacket temperature.

Fig. 2-66



Testing for air suction into cooling system. Arrows indicate points at which air might enter.

Fig. 2-67



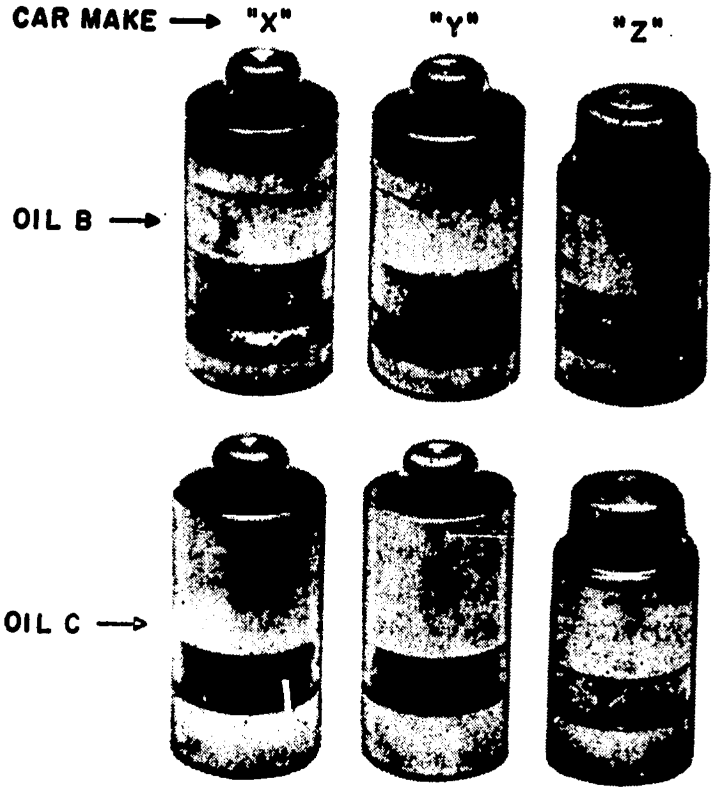
Testing for exhaust-gas leakage into system.

Fig. 2-68

Neutralization. Once the hydrogen in an acid has been replaced by a metal atom, it is changed to a salt. The acid is then dead or neutralized. Rather than let an acid dissolve metal, we can neutralize it with a special type of compound called a base or alkali. Sodium hydroxide (NaOH, household lye) neutralizes sulfuric acid like this:

$$\underset{\text{sulfuric acid}}{H_2SO_4} + \underset{\text{sodium hydroxide}}{2NaOH} \longrightarrow \underset{\substack{\text{sodium sulfate}\\ \text{(a salt)}}}{Na_2SO_4} + \underset{\text{water}}{2H_2O}$$

Motor oils and antifreezes generally have in them some kind of base which neutralizes acids that come from oxidation in use. Fig. 2-69 shows how some oils are better than others in preventing rusting of valve lifters.

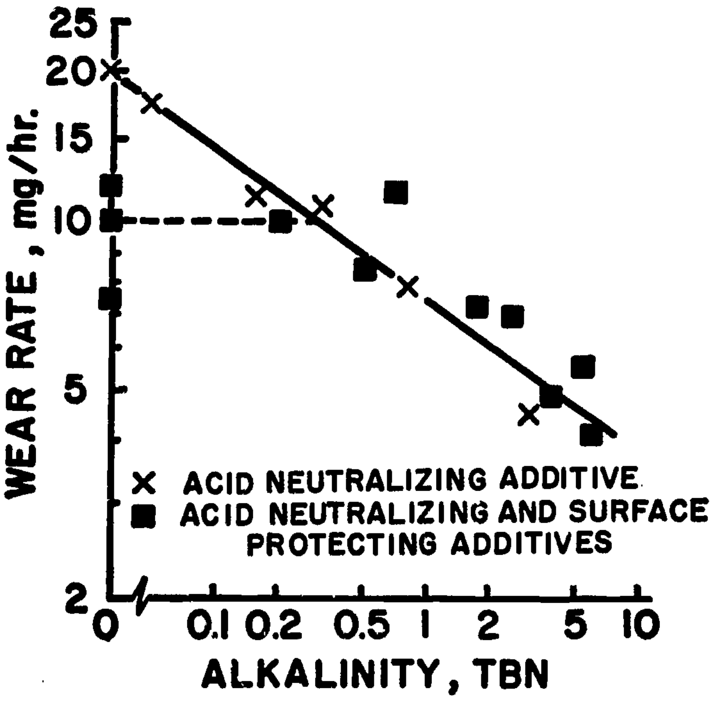


— Hydraulic valve lifter plungers after 300 miles of "home-to-work" driving on two different oils.

Fig. 2-69

The alkalinity of oils is reported to TBN (Total Base Number). As the oil is used, the amount of base in it drops and the wear rate goes up, as shown in Fig. 2-70.

We have seen that motor oils have additives in them for many purposes. Table 8 lists the main ones in use at this time.



— Effect of alkalinity depletion on corrosive wear.

Fig. 2-70

MOTOR OIL ADDITIVES

Type of Additive	*Type of Compound Used*
Oxidation and Corrosion Inhibitor	Organic compounds, usually containing phosphorus and sulfur plus a metal such as tin or zinc; hindered phenols.
Detergent-Dispersant	Metallo-organic compounds such as phosphates, sulfonates, and naphthenates; high-molecular-weight metal soaps; non-metallic polymeric dispersants.
Viscosity Index Improver	Long-chain, high-molecular-weight polymers with extremely high viscosities.
Wear Reducer	Organic compounds containing chlorine, sulfur, and phosphorus plus a metal such as zinc or lead.
Rust Preventive	Sulfonates, amines, amine salts, phosphates, some fatty acids.
Pour Point Depressant	High-molecular-weight polymers, similar to those used as viscosity index improvers.
Antifoam Agent	Primarily silicone polymers; also some alcohols, amines, and chlorinated phenols.
Dye	Oil-soluble organic compounds with high coloring power.

Table 8

Earlier we saw that oils are chosen by SAE viscosity numbers, depending on the season and temperature (Table 2). The type of service is also a factor in choosing an oil. Three classes of service are described in the American Petroleum Institute's classification (Table 9). Because of modern engine design and the amount of stop-and-go driving that most cars do, the MS (heavy-duty) grade is almost standard. A grade of oil having ashless additives which burn clean, leaving no deposit, will probably be put out soon, to reduce surface ignition. This problem will be discussed in the next few pages.

TABLE 1

API SERVICE CLASSIFICATIONS

Service MS

For severe service—extensive start-stop, high-speed or heavy-load driving and engines which are sensitive to deposits, wear or bearing corrosion.

Service MM

For moderate service—normal operation with occasional high-speed driving, no extensive start-stop driving, and engines that are insensitive to deposit formation or wear.

Service ML

For light service—most driving at medium speeds in mild weather and engines that are insensitive to sludge, deposit formation, bearing corrosion or wear.

Table 9

EXPERIMENT 9. SOLUBILITY OF COMMON LIQUID TYPES

Liquids that are used in the auto business and other fields include water, many hydrocarbons and many oxygenated organic compounds such as alcohols, glycols, and ketones. In this experiment you will see which of these are similar and which are different. Starting with water as an example, liquids would be called similar if they mixed with it. The tests will be the mixing of two liquids: if they mix, we will say they are soluble; if they don't, they are insoluble; and if they mix a little, partly soluble.

MATERIALS: 5 semimicro test tubes; rack; 4-ounce dropping bottles containing water, hexane, methanol, acetone, lubricating oil, glycol, kerosene, chlorinated solvent, butyl acetate, or other liquids of interest.

PROCEDURE:

1. Prepare a page in your notebook for recording your results. Check with your instructor to be sure which liquids he wants you to use. Then make a table like this:

	Water	Hexane	Methanol	Acetone	Oil	Glycol
Water						
Hexane						
Methanol						
Acetone						
Oil						
Glycol						

2. Set the test tubes in the rack and put 20 drops of water in each.

3. To the first add just one drop of hexane. Shake it hard 20-30 times. If the two liquids form a clear mixture with no little drops in it, add four more drops of hexane and shake the tube again.

4. Classify the solubility of hexane in water this way:

I--insoluble--one drop does not mix
PS--partly soluble--one drop mixes but five do not
S--soluble--five drops mix in completely

5. In your notebook on the line next to water, in the space under hexane, write I, PS, or S to show the result of the test.

6. Repeat the test in exactly the same way, but using methanol with the water in the second tube. Then go on to the other liquids shown in the table or suggested by your instructor.

7. Clean out the tubes. Your instructor will tell you where to dump them. Dry them thoroughly with a piece of rolled-up paper towel. They must be completely dry. Put 20 drops of hexane in each one and test the solubility of the various liquids in it, as you did with water in the previous tests.

8. In the same way, carefully and accurately, try all the other combinations and write the results in your table.

9. Clean and dry the tubes and test the following liquids, first with water and then with hexane: kerosene, a chlorinated solvent, and butyl acetate. Make a new table for your results.

CONCLUSIONS:

1. Which liquid in this test is the most like water?

2. Which one is the most like oil, by this test?

3. If you wanted to make oil and water mix, how does this experiment show that it could be done?

4. From the results with water and hexane, do you think the chlorinated solvent should mix with glycol? Why?

6. ENGINE COMBUSTION

You have seen that gasoline burns in an engine to give a variety of subtances. One thing we have not yet looked at is the speed of this process. When gasoline burns too fast we hear a knock or other unusual sounds in the engine. Power is lost and the engine may be damaged. How does this come about?

In a gasoline engine, when the spark plug fires, a flame moves through the gasoline-air mixture. Normally it goes through the chamber in about 1/350 of a second (Fig. 2-71).

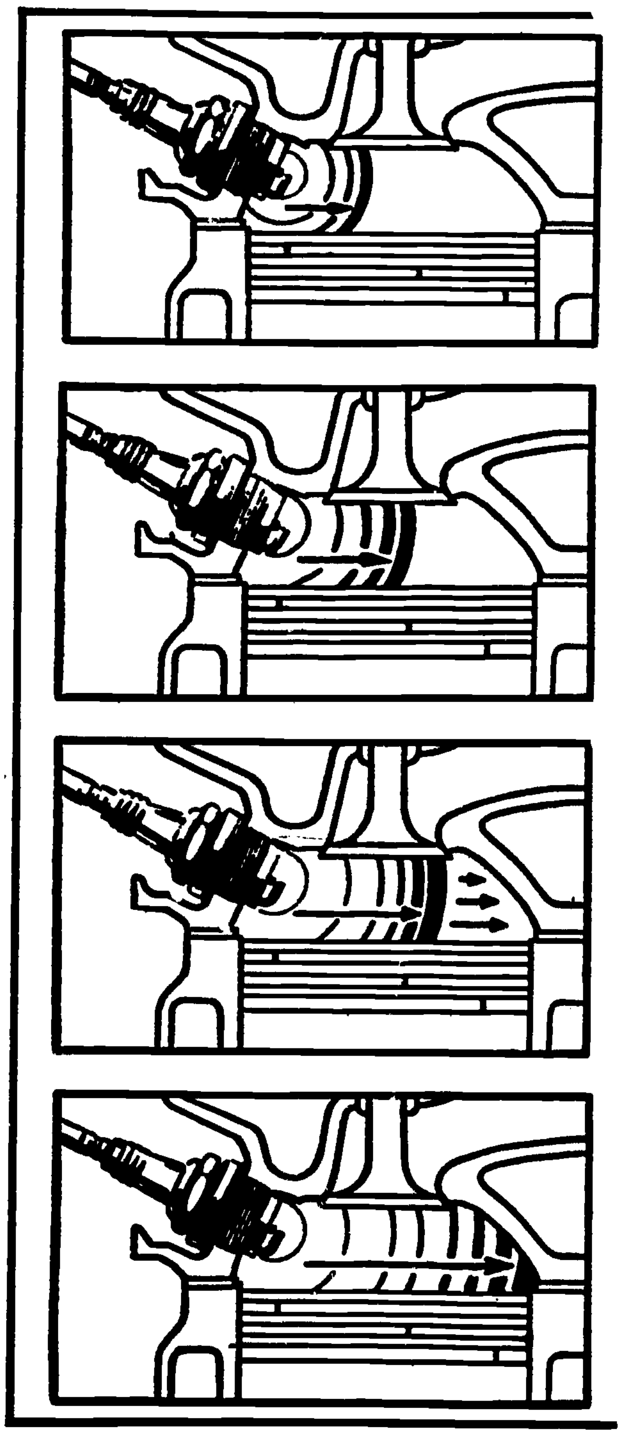


Fig. 2-71

Under knocking conditions, the end-gas (in the far end of the chamber) is heated by compression, and starts to burn before the flame gets to it. It burns almost at once, and a knock is heard. (Fig. 2-72)

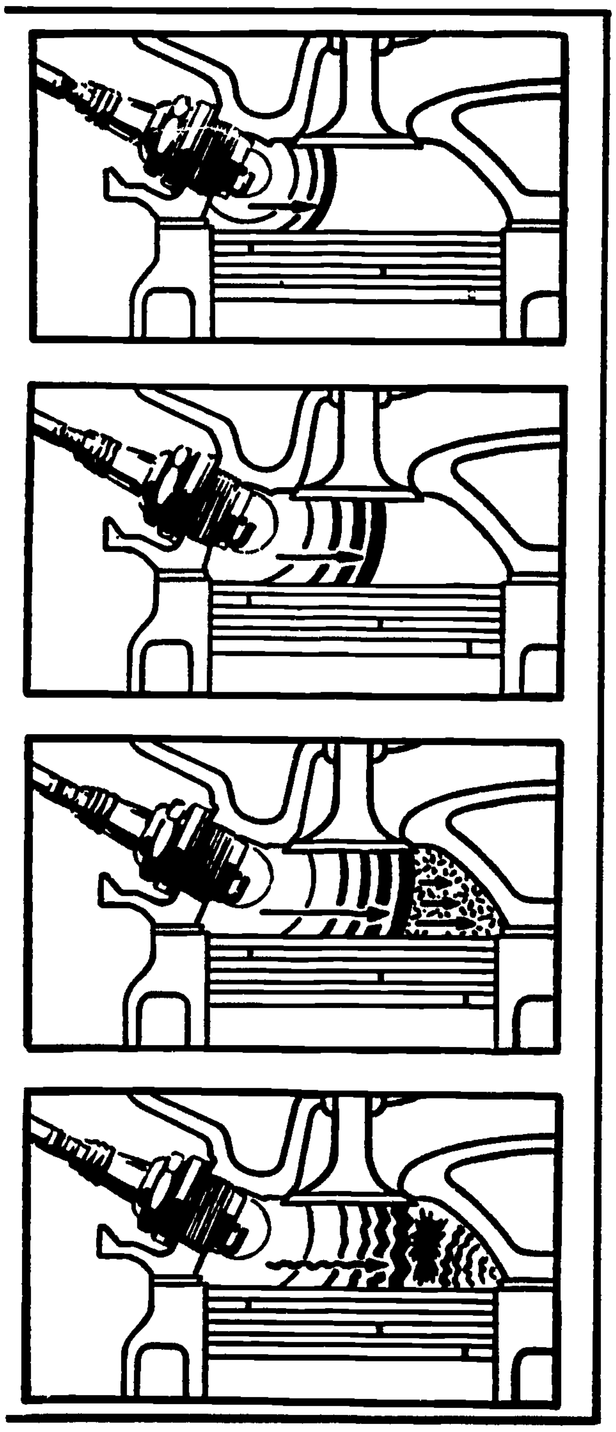


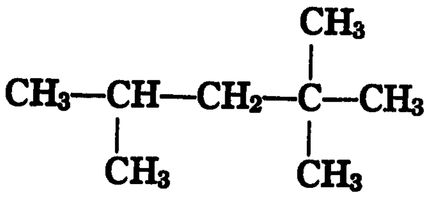
Fig. 2-72

Knock has been studied a great deal. Here are some of the main things that have been found out:

1. Some hydrocarbons knock more easily than others. It is thought that the CH_2 groups are the bad actors. Straight-chain compounds, like normal heptane

$$CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3$$

are the worst. The branched chain is <u>iso-octane</u>



$$CH_3{-}\underset{\displaystyle CH_3}{\underset{|}{CH}}{-}CH_2{-}\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}{-}CH_3$$

causes much less knocking. Aromatics and unsaturated compounds are also better in their antiknock qualities.

Gasolines are knock-tested in a special one-cylinder (Fig. 2-73) engine which compares them to mixtures of iso-octane (which is given a rating or <u>octane</u> number of 100) and heptane (which is given an octane number of 0). Petroleum companies spend millions of dollars to make gasolines with molecules of the right shape for high antiknock ratings. The antiknock quality is the main difference between standard and premium gasolines.

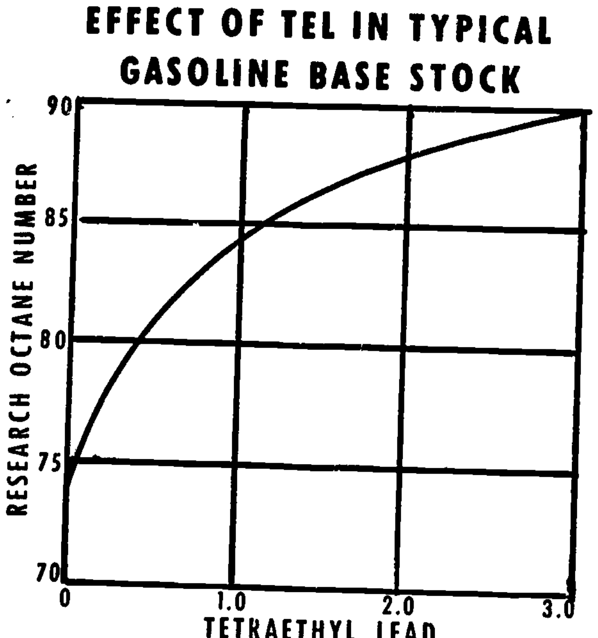


Fig. 2-74

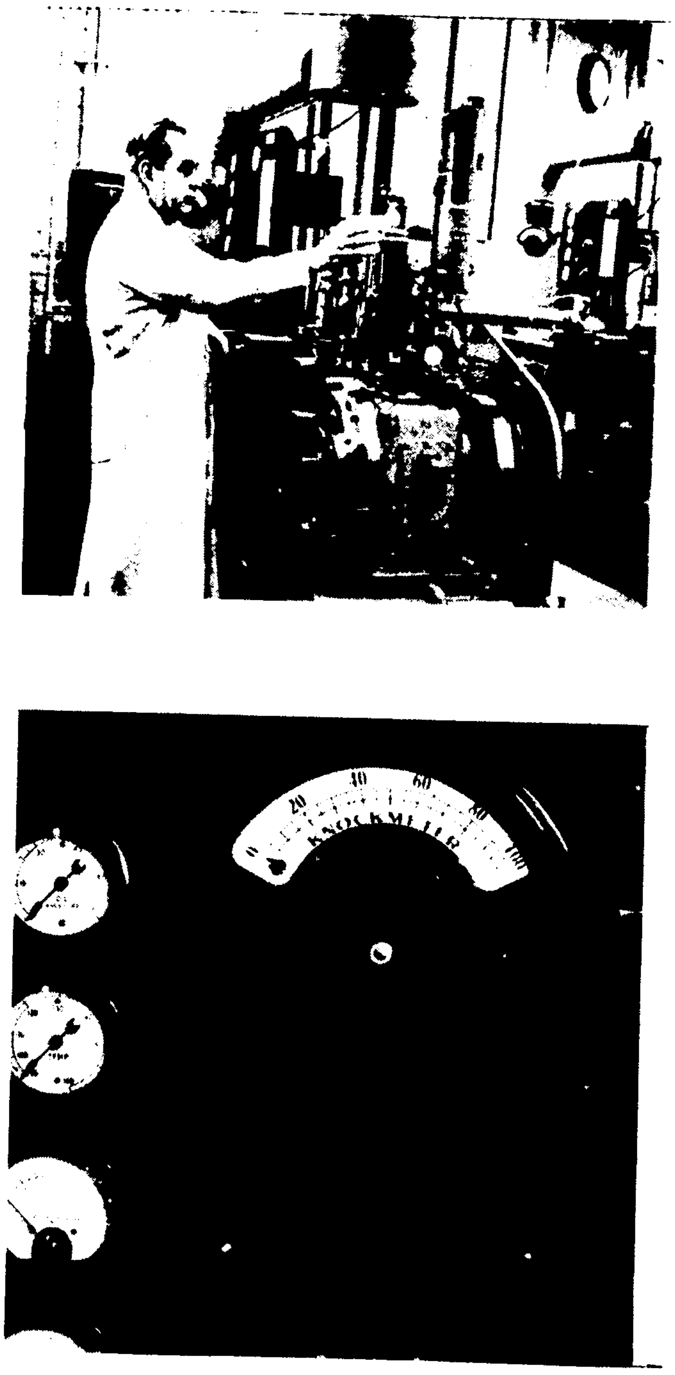


Fig. 2-73

2. Knock can be cut down by adding tetraethyl lead (TEL) to the gasoline, which slows down reactions in the unburned gasoline. Most brands of gasoline use TEL to raise the octane number.

3. Surface ignition, by deposits left by the fuel, such as carbon or lead compounds, may lead to knocking. Sometimes they glow, even at fairly low temperatures; they act like a spark plug, lighting the gas. If the ignition is turned off and the engine keeps running, this after-run or run-on is caused by surface ignition. If surface ignition starts to come earlier and earlier, the heat and shock can quickly damage the engine (Fig. 2-76).

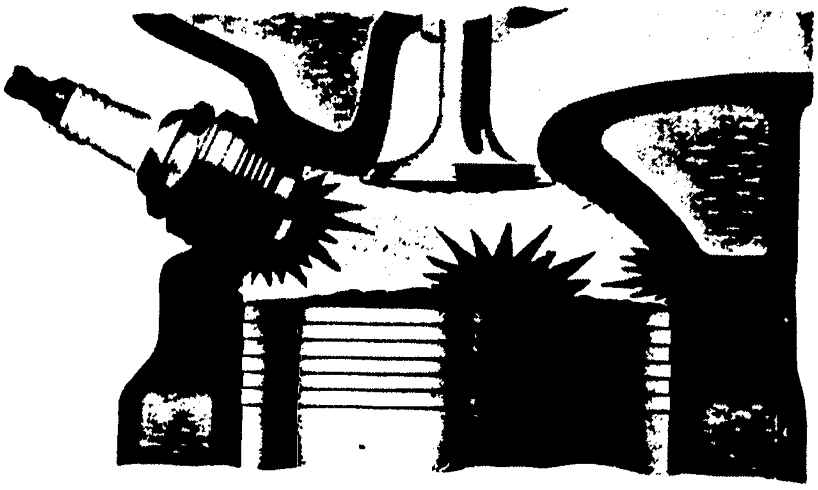


Fig. 2-75

Surface ignition leads to other kinds of improper combustion, sometimes known as wild-ping and rumble. It is a severe problem in high-compression engines.

Some control of surface ignition can be obtained from use of a phosphorus compound in the gasoline, such as tricresyl phosphate (TCP).

Fig. 2-76

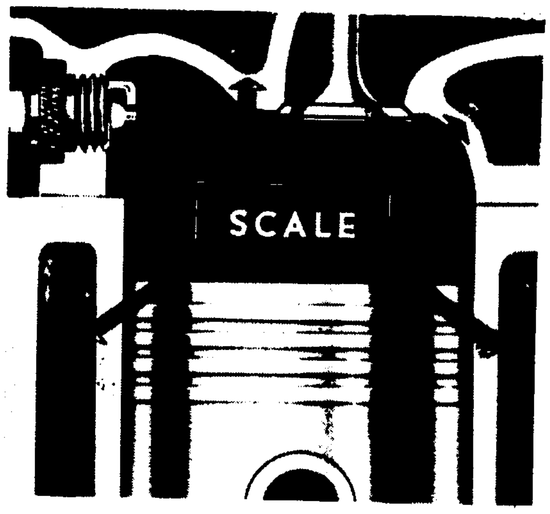
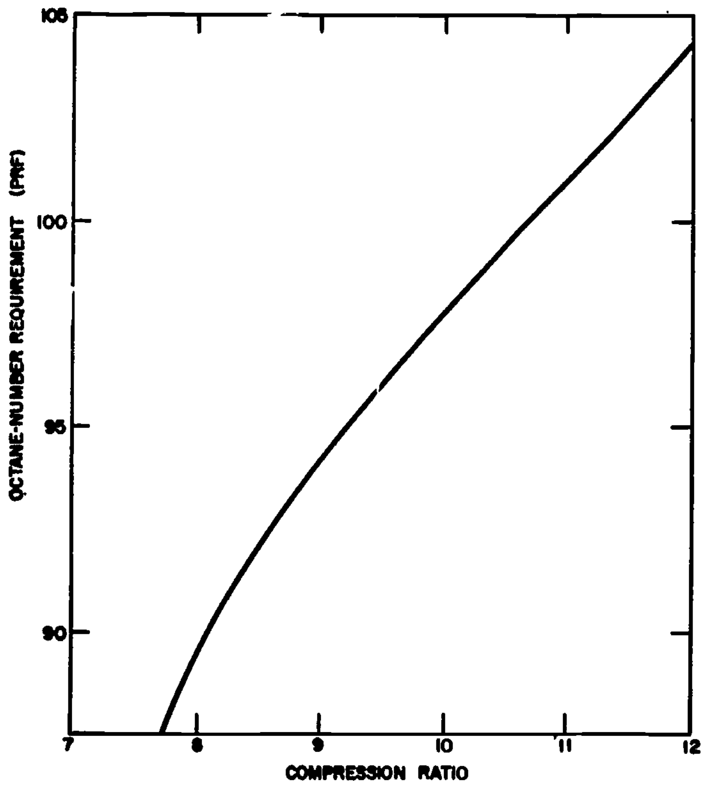


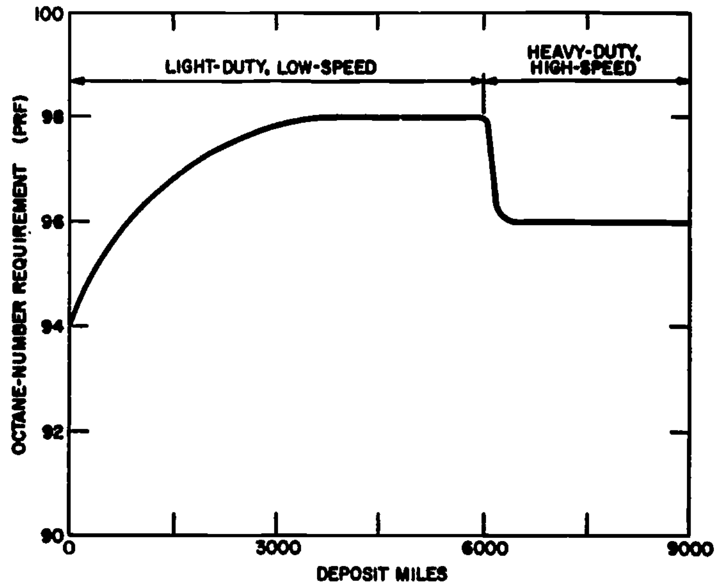
Fig. 2-77

4. Overheating of the fuel mixture before ignition causes knock. This may come from deposits of carbon inside the chamber, which prevent heat from being carried away, or from a dirty cooling system (Fig. 2-77), worn fan belt, plugged hoses, bad thermostat, or use of antifreeze in the summer. Anything that keeps the combustion chamber hotter than it should be can lead to knocking.



Effect of Compression Ratio on ONR

Fig. 2-78



Effect of Operating Conditions on ONR

Fig. 2-79

The temperature of the air-fuel mixture can also be cut down by injecting a little water into the cylinder or by using alcohol as part of the fuel. These methods have been used at times but are not of importance in this country now.

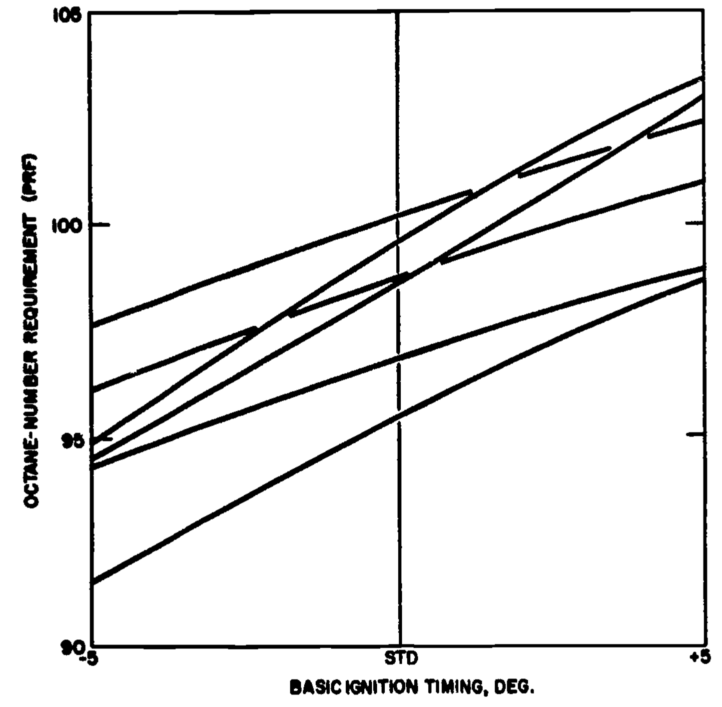
5. High compression ratios lead to knocking, partly because the gas is heated more. The octane number required by engines of various compression ratios is shown in Fig. 2-78.

Deposits of carbon or other material in a combustion chamber take up space, which has the effect of increasing the compression ratio. This is one of the reasons that engines need higher octane gasoline after they have been run (Fig. 2-79) than when they were new and clean.

These deposits are shaken loose and cleaned out by running at high speed. As the graph shows, the octane number that the engine needs goes down.

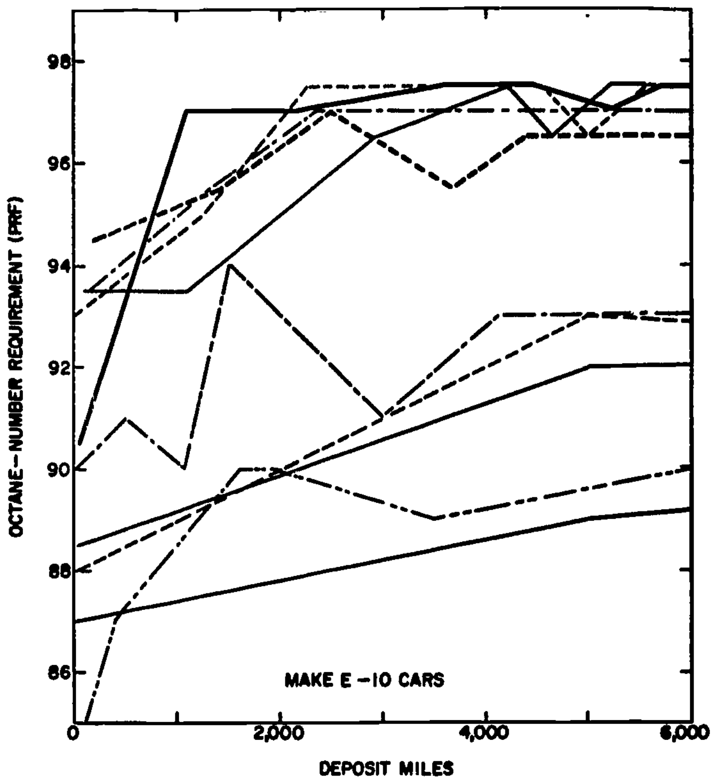
6. Engine adjustments that give a lean mixture or spark that is too advanced may cause knocking.

7. Cars of the same make and model do not all need exactly the same octane number fuel.



Effect of Ignition Timing on ONR

Fig. 2-80



Variations in ONR for Cars of a Given Make

Fig. 2-81

Effects of knocking and surface ignition. When gasoline knocks, the push on the piston is like a hammer blow, rather than an even push. The engine cannot accept the power at once, so some is wasted. It also leads to overheated valves, spark plugs, and pistons, which will shorten the life of these parts.

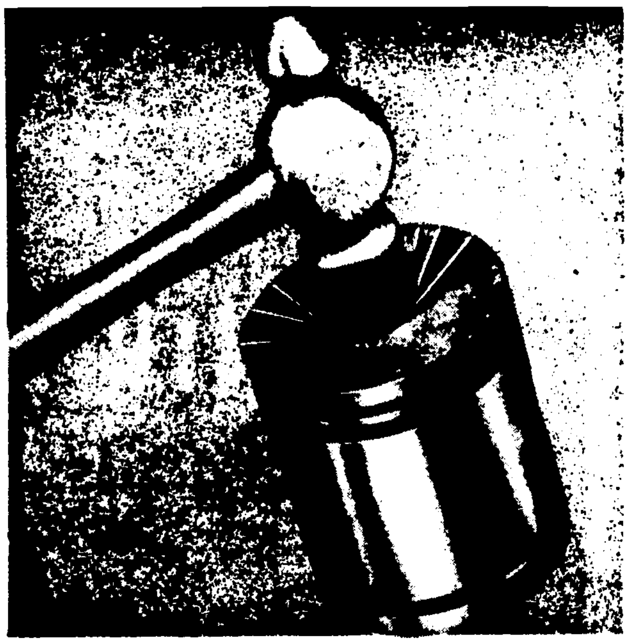


Fig. 2-82

Fig. 2-83

EXPERIMENT 10. COMBUSTION

Combustion means burning. When hydrocarbon fuels burn, several things are formed. In this experiment you will see what substances are formed under various conditions.

The fuel you will use is propane, a hydrocarbon gas like the compounds in gasoline. The bunsen burner, while quite different from an engine, can be varied to give a rich or lean mixture.

MATERIALS: Propane tank, fittings, and ¼" x ¼" hose; bunsen burner; Pyrex beaker; soft glass rod; funnel, filter paper, Erlenmeyer flasks, calcium hydroxide, water; steel wool.

PROCEDURE:

1. Fold a filter paper (your teacher will show you how). Put it in a funnel and set the funnel in the neck of a flask.

2. In a second flask put a little calcium hydroxide (about as much as a pea or a bean) and fill the flask about ¼ full of water. Shake the mixture and pour it through the filter paper into the first flask. The filtrate which passes into the clean flask is limewater.

3. Wash the dirty flask. Put a little limewater into it and blow into the mouth of it. Cover the opening with your hand and shake it. The cloudy, milky color of the limewater is a test for carbon dioxide, a gas your body makes from the food you eat. Save the rest of the limewater for use later.

4. Examine the bunsen burner. Find the gas inlet, the air inlet holes around the bottom of the barrel, and the needle valve. Unscrew the barrel. Turn the needle valve in until it blocks the gas supply. Then back it off 2-3 turns until the orifice (hole) is open. Put the barrel back. Screw it down until the air inlet holes are blocked.

5. Connect the burner to the propane tank by a foot or so of hose. Be sure the hose is tight at both ends.

6. Open the valve on the propane tank a little. Smell the gas at the burner. Light the gas. Do the following tests:

   a. Record the appearance of the flame.
   b. Hold the flame in the mouth of a flask for a moment and test the gases with limewater.
   c. Hold a cold beaker above the flame for 3-4 seconds. Examine the surface for any materials that condensed on it.

d. Smell the gases from the flame, being careful not to burn yourself.

e. Hold a glass rod in the flame for two minutes to see if the flame is hot enough to melt it.

f. Hold steel wool in the flame to see if it burns.

7. Open the air inlets by unscrewing the barrel of the burner until the flame has a completely different color. Repeat the tests listed in (6).

CONCLUSIONS:

1. What combustion products did propane give under all conditions?

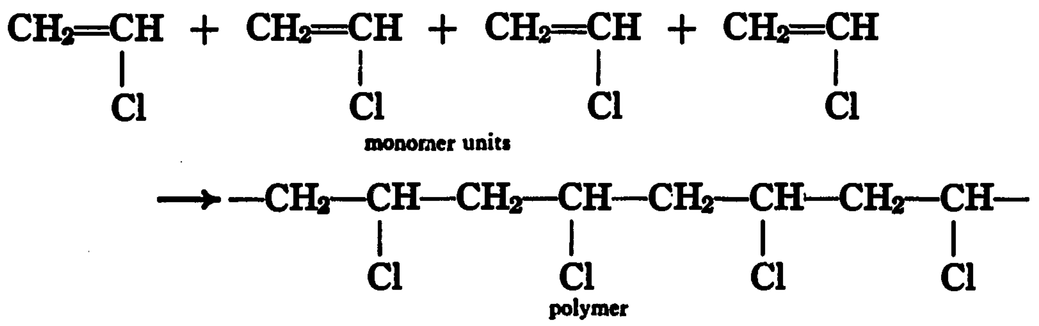
2. Which product can be cut down, and how is this done?

3. Which type of fuel mixture is the hotter?

4. What type of flame burns metals?

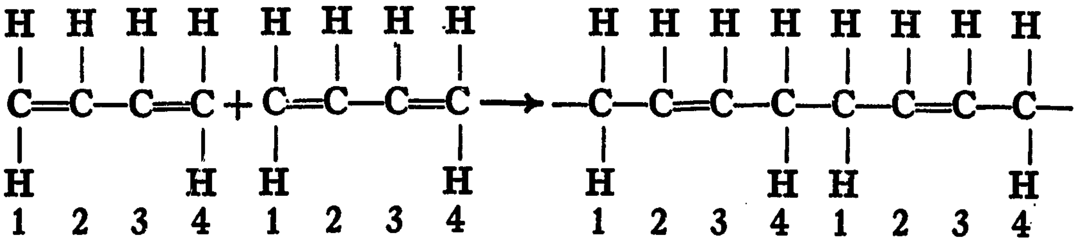
7. POLYMERS

Our study of organic compounds showed how one aldehyde molecule can link with others to form a very long polymer molecule. Unsaturated molecules also have double bonds and can polymerize. The little vinyl chloride molecule $CH_2 = CHCl$, a gas, polymerizes into a very useful polyvinyl chloride plastic used in making sea covers.

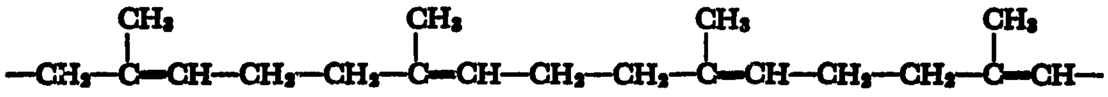


$$CH_2{=}\underset{Cl}{\underset{|}{CH}} + CH_2{=}\underset{Cl}{\underset{|}{CH}} + CH_2{=}\underset{Cl}{\underset{|}{CH}} + CH_2{=}\underset{Cl}{\underset{|}{CH}} \longrightarrow -CH_2-\underset{Cl}{\underset{|}{CH}}-CH_2-\underset{Cl}{\underset{|}{CH}}-CH_2-\underset{Cl}{\underset{|}{CH}}-CH_2-\underset{Cl}{\underset{|}{CH}}-$$

Rubber. Unsaturated hydrocarbons with two double bonds per molecule such as butadiene ($CH_2 = CHCH = CH_2$) are expecially easy to polymerize:

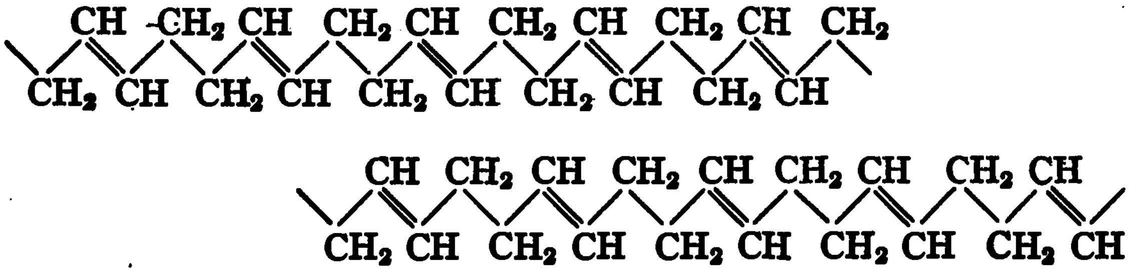


Because of the double bonds still left in the chain, this molecule is similar to natural rubber, which has a formula like this:



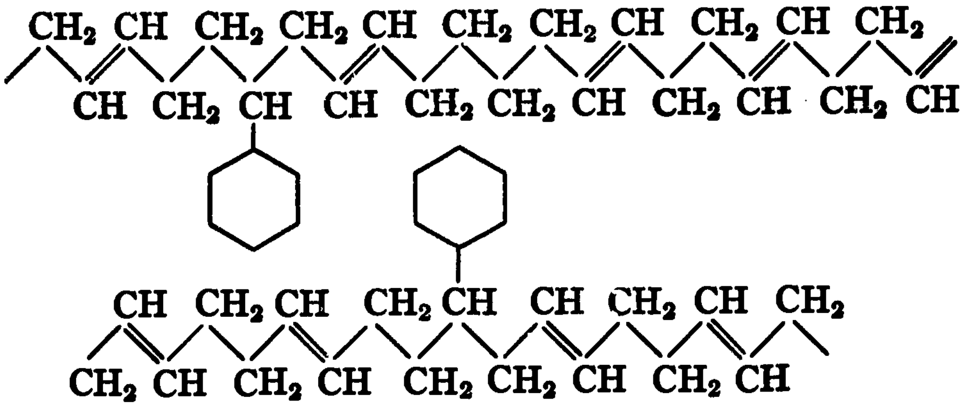
$$-CH_2-\overset{CH_3}{\overset{|}{C}}{=}CH-CH_2-CH_2-\overset{CH_3}{\overset{|}{C}}{=}CH-CH_2-CH_2-\overset{CH_3}{\overset{|}{C}}{=}CH-CH_2-CH_2-\overset{CH_3}{\overset{|}{C}}{=}CH-$$

In the synthetic rubber made from butadiene, the chains lie closer together than in natural rubber (above) with its CH_3 branches:



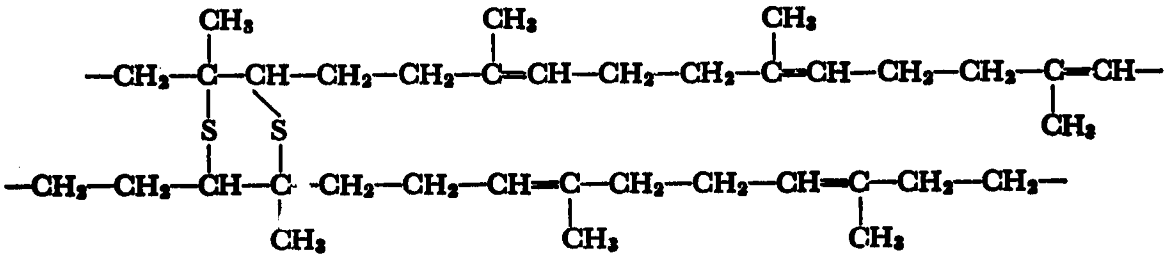
Close-lying chains of butadiene polymer

Chemists learned to put spacers in the molecules, using styrene with the butadiene. Most of our tires are made of this butadiene-styrene copolymer:

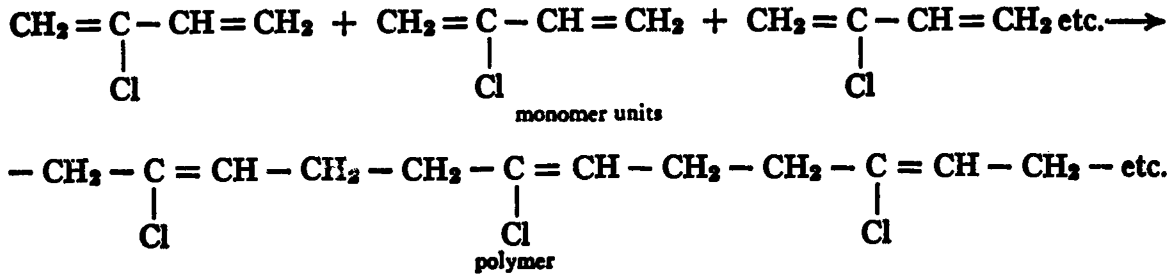


Chains of butadiene-styrene polymer kept apart by benzene rings

If natural rubber is held out of shape for a long time, the molecules will creep, and the rubber will stay out of shape. To prevent this, and to strengthen the rubber, the molecules lying alongside one another are joined by crosslinking. The easiest way to do this is to heat the rubber with sulfur. This process is called vulcanization, and gives a structure like this:



Rubber is a hydrocarbon, and has attractions for other hydrocarbons, especially aromatics. This is why it absorbs gasoline and oil, swelling up and getting weak. When synthetic rubber is made from chlorobutadiene, we get neoprene. The chlorine atoms in the molecule make it oil-resistant:



$$\mathrm{CH_2{=}\underset{Cl}{C}{-}CH{=}CH_2 + CH_2{=}\underset{Cl}{C}{-}CH{=}CH_2 + CH_2{=}\underset{Cl}{C}{-}CH{=}CH_2\,etc.} \longrightarrow$$

monomer units

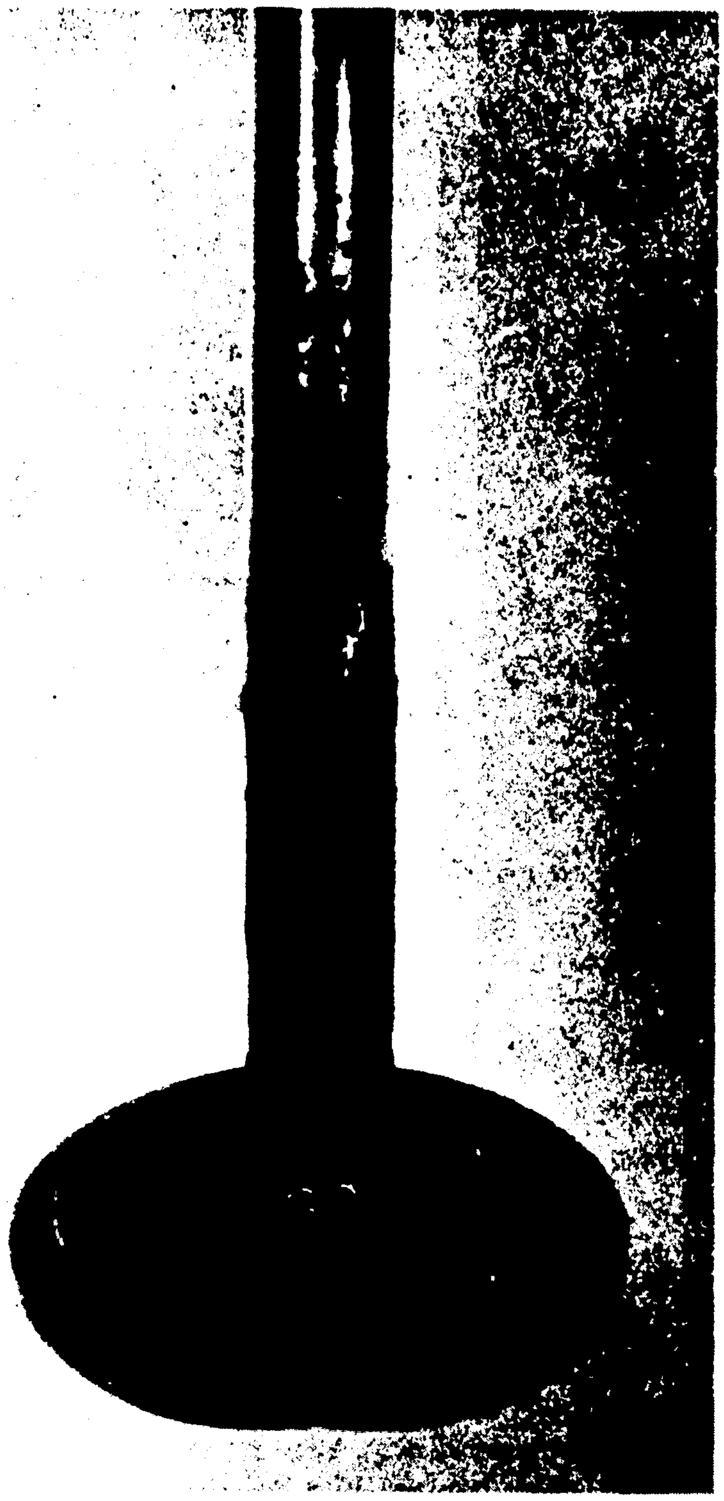
$$\mathrm{-CH_2-\underset{Cl}{C}=CH-CH_2-CH_2-\underset{Cl}{C}=CH-CH_2-CH_2-\underset{Cl}{C}=CH-CH_2-etc.}$$

polymer

Gum in gasoline. When unsaturated compounds in gasoline polymerize, they form a soluble, rubbery gum. It cannot evaporate, but is left behind when the gasoline is vaporized in the carburetor. The gum is carried as a fine, sticky spray in the gasoline vapor, and forms a coating on carburetor jets, intake manifold, and intake valves. Building up on the valve stem, the gum may keep the valve from seating properly, and lead to burning of the face. (Cooling of the valve face depends on its touching the water-cooled seat each time it closes).

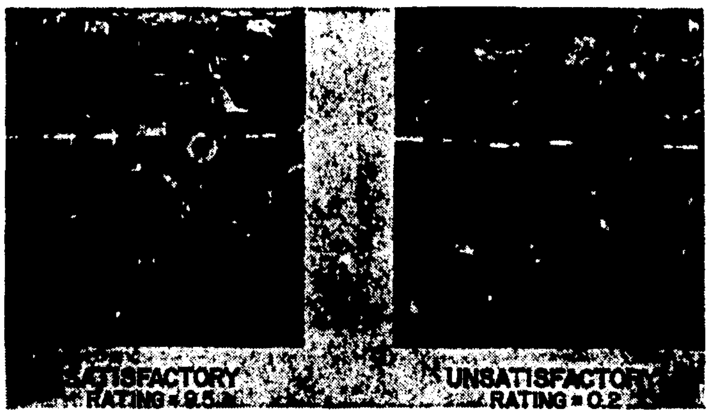
Most gasoline has an inhibitor to prevent gum.

In a cold engine, gasoline vaporizes incompletely. The parts which do not vaporize may dissolve in the oil on the cylinder walls or condense on the cold walls and collect in the crankcase. Then when the engine warms up, the unsaturated compounds in the gasoline polymerize, forming a varnish on pistons and a brown sludge in the oil. This sludge can block the flow of oil to piston rings, valve springs and lifters, and other vital parts. Detergent additives are used in oils to keep this sludge in suspension, but the amount that forms in light stop-and-go driving in winter (Fig. 2-85) has led to recommendations that oil be changed every 30 days in this type of service.



Valve Face Burning due to Stem Deposits

Fig. 2-84

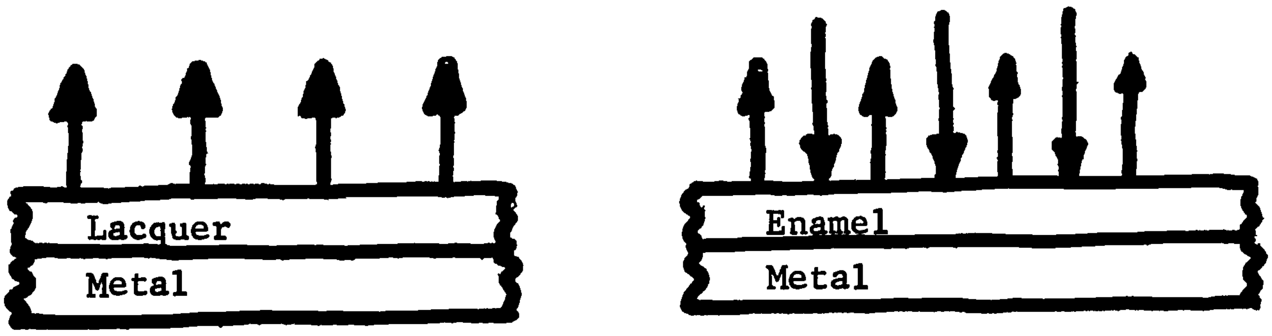


— Comparison of good and poor levels of engine cleanliness.

Fig. 2-85

Solubility of polymers. The automobile industry uses large amounts of polymers for finishes (paints). A finish is made up of a pigment (colored solid), a binder (polymer), and solvents which will evaporate in drying.

There are two basically different types of binders. Lacquers are made from a binder that is a non-crosslinking polymer. It dries simply by evaporation of solvent; if it is wiped with solvent later, it will dissolve again. Enamels dry in two ways: by evaporation, and by reaction with oxygen, which cross-links the molecules. Both processes are speeded up by heat, as in a drying oven. Enamels cannot be redissolved with the usual solvents.

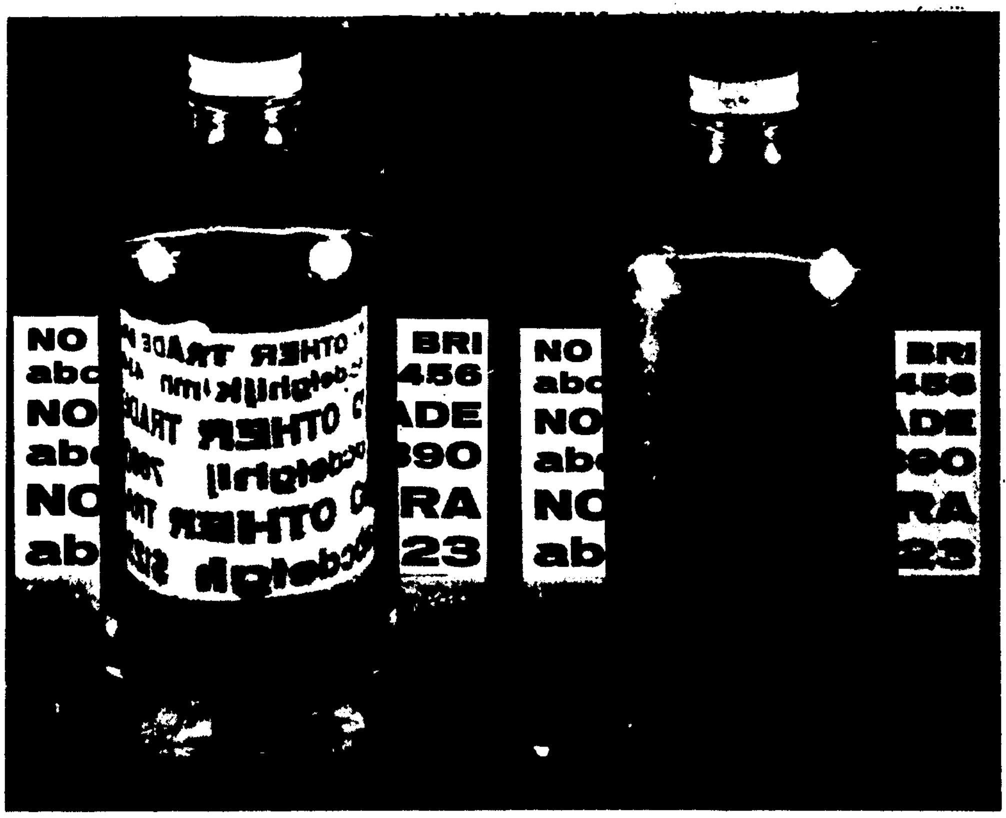


Lacquers dry by evaporation

Enamels dry by evaporation and by absorbing oxygen

Fig. 2-86

To thin down a finish, you need a reducer that will dissolve the polymer binder. These are usually special organic solvents (alcohols, esters, or other types), which are fairly expensive. To some extent they can be replaced by thinners (hydrocarbons like gasoline or naphtha). Thinners are not solvents for the polymeric binders. Too much thinner will knock the binder out of solution (as shown in Fig. 2-87). This gives a dull finish.



Left: Balanced reducer.

Right: Unbalanced reducer.

Fig. 2-87

Breakdown of finishes. An automobile is left outdoors a large part of the time. This will eventually break down every finish that has been invented up to this time. The polymer molecules holding the pigment together are gradually broken, and washed or torn off, leaving chalky dull, light-colored appearance. The main causes of this coating-breakdown or chalking are: (1) ultraviolet light, (2) water, (3) oxygen, and (4) acids and chemicals in the air.

EXPERIMENT 11. POLYMERIZATION

Plastics and rubber are made by polymerizing small molecules into large ones. There are a great many of these materials on the market, each with its own trademark. We shall manufacture four of these substances in this experiment.

1. Polymerization of a single unsaturated monomer by the action of a peroxide initiator. Using methyl methacrylate we shall get Lucite or Plexiglas.

2. Copolymerization of an epoxy compound with another chemical to give a hard, Epoxy resin.

3. Copolymerization of two chemicals with formation of a gas to make a foamed plastic.

4. Molding a partially polymerized mixture into a hard, Bakelite resin.

MATERIALS: Methyl methacrylate monomer, 5% sodium hydroxide solution, corks, test tubes, medicine dropper, benzoyl peroxide, Buehler 1" glass ring molds, paper cups, laboratory balance, Buehler or Quickmold epoxy resin and hardener, mold release compound, Nopco F-706 flexible foam resin or G-502 rigid foam resin (samples gratis from Nopco Chemical Co.), Bakelite molding powder, molding press complete.

PROCEDURE:

1. Vinyl plastic. Fill a ½" x 5" test tube about one-third full of methyl methacrylate monomer. Add about an equal volume of the dilute sodium hydroxide solution. (CAUTION: Do not let this solution get in the eyes; wash off any that gets on the skin promptly.) Shake the tube vigorously for a minute. Then let it settle. When it is clear, take off most of the top layer into another test tube by use of a medicine dropper (but do not take over any of the sodium hydroxide bottom layer). Add to the methacrylate 3-4 little grains of benzoyl peroxide. Tightly cork the tube and shake it until the solid dissolves. Set it in a beaker of boiling water for 15 minutes. Then break the tube to get the plastic.

Methyl methacrylate has a strong smell. Wash out the first test tube with soap and water or a little ethanol. Any spilled material should be wiped up and the towels carried out so the smell will not stay in the work area.

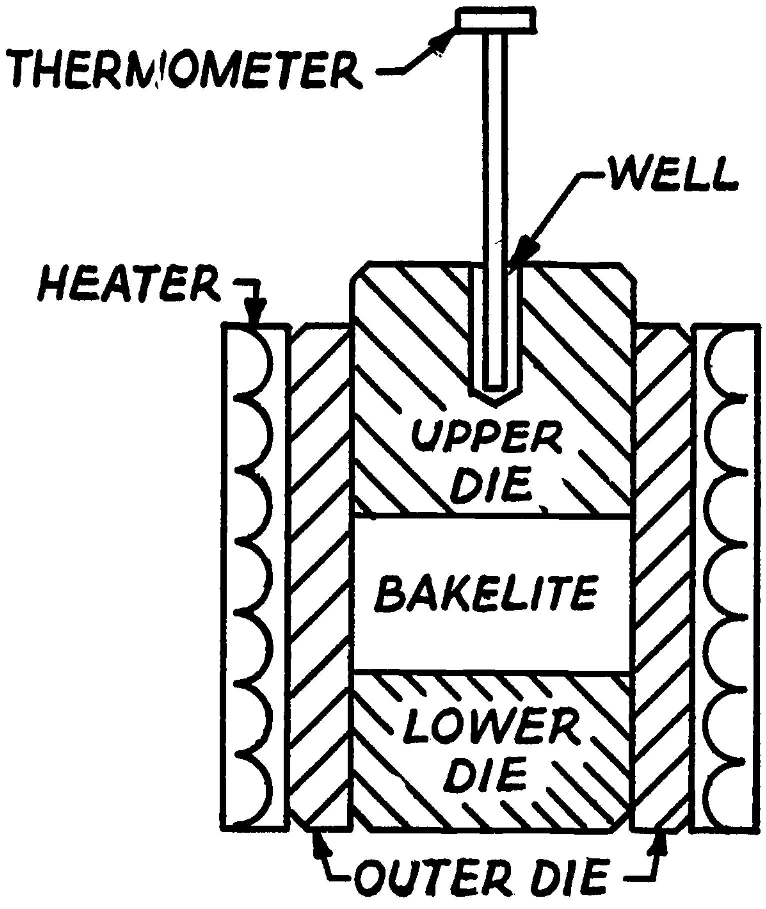
2. Epoxy. Wipe a glass plate with mold release compound. On it set out glassring molds for each participant and have a coin or medal to be embedded in each mold. In a paper cup, mix the two chemicals

as directed by the manufacturer. Pour a $\frac{1}{8}$" layer of the mixture in the bottom of the mold. Set the coin or medal in it; then cover it with another $\frac{1}{8}$" of the liquid. Set the molds aside to cure as directed by the manufacturer.

3. Foam plastic. Work over a large sheet of paper, in case of overflow. In an 8 oz. paper cup weigh out a total of about 50 grams of the two chemicals, in the proportions suggested by the manufacturer. Mix quickly and vigorously as recommended, and then stand back. CAUTION: The chemicals used are nasty. Avoid inhaling vapors unnecessarily; be very careful not to get any in the eyes; wash spills from the hands promptly. Be sure the chemical containers are tightly closed after use.

4. Bakelite resin, molding in Buehler specimen mount press. Read through the entire procedure. As you go along, study the various parts of the die and press.

Clean the dies with steel wool. Coat them lightly with die release compound if available. Set the lower die, smooth face up, on the press. Put the outer die around it as shown in the diagram. Weigh on a paper about 5 grams of molding powder. Pour it into the mold. Set the upper die in place, with the thermometer well up. Now put the heater around the die. Lower the metal thermometer through the frame of the press into the well as shown. Set the heater handle at an angle where it will not hit anything when the press is pumped and the table rises.



Close the pump valve by gentle use of the pump handle. Force is not necessary and can damage the valve. Pump up 2000 pounds pressure on the "one-inch mold" scale of the pressure gauge. Plug in the heater. As the pressure drops, keep it pumped up, but do not go over 2000 pounds. When the temperature reaches 130°C., turn off the heater. Open the pump valve a half turn to drop the pressure. Push the press table down, pushing both sides if it sticks. (The heater is hot, so be careful not to burn yourself.) Move the heater and die into the socket at the left front edge of the table and push out the molded plastic by pressure. Catch it in a metal cup and cool it with water before picking it up.

EXPERIMENT 12. ACTION OF SOLVENTS ON POLYMERS

Auto makers are using more and more polymers in the form of hard plastics, rubber, and finishes. Some of these are affected by solvents. Solvents may be necessary in spraying lacquer, but they are ruinous to tires. In this experiment you will see solvents at work.

MATERIALS: Small pieces of gum, vulcanized and neoprene rubber; polyvinyl (Tygon) tubing; test tubes, alcohol, acetone, and gasoline, various plastics.

PROCEDURE:

1. Prepare a page in your notebook with a sample data table like this:

Solvent	Alcohol	Acetone	Gasoline
Gum rubber			
Vulcanized rubber			
Neoprene rubber			
Vinyl plastic			

2. Line up four test tubes. Put a different sample of polymer in each. Cover the samples with alcohol for five minutes. Then pour the alcohol into a waste container and examine the samples for swelling, stickiness, or loss of strength (resistance to cutting with a dull edge).

3. Replace any affected specimens and repeat the test with the other solvents, one at a time.

4. In a similar way other plastics, such as those made in the previous experiment, can be tested. If you can get a piston from an old engine, wipe it clean and test the brown deposit in different places with a small amount of each solvent.

CONCLUSIONS:

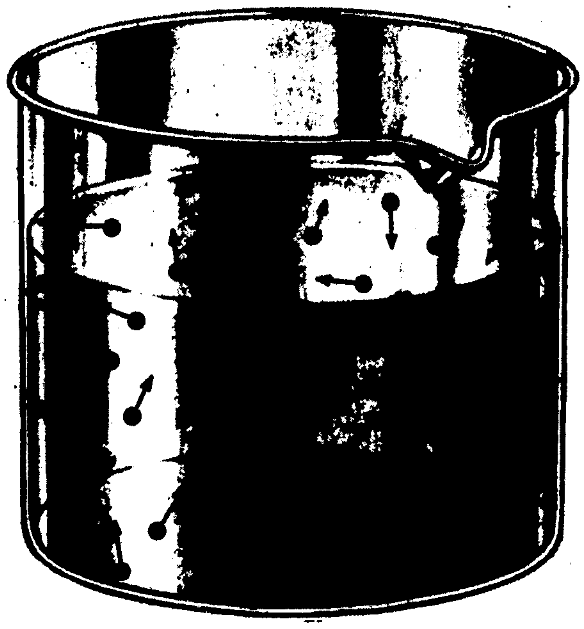
1. What general rules tell whether a solvent will dissolve a substance?

2. How are molecules changed in vulcanization of rubber?

8. SOLIDS

We have seen that molecules in a liquid move about freely. If the liquid is cooled, they move more and more slowly, until they fit themselves into a regular geometric pattern and can only vibrate in a limited amount of space. (Fig. 2-89)

Particles of a Solid
Vibrating about Fixed Positions
Fig. 2-89

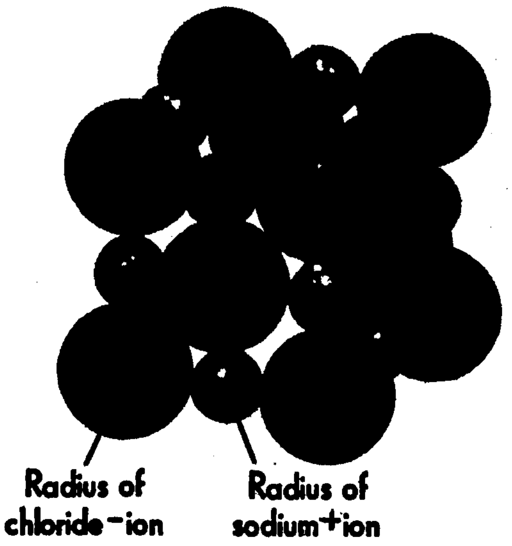


Particles of a Liquid in Random
Motion

Fig. 2-88

In a solid, each atom is attached to the ones next to it so it cannot skip around. This is why, in the solid state, matter has definite volume and shape.

The shape of a snowflake or the spangles on galvanized steel show a crystal pattern. Most solids have an invisible pattern due to the exact spacing of their atoms or molecules. Fig. 2-90 shows the crystal pattern of sodium cholo-ride (table salt). Compare it to the typical structure for metals in Fig. 2-91.

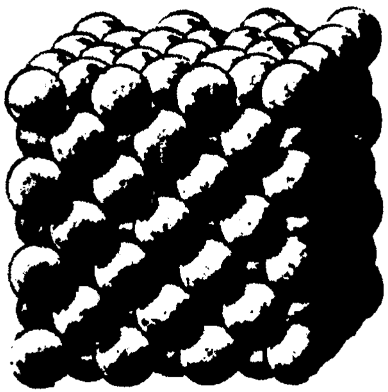


A Portion of a Sodium Chloride Crystal
—a Typical Ionic Substance
Fig. 2-90

Metals. More metal is used in making a car than all the other materials put together. Fig. 2-92 shows some of the metals and alloys (mixtures of metals) that are needed.

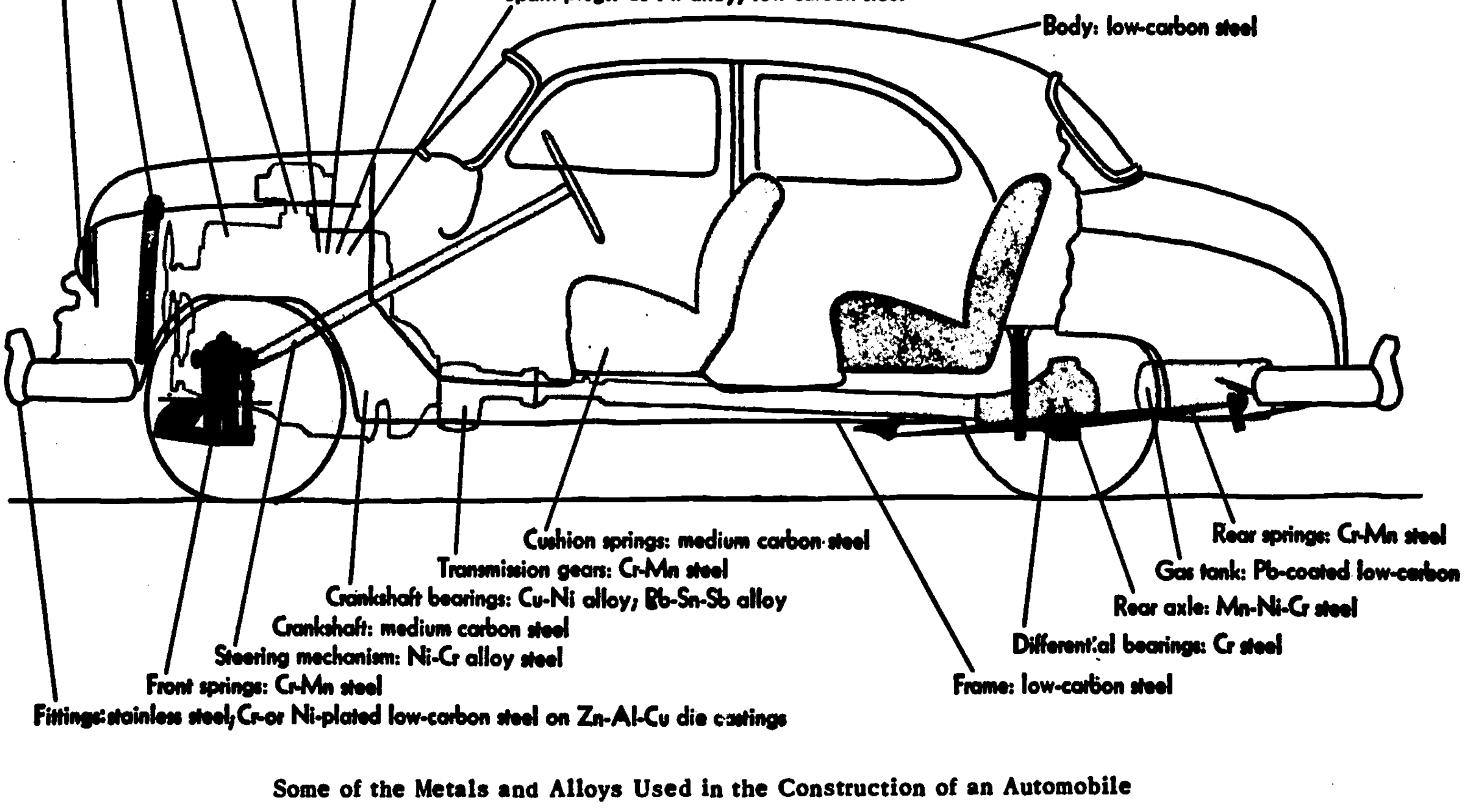
Metals are divided into two large groups. The ferrous metals are iron and its alloys, including steel. Since iron is the cheapest metal and also has very good properties, it is used for many parts. The non-ferrous metals are used in much smaller amounts, where special properties are needed. For example, aluminum is used in pistons for its lightness, in cylinder heads for its heat conduction, and in body trim for its corrosion resistance. Copper is used in wires for its excellent electrical conduction, and in radia-tor cores for its good heat conduction and corrosion resistance. Zinc is used for many die-cast items (grills, carburetors, door handles, etc.). Its low melting point makes it cheap to die-cast.

The good properties of metals are due to the way their atoms are held together. The metal is believed to be a lattice of atoms neatly arranged as in Fig. 2-91. This type of orderly arrangement is called a crystal. The outer, or valence, electrons float freely between the atoms, like a fluid (Fig. 2-100). These electrons belong not to any one atom, but to all of them. The attraction of the positively charged atoms to these fluid electrons holds the metal together and gives it strength.



A Schematic Representation of the Type of Close-packed Arrangement of Atoms Which Occurs in Crystals of Many Metals, e.g. Aluminum, Calcium, Iron, Copper, and Silver

Fig. 2-91



Some of the Metals and Alloys Used in the Construction of an Automobile

Fig. 2-92

Strength is the ability to resist a force. We usually think of a force as a push or a pull. Actually, there are several kinds of forces:

1. Tension--a stretching force.
2. Compression--a crushing force.

3. Torsion--a twisting force.
4. Flexion--a bending force.
5. Shear--a cutting force.

Fig. 2-93 and 2-94 show these different types of forces.

The strength of some materials is not the same against all types of forces. For example, cast iron is as strong as steel when compressed, but much weaker if it is being pulled, twisted or bent.

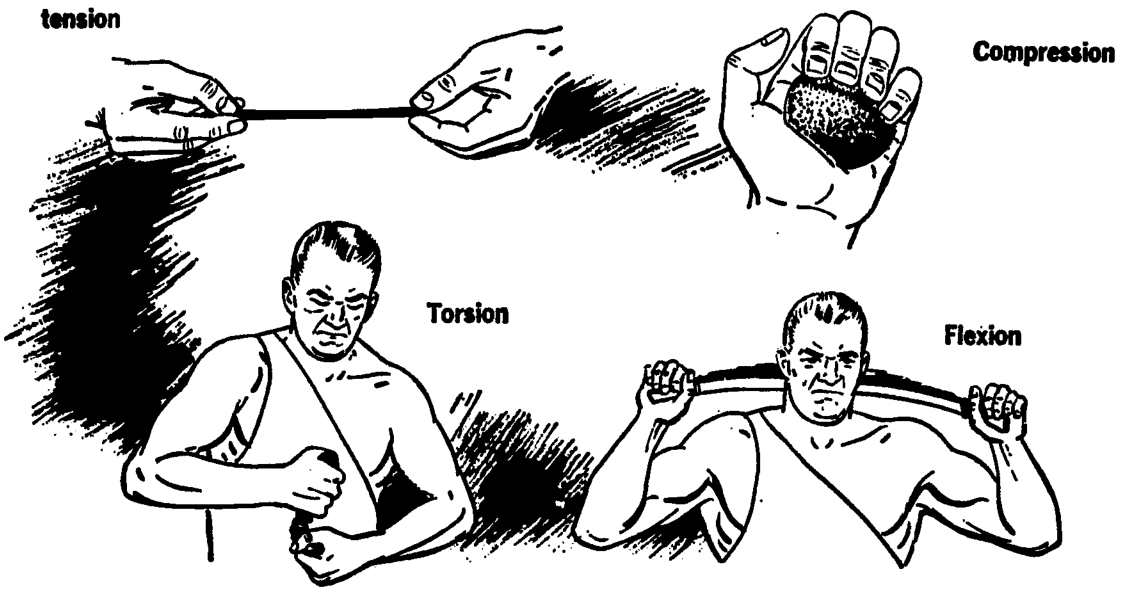


Fig. 2-93

Shears
Fig. 2-94

Fatigue. If a piece of metal is bent by hanging a weight on it, one side of it is stressed in compression and the other side in tension, as shown in Fig. 2-95.

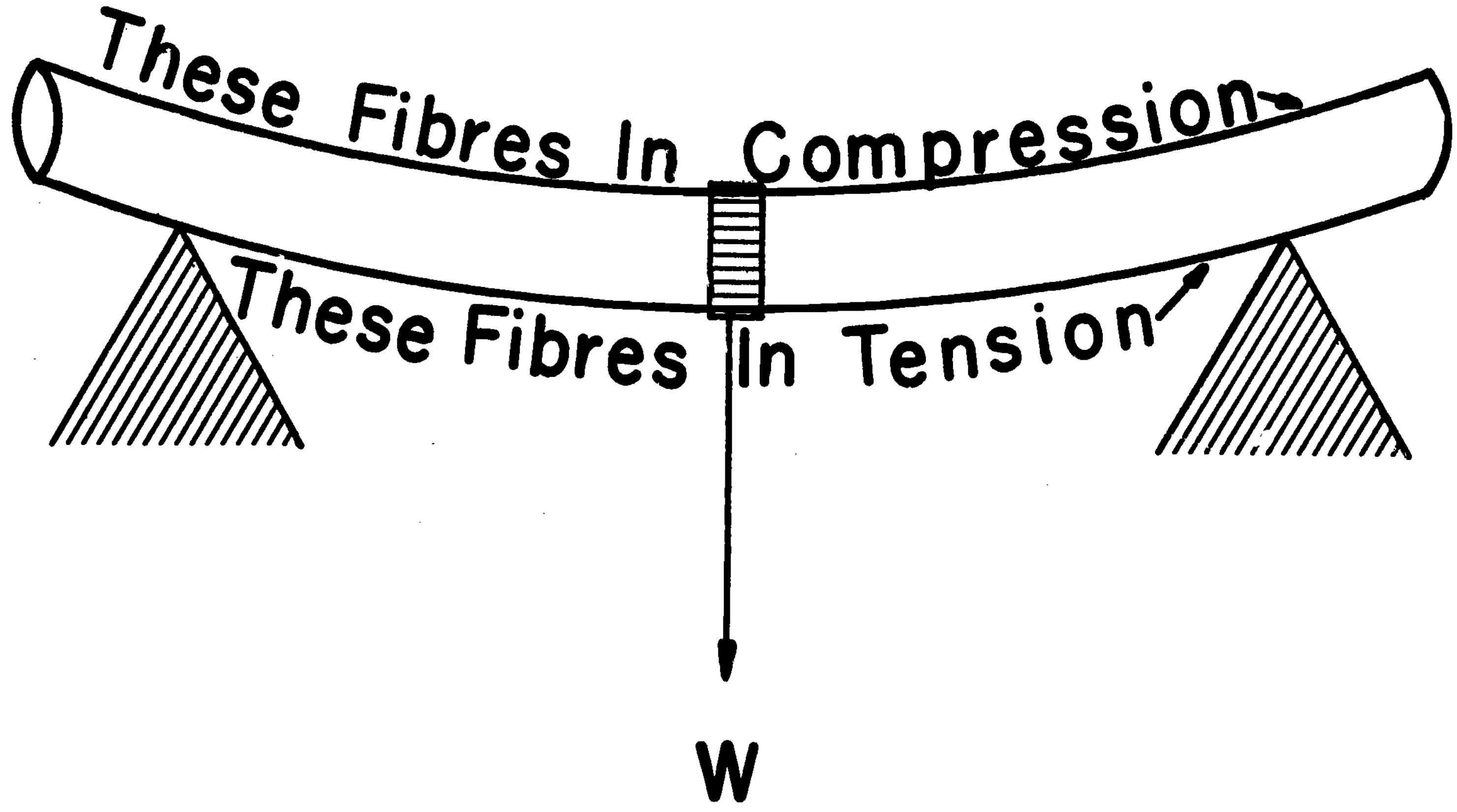


Fig. 2-95

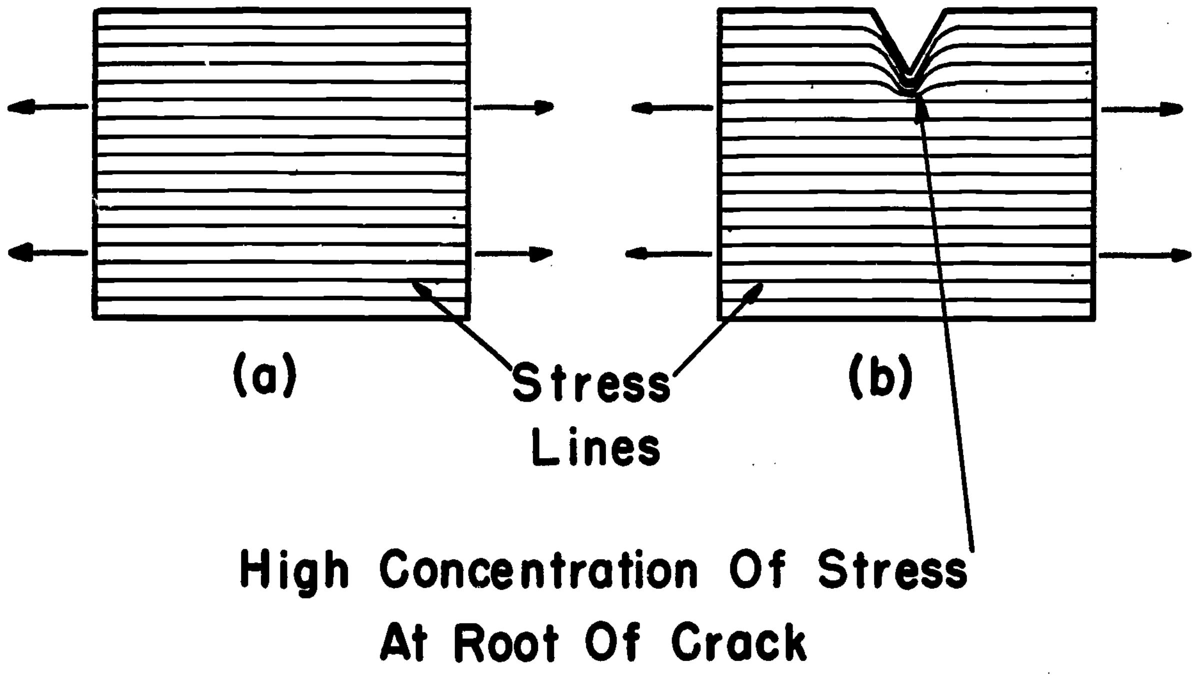


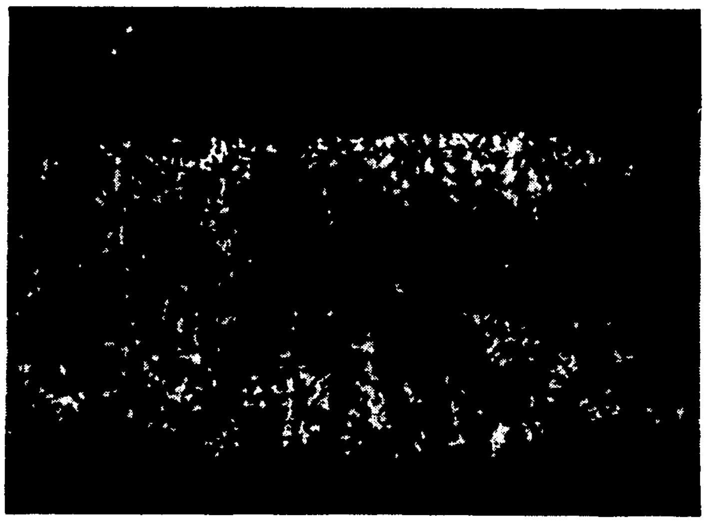
Fig. 2-96

When it is bent back the other way, the stresses are reversed. These stresses become very high any place where there is a crack, where corrosion is going on, or even where the piece changes shape. At the tiny root of a crack, as shown in Fig. 2-96, the material gives way a little bit each time it is bent. With many bendings, the crack grows bit by bit until the part breaks. This type of failure is called fatigue, which means a gradual getting tired.

Parts which have heavy loads put on them again and again are likely to break under fatigue. For example, the rear axle of a truck carries a torsion load which is very high and is put on and off every time gears are shifted. When a truck is loaded beyond its capacity, the rear axle is likely to fail after a while through fatigue.

Another part that may fail by fatigue is an engine bearing. Continual pounding, especially by an out-of-round journal or by very heavy service, bends the bearing back and forth. Cracks form, pockets of metal break away, and in time there is no bearing left.

Impact strength or toughness is the ability to take sudden loads. It is needed in such parts as crankshafts and connecting rods, which are pounded every time the gasoline in a cylinder explodes. Steel is often treated in special ways, we will see, to make it tougher.

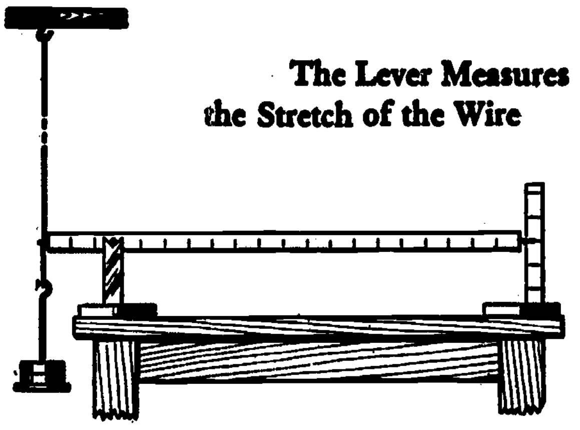


Photomicrograph showing fatigue in a copper-lead bearing.

Fig. 2-97

Hardness is the strength to resist compression at the surface of a material.

When a force or load is applied to a material which is held in place, it becomes a stress. The effects of stress can be seen if you mount a wire as in Fig. 2-98, with a stick fastened to it and pivoted so that the stretching of the wire can be measured on the scale at the right. As you hang one weight after another on the wire, and record the results on a graph as in Fig. 2-99, three things are seen:



The Lever Measures the Stretch of the Wire

Fig. 2-98

a. Up to a certain stress, the elastic limit, it stretches in an amount proportional to the load; if the load is taken off it goes back to the size it had before.

b. Beyond the elastic limit, it stretches permanently. In this range of load, the material is plastic.

c. As the wire is loaded still further to its ultimate strength, it breaks.

We see then that the strength of a material has two ranges: (1) elastic, in which its stretch is proportional to the load and it returns to the shape it had before loading; and (2) plastic, in which it keeps its new shape.

Plasticity, the ability to be forced into a new shape, is widely used in working metals.

Demonstrating Hooke's Law • The stretch of the brass wire is proportional to the stretching force, up to the elastic limit

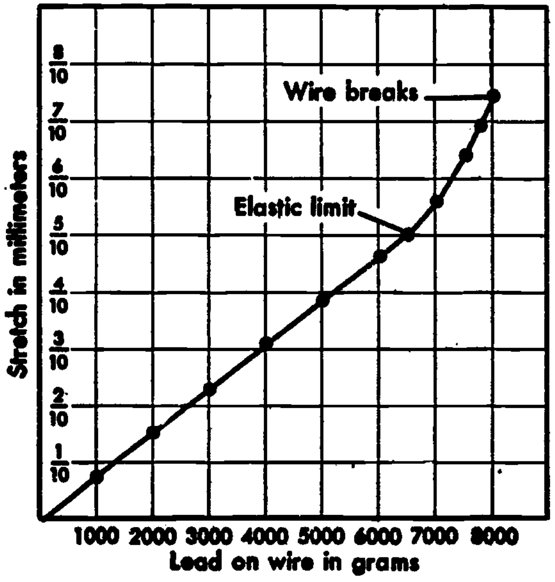
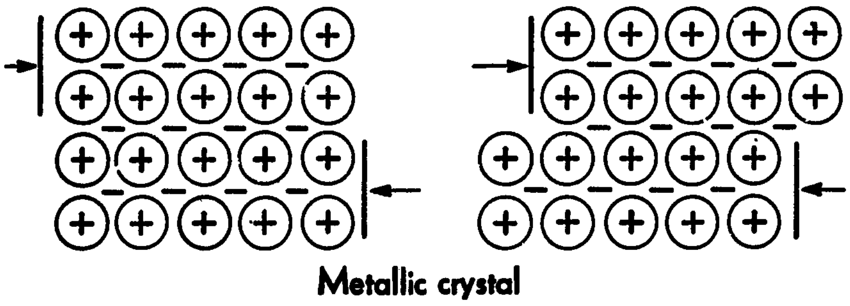


Fig. 2-99

Plastic changes of shape involve shifts of atoms. Remember that all atoms in a metal crystal are positively charged, and between them are loosely held, negative electrons. Fig. 2-100 shows how shifts of atoms in a metal still leave it with charges arranged + - +. With every charge next to one of opposite sign, there are still strong attractions to hold the metal together.



Effect of Distortion on a Metallic Crystal (Explaining Malleability of Metals)

Fig. 2-100

When atoms in a crystal made up of + ions and -ions, like stone or plaster, are forced to shift, + to + and - to - contacts are made; since charges of the same kind repel each other, these places push apart and break.

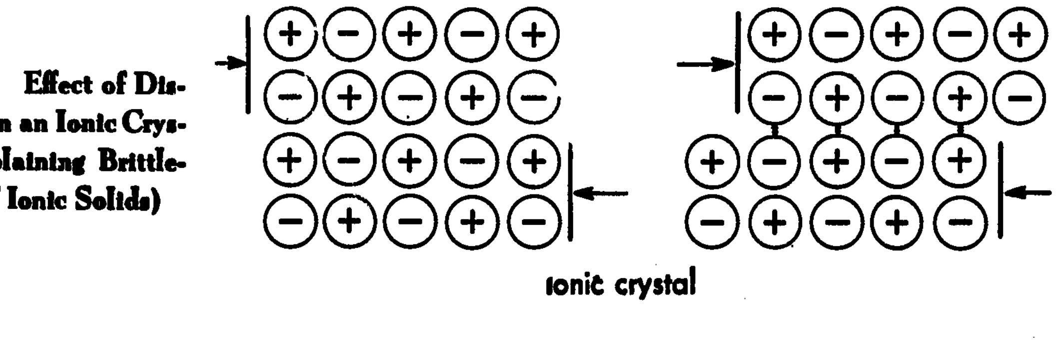


Fig. 2-101

Wires are made by pulling metal through a die, as in Fig. 2-102. Where tension (pulling) is used to change the shape of a metal, we speak of the metals's ductility. Ductility means its ability to be drawn into a wire.

The ductility of sheet steel makes it possible to press deeply curved body shapes between dies in a giant press.

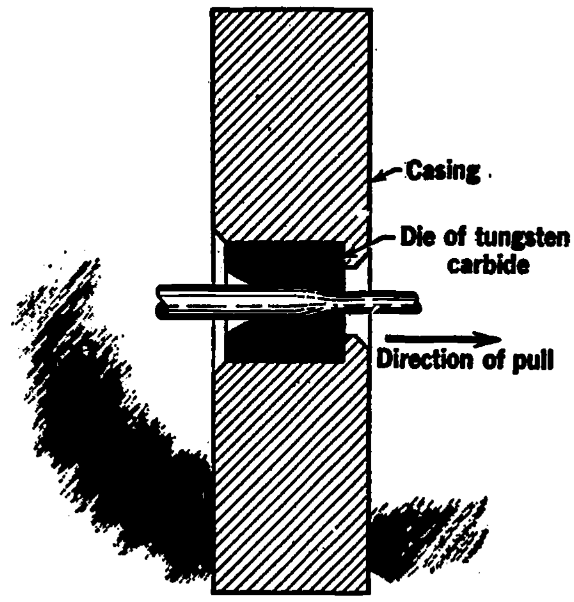


Fig. 2-102

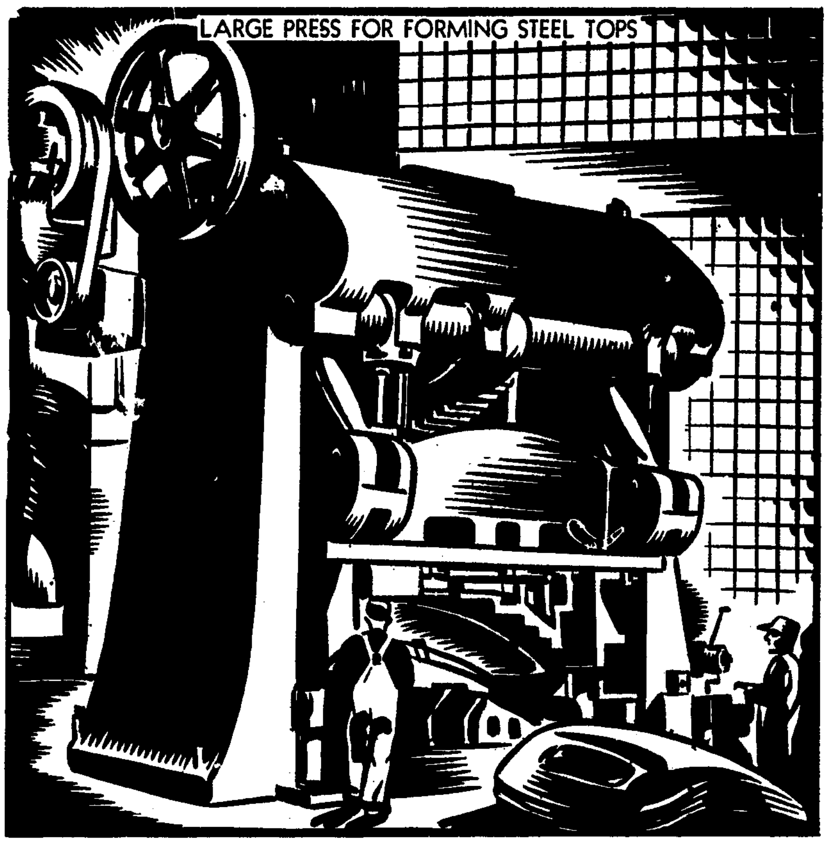


Fig. 2-103

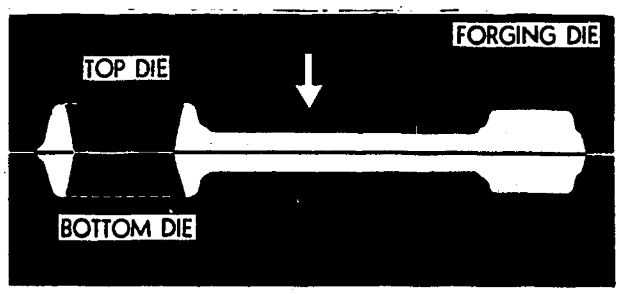


Fig. 2-104

If pushing is used to change a metal's shape, we speak of malleability, which comes from the Latin word for hammer.

Hammering is still used to shape metal, in body repair work and in manufacturing. Steel is often forged into shape while it is red hot. A connecting rod, for example is made in a pair of dies, as sketched in Fig. 2-104.

Large forgings, such as crankshafts, are made with giant power hammers. The grain is shaped as shown by the insets of the picture. This type of grain pattern is strong and tough.

Rolling is another way of shaping metal under pressure. As shown in Fig. 2-106, the rolls drive the metal and squeeze it at the same time.

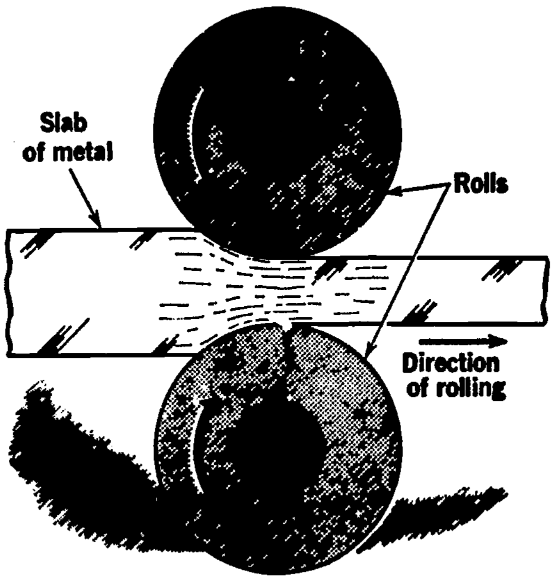


Fig. 2-106

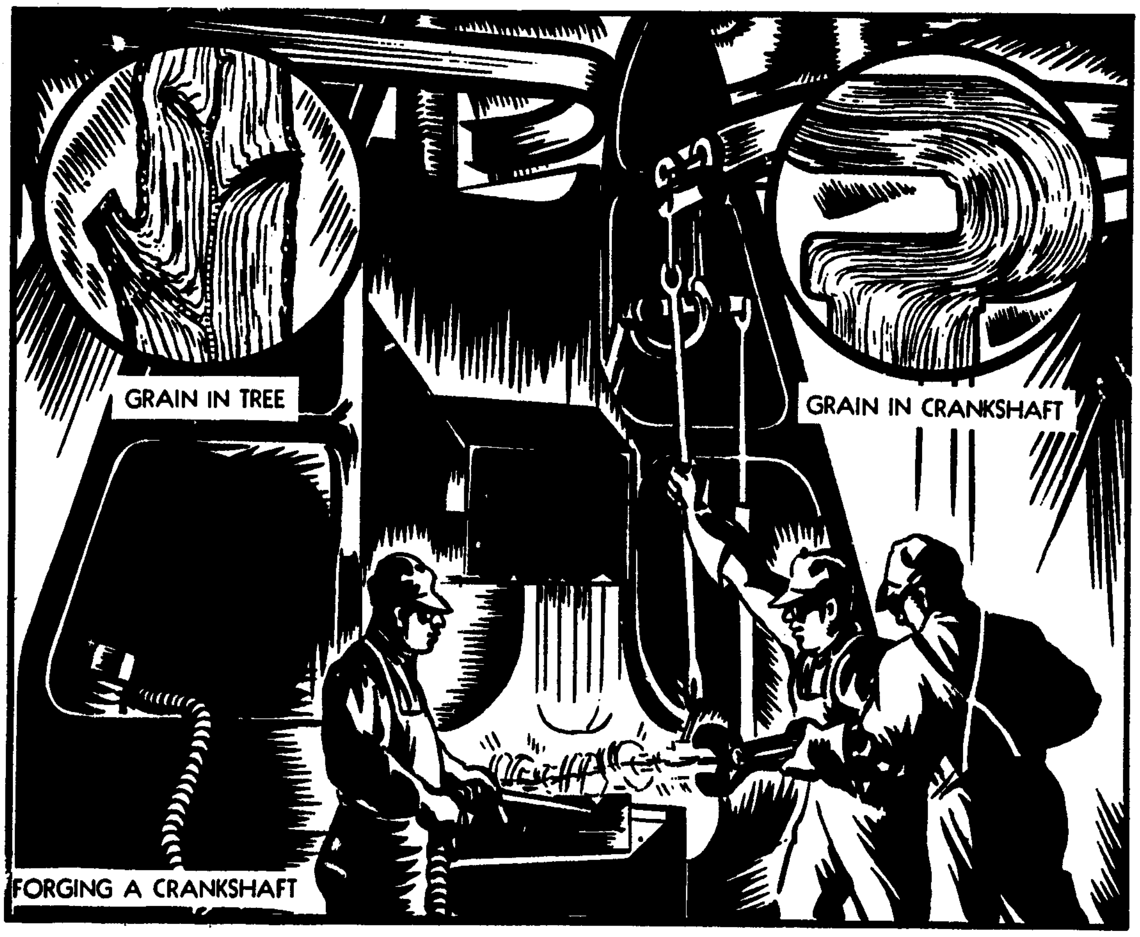


Fig. 2-105

Metals are easier to work when hot, but hot-rolled steel comes out rough and scaly. Cold-rolled metals are clean and smooth; due to the strains left by the rolling process, they become stiffer and stronger. Any kind of cold work to change the shape of a metal has this result.

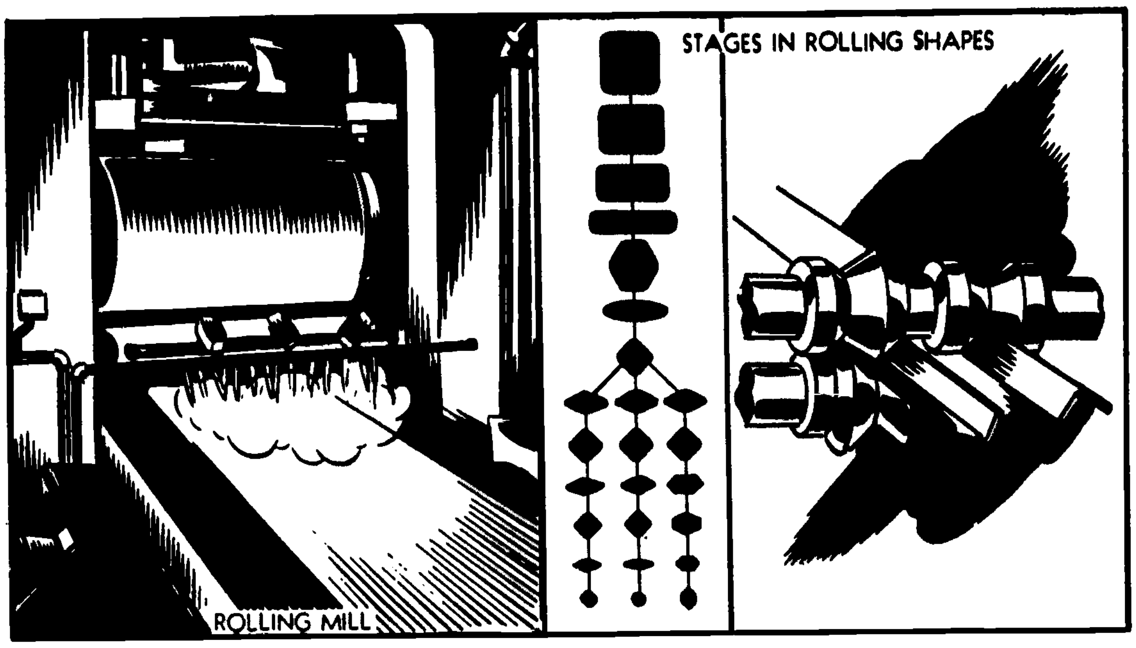


Fig. 2-107

Besides flat sheets, industry rolls many special shapes -- angles, I-beams, channels, etc., using special rolls like those in Fig. 2-107.

Cutting. Just as important as the plastic working of metals is removal of excess metal by machining, cutting, grinding, and so forth.

Melting is another way that metals are processed. Many parts that cannot easily be shaped from solid metal are cast. This means the metal is melted to a liquid and poured into molds.

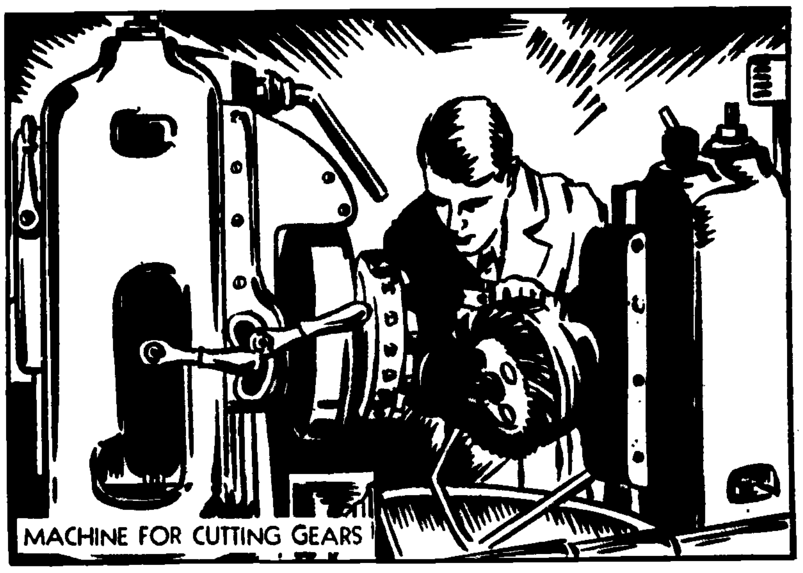


Fig. 2-108

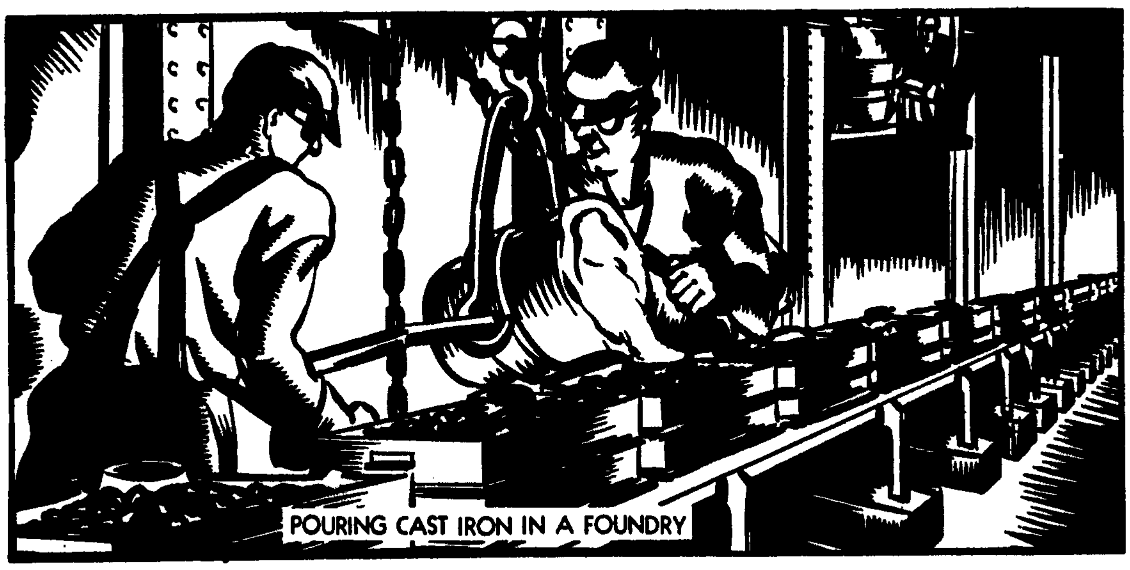


Fig. 2-109

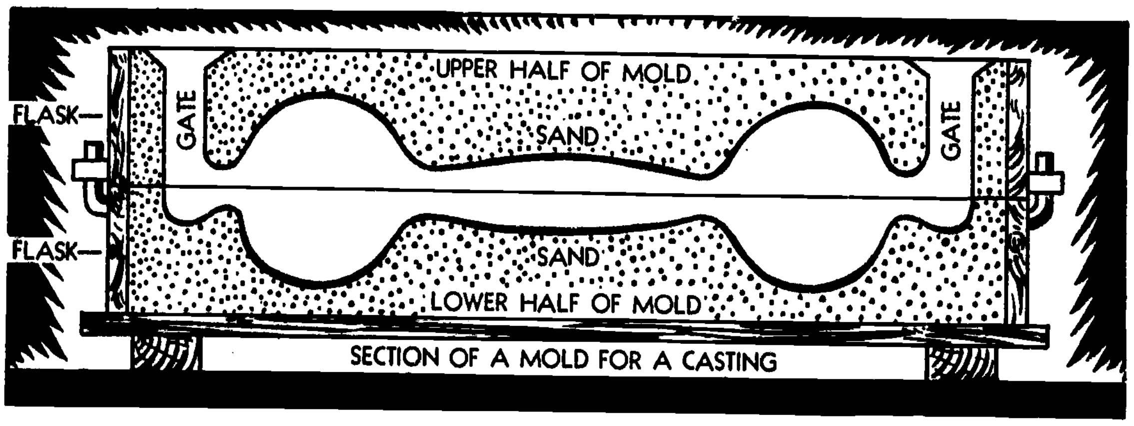


Fig. 2-110

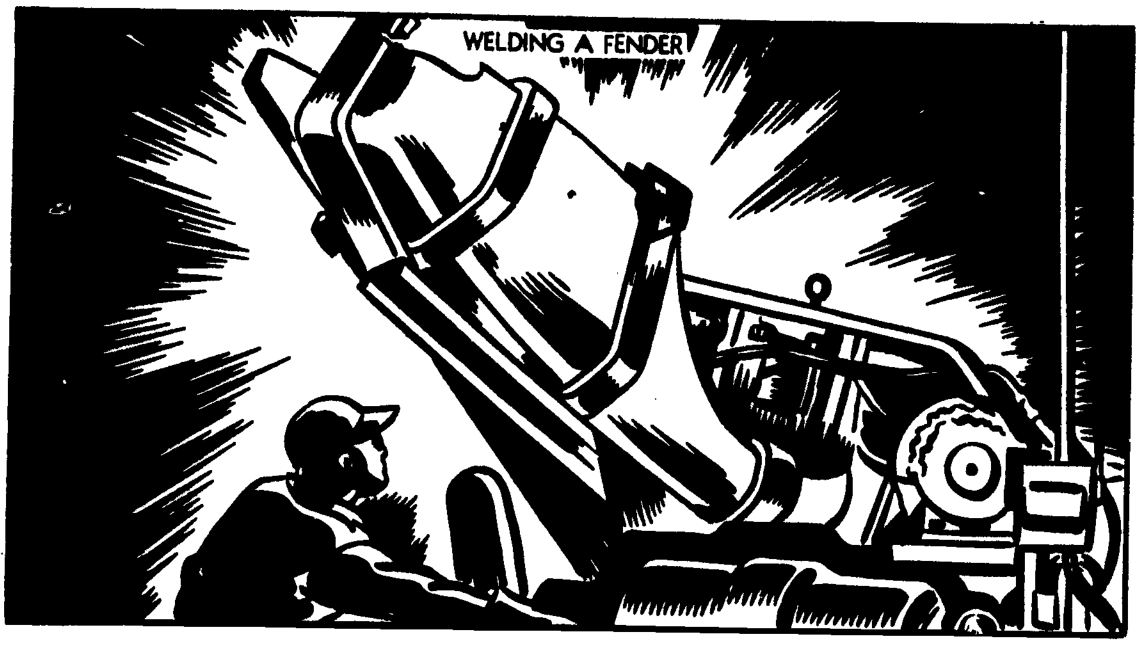


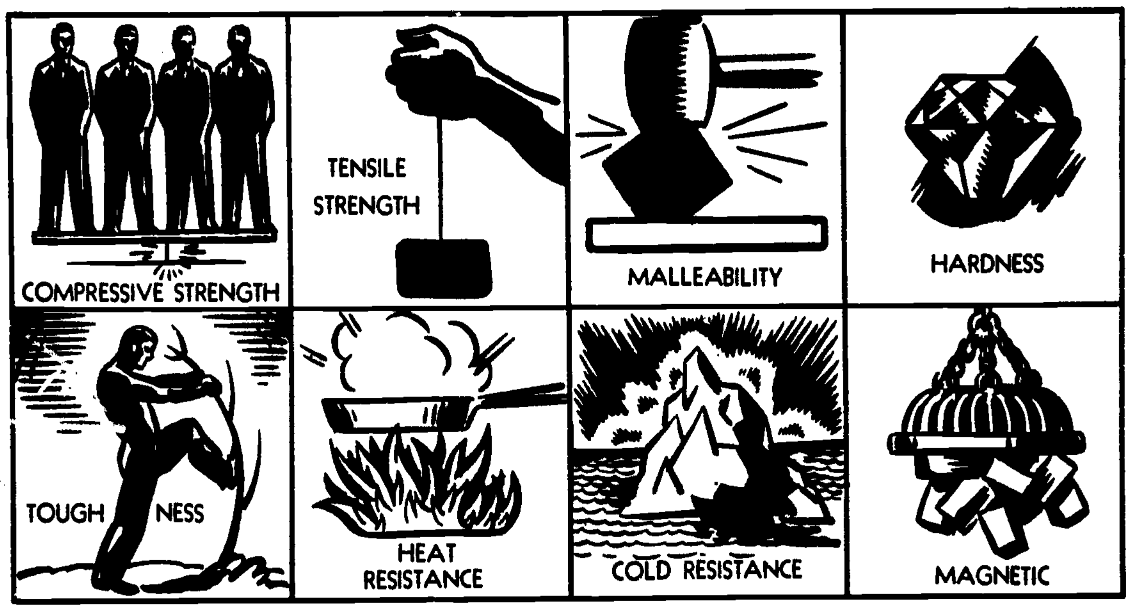
Fig. 2-111

Most castings are made of iron and are poured into sand molds (Fig. 2-110). These molds are cheap and are used only once. Permanent molds, or dies, made of steel are used in casting the low-melting-point metals, such as zinc and aluminum. Die castings come out of the mold smooth. Pistons, door handles, grills, etc. are usually die cast.

Welding is the joining of two pieces of metal by melting the joints. The high temperature which is needed can come from an electric arc or an acetylene flame. Lower-melting metals can be used at the joint. We call this soldering when a lead-tin alloy is used, or brazing when a copper-zinc alloy is used.

Iron and steel. Of all the metals, iron might be called the leader. It is not only the commonest and cheapest, but offers the greatest variety of properties (Fig. 2-112).

Pure iron is one of the 92 natural elements. It is commonly found as its red oxide, rust, which gives dirt its brown color. Where dirt contains high amounts of rust, it is mined as an iron ore.



Some important properties of iron.
Fig. 2-112

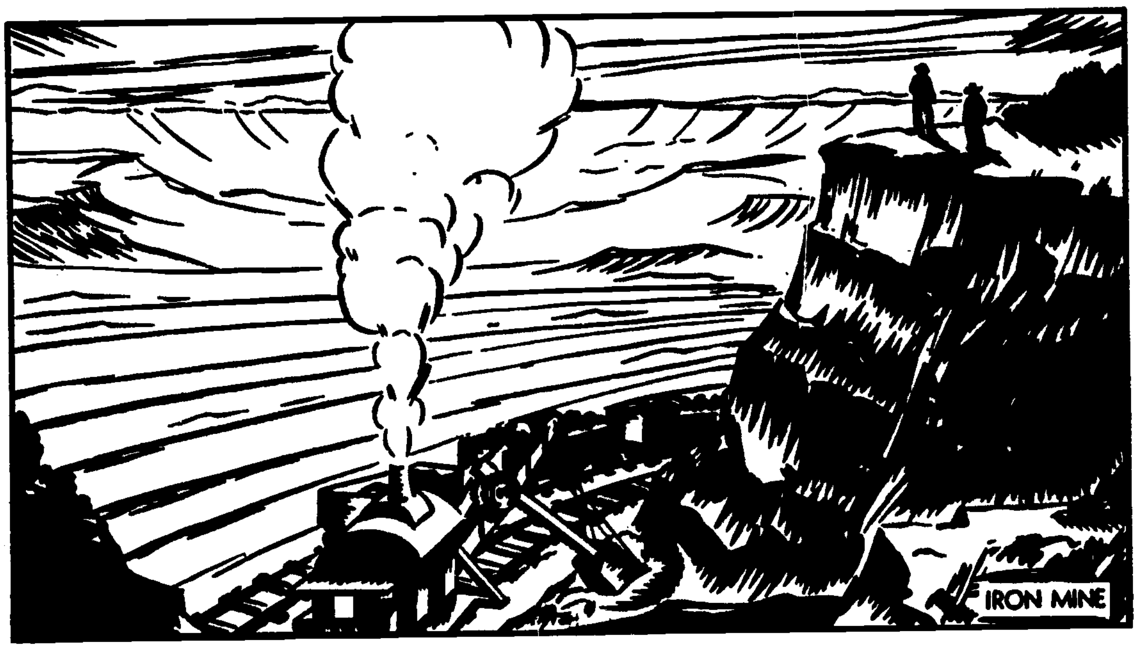


Fig. 2-113

An oxide is a compound with oxygen. To get the iron away from the oxygen in the ore, it is smelted in a <u>blast furnace</u>. Here it is mixed with coke; at high temperatures the coke (which is mostly carbon) takes the oxygen away as carbon oxide gases, leaving the iron. As the iron melts in the furnace, it sinks to the bottom and is drawn off. It contains 3½ to 4% of carbon and other substances. This mixture is <u>pig iron</u>; its carbon content has to be cut down before it can be used - most purposes.

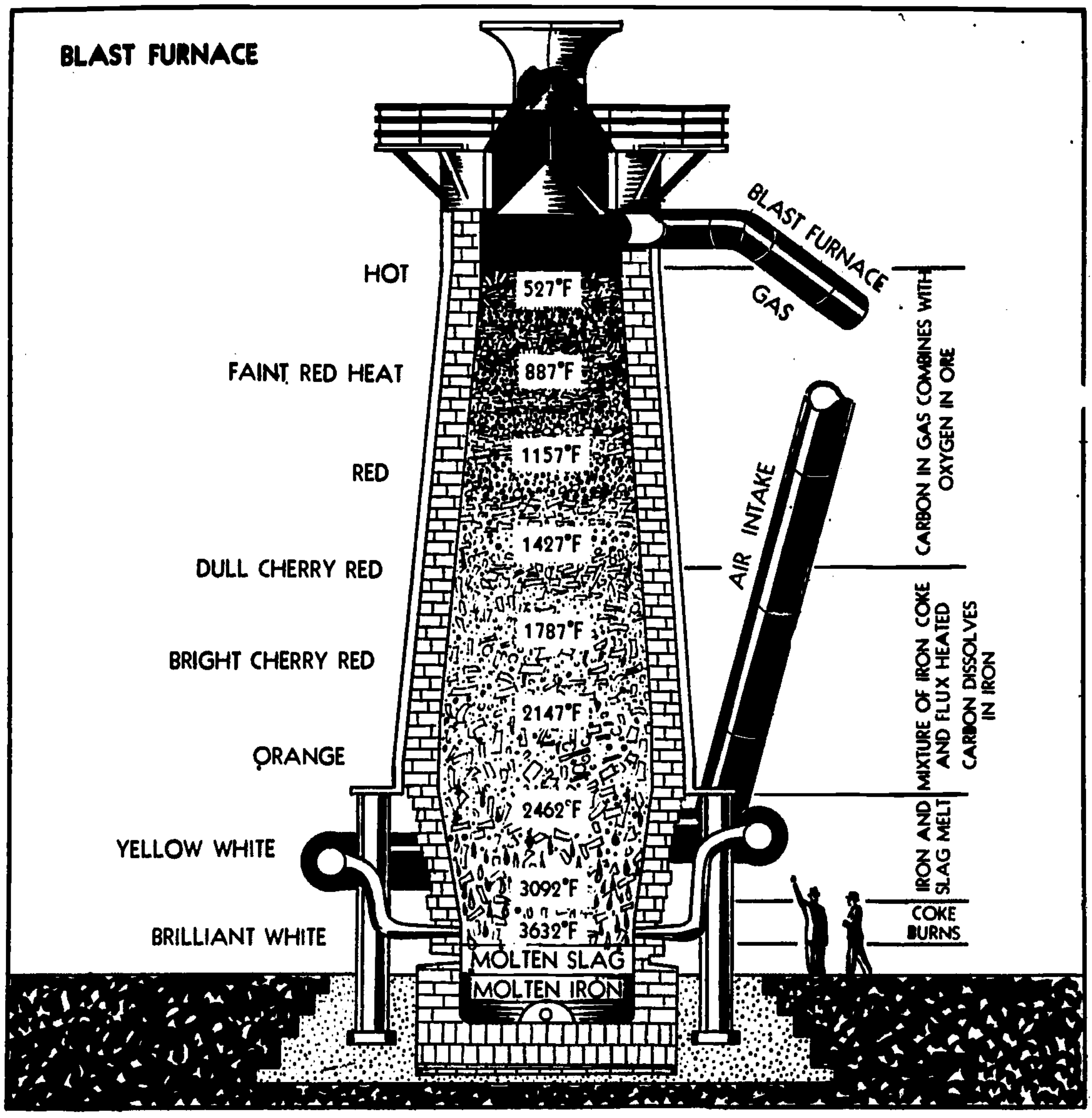


Fig. 2-114

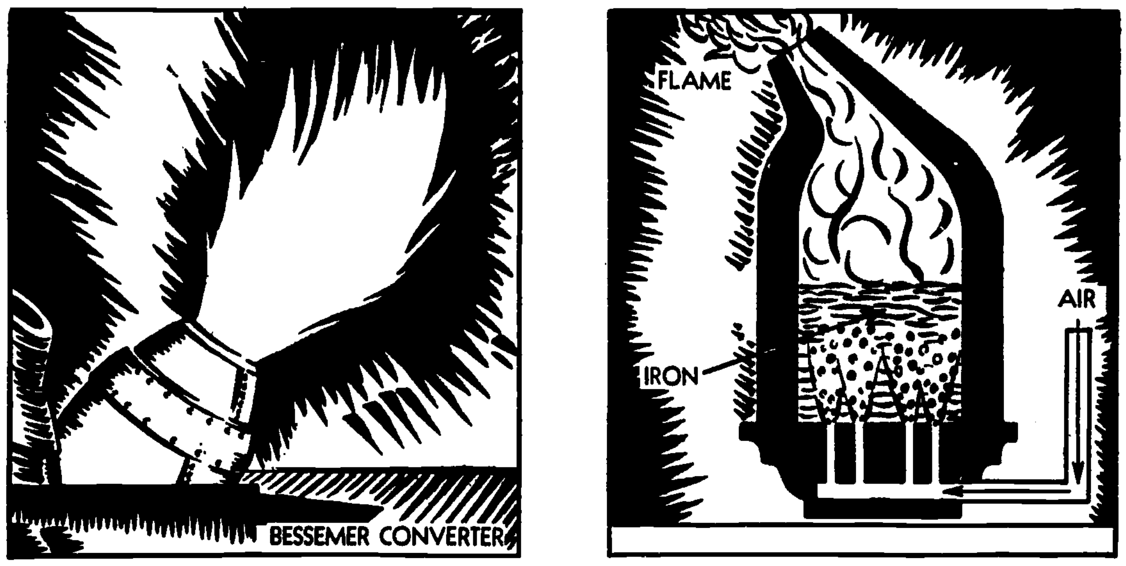


Fig. 2-115

One way of taking carbon out of pig iron is by blowing air or oxygen through it in a converter, while it is a white-hot liquid.

After 10-15 minutes most of the carbon has burned out, leaving steel.

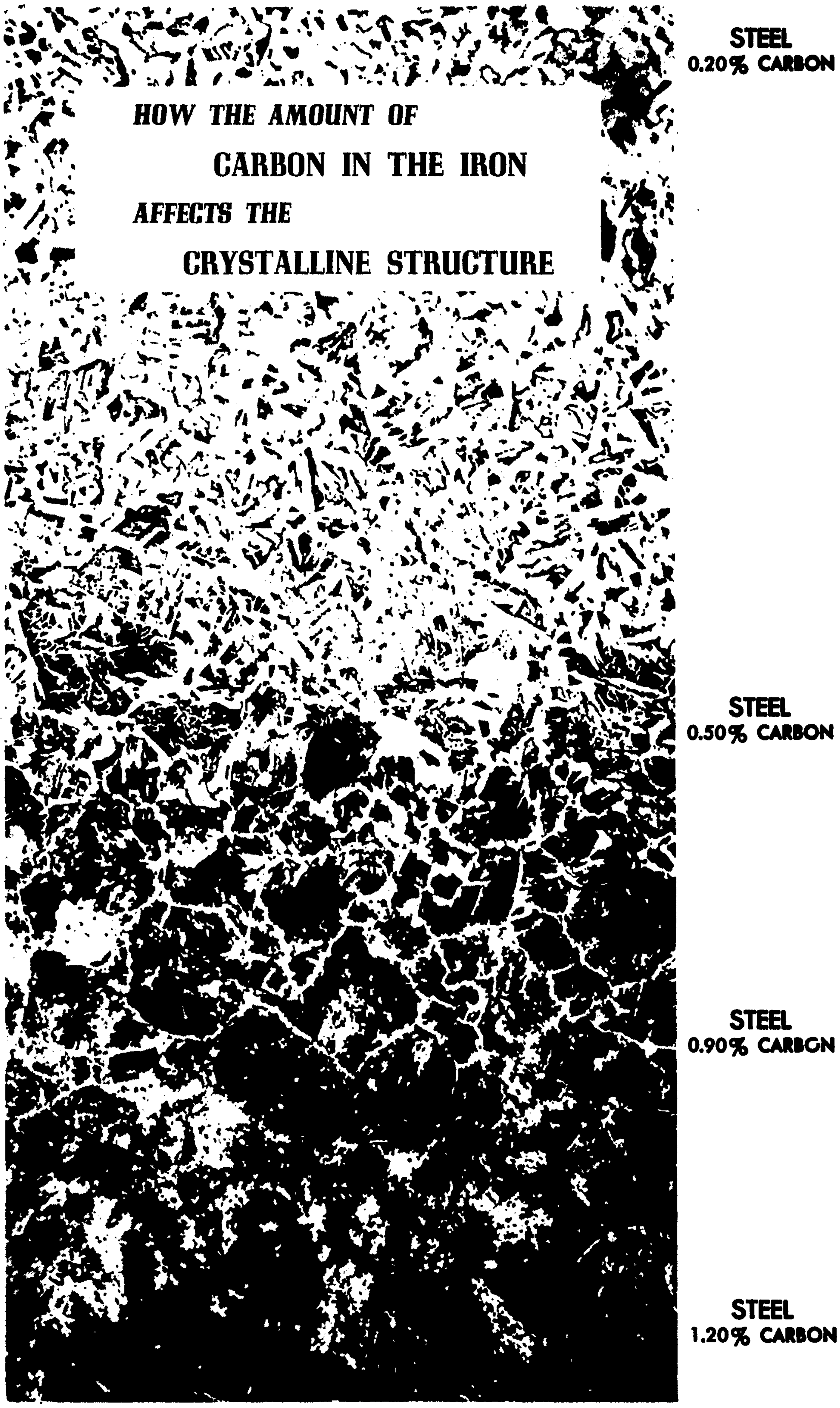

HOW THE AMOUNT OF
CARBON IN THE IRON
AFFECTS THE
CRYSTALLINE STRUCTURE
STEEL
0.20% CARBON
STEEL
0.50% CARBON
STEEL
0.90% CARBON
STEEL
1.20% CARBON

Fig. 2-116

Steel is made up of fine crystals of iron, carbon, and other elements. If it is specially polished and then dipped in acid, the crystals or grains can be seen under a microscope. Fig. 2-116 shows how steels having different amounts of carbon look after this is done.

Low-carbon steels (around 0.20%) are soft, easy to roll, bend, or draw. They are used for sheet metal parts--bodies, fenders, etc. The more carbon a steel has, the stronger it is and the more it responds to heat treatment. (We'll see how that is done in a little while.)

Medium-carbon steels are much stronger than low-carbon steels and are made even stronger by heat treatment. Connecting rods, crankshafts, axles, and other strong parts are made of these steels.

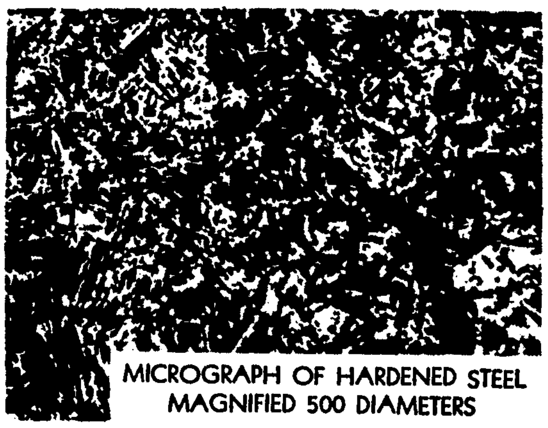
High-carbon steels, having about 1% carbon, get very hard and stiff when heat-treated. They are used for ball bearings, springs, files, and cutting tools.

Alloys are mixtures of several metals that have been melted together. They are better in some ways than the original metals by themselves. Alloy steels are steels to which have been added manganese, nickel, chromium, or other metals. Adding even a few percent of other metals can make steels that are stronger, tougher, more wear - or corrosion - resistant, or better at high temperatures. Some uses of alloy steels were shown in Fig. 2-92.

Heat treatment. You can make a piece of steel quite soft or very hard by heating and cooling it. If steel is cooled very slowly from high temperatures, the crystals that form will be coarse, flat ones, as in Fig. 2-117 (greatly magnified). The light layers are soft iron; the dark ones are very hard iron carbide, that can slide past one another in the weak iron layers. If the steel is cooled from a high temperature rapidly, by quenching in water or oil, the crystals will be jumbled, as in Fig. 2-118. Here the iron carbide meshes every way and makes the steel strong and hard. Medium-carbon steels are used for high strength, and high-carbon steels for the fullest hardness.

Fig. 2-117

Quenching leaves stresses in steels, which may lead to cracks and breaking. By tempering, which is a process of reheating the steel to 400° F. or higher, the stresses are relieved. At higher temperatures the steel becomes gradually softer and tougher. All hardened parts are, tempered after quenching.



MICROGRAPH OF HARDENED STEEL
MAGNIFIED 500 DIAMETERS

Fig. 2-118

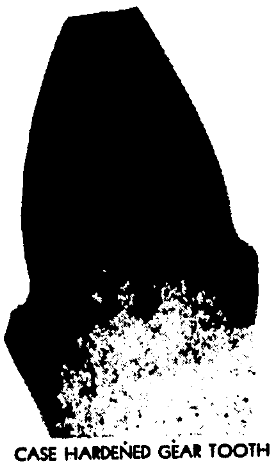
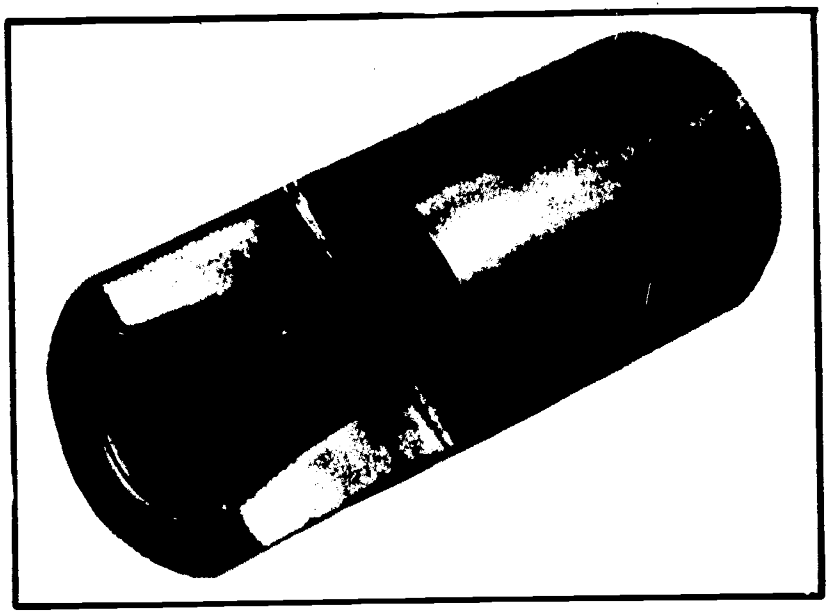


Fig. 2-119



A cutaway of a Pin, showing the uniform depth of the heat treat case.

Fig. 2-120

Carburizing and case-hardening. When a steel part like a gear or camshaft must be very tough against shocks and hard enough to resist wear, the outside of it can have its carbon increased by carburizing. One way of doing this is by heating it to yellow heat with charcoal. The charcoal gives off gases rich in carbon. At the high temperatures of this process, the carbon soaks into the steel at a rate of several thousandths of an inch an hour. Where the carbon has soaked in a high-carbon steel case forms (Figs. 2-119, 120). The part can be quenched and hardened on the outside, yet the low-carbon core is always soft and tough.

CAST IRON

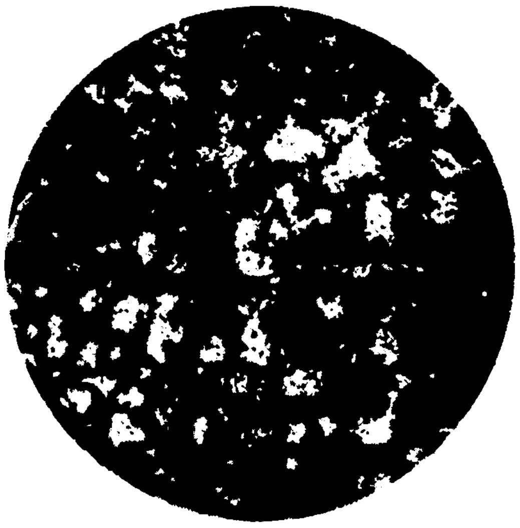


Fig. 2-121

MALLEABLE IRON

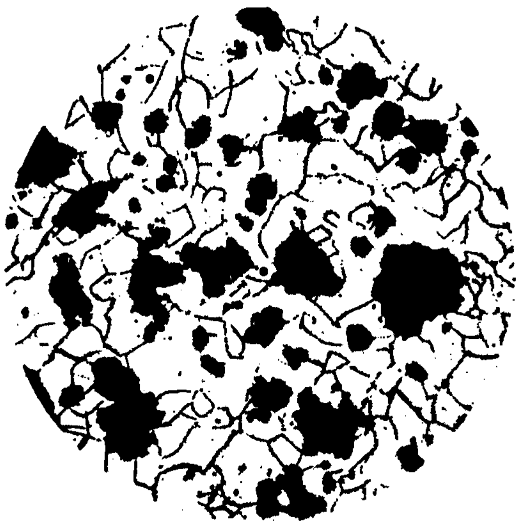


Fig. 2-122

Cast iron. Many odd-shaped parts are easier to make by casting than any other way--cylinder blocks, heads, pistons, manifolds, water-pump cases, etc. Cast iron is cheap and wears well, but it is not very strong. It is brittle and cannot be hammered or formed. This is because ordinary grey cast iron contains so much carbon that some of it forms flakes of graphite, which are weak, like the lead in a very soft pencil. Under the microscope the graphite shows up as black lines. If grey cast iron is hammered, it splits easily through the graphite flakes; only a little of the iron itself has to break.

In certain cast irons the graphite is clumped into balls (Fig. 2-122) by heating the iron in a furnace again. This is malleable cast iron. It is tough and strong enough for wheel hubs, differential parts, clutches, brake pedals, and other odd-shaped parts that must be strong.

EXPERIMENT 13. ELASTICITY

Rubber is valued for its elasticity--it changes shape when a force is put on it, and when the force is taken off, it goes back to the shape it had before.

In this experiment you will try to find out to what extent the stretching of a piece of rubber depends on the amount of pull.

MATERIALS: Rubber bands, metric ruler or meter stick, slotted or hooked weights, graph paper, sheet steel, ring stand.

PROCEDURE:

1. Prepare a page in your notebook to record the data. Use a table like this:

(Two students work together).

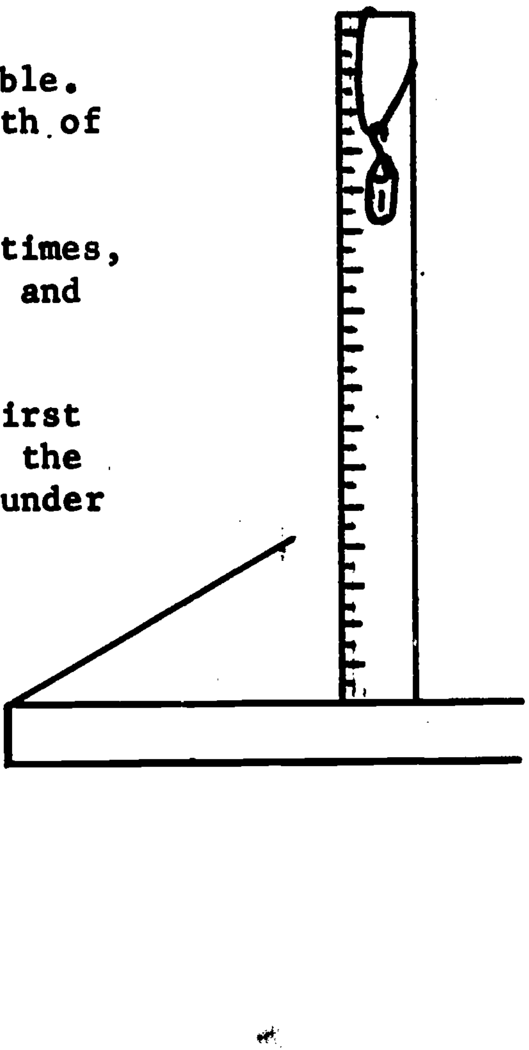
Load		Length		Stretchability
Grams	Change	Cm.	Change	Change, length change, load

Do not close off the bottom of the table, for you do not know how long it needs to be.

2. Stand the ruler, zero end up, at the edge of the table. Hang a rubber band on its upper end. Measure the length of the band and record it. The load is 0.

3. Put a 100 gr. weight on the band. Jiggle it a few times, noting its length each time. Record the average length and the load.

4. Subtract the first load from the new one, and the first length from the new one. Record these changes. Divide the change in length by the change in load and record this under Stretchability.



5. Add more loads, 100 or 200 grams at a time, recording the data each time as before. Do this until the band does not stretch much more. Then remove the weights.

6. Make a graph of the data, with load across the bottom and length up the side.

7. Optional: Run through the experiment again with the same band. This time you may go faster by increasing the weight 200 or 500 grams each time. Graph these data on the same paper as the first set, but using a different symbol....If you have time, you may do the experiment with a different size band, or compare data with other students.... Mount a thin strip of sheet steel or other metal, or a stiff wire, horizontally on a ring stand. Load the end of it step by step, recording the data as you did with the rubber band.

CONCLUSIONS:

1. What is the relationship between the stretching of the band and the load you put on it?

2. Was the band perfectly elastic?

3. Can rubber safely be overloaded?

4. How is the elasticity of metal like that of rubber, and how is it different?

EXPERIMENT 14. HARDENING OF STEEL

Steel is an alloy of iron and carbon. The carbon may range from 0.1 to over 1%. The low-carbon steels are soft, while the higher carbon steels may be strong, hard, and wear resistant. Steels having over 0.4% carbon are usually heat-treated to bring out fully their strength. This is a three-step process:

1. Heat above a certain temperature.
2. Quench, that is, cool rapidly in water or oil.
3. Temper by mild heating, to take out stresses.

In this experiment you will find out how hot a steel has to be for successful hardening, by quenching pieces from various temperatures. The metal will be hot enough to glow (red hot) and this color is a useful gauge of temperature. For accuracy, though, you will use a thermocouple with an electric meter.

MATERIALS: Furnace with thermocouple control; water bucket; specimens of plain carbon tool steel about ½ x 1"; iron wire or long tongs; tool-steel scriber stock or the equivalent; Rockwell tester; belt sander or grindstone.

PROCEDURE:

1. An hour before the experiment is to start, set the furnace at 1200°F. and turn it on.

2. Prepare a page in your notebook with a table like this: (Write the temperatures in with a pencil, as you may use somewhat different ones.)

Temperature, F.	Unheated	1200°	1300°	1400°	1500°	1600°
Specimen No.						
Hardness, RC (before cleaning)						
(after cleaning)						
Average						

3. Put two specimens of the steel in the furnace; ask your instructor whether to tie wire to them or whether you will use tongs. Put a bucket of water on the floor in front of the furnace.

4. When the electric pyrometer shows the furnace temperature is 1200°, and the metal is the same color as the thermocouple, take a piece out and quench it quickly. If tongs are used, grip it by a surface you are not going to test. In the water, move it up and down but keep it under the surface. When it is cool, mark it with the temperature (1200°) or, if it has a number, write the number down in your chart to avoid mixups.

5. Reset the furnace to 1300° and put another specimen in.

6. While the furnace is heating, measure the hardness of the first piece on the Rockwell tester at three places on a clean face. (Your instructor will show you how to do this.) Grind a little off the same face to get down to fresh steel, without grinding long enough to heat the metal. Retest the surface three more times. Average the last group of results. While waiting, also test a piece of unhardened steel.

7. As soon as the furnace is at 1300° and one piece of steel is at the same color as the thermocouple, take it out and quench it as before. In the same way quench pieces from 1400°, 1500° and 1600°. Each time you reset the furnace, add a second piece of steel to the one already there. Complete your data table.

8. In preparation for the next experiment, harden six pieces of $\frac{3}{16}$" x 2" scriber stock.

CONCLUSIONS:

1. To what temperature must steel be heated before it can be hardened?

2. Is it any help if it is hotter?

3. Can it be hardened below this temperature.

4. Why does grinding the steel give a different result?

5. Are any of the results questionable, in your mind? How do you think they might be explained?

EXPERIMENT 15. TEMPERING OF STEEL

Steel is brittle after it is hardened, almost like glass. It may break if it is hit hard or even dropped. For most uses it must be tough enough to take some shock or pounding. Tempering makes it tough.

After the sudden cooling of a quench, steel also has stresses left in it. These stresses may crack it even without its being hit. Tempering takes out these stresses. After the hardening heat treatment, steel is always tempered.

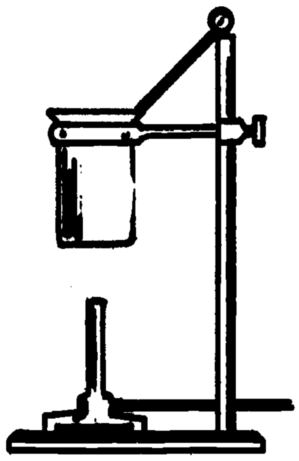
Tempering is done by heating the steel to a temperature between 400° and 800°F. This leads to a change in hardness which is easily measured with a Rockwell tester. It can also be gauged by simple tests of bendability. In this experiment you will temper several pieces of hardened steel at various temperatures, using a bath of molten salt to give controlled heat.

MATERIALS: Hardened pieces of $\frac{3}{16}$" tool-steel scriber stock or the like, about 2" long; 8 oz. stainless-steel beaker filled with heat-treater's eutectic salt mixture; burner; Rockwell tester; iron wire, about 26-32 gauge; cutting pliers; bimetallic dial thermometer (-150° to +1000°F.); hammer.

PROCEDURE:

1. Prepare in your notebook a page for recording the experiment. Use a data table like this:

Temperature, F.	--	450°	550°	650°	750°
Color					
Hardness, RC 1					
2					
3					
Average					
Bendability					



2. Get six pieces of the scriber stock that were hardened in the last experiment. If there are none, or if they do not have a hardness of RC 65 on a clean surface, harden them by heating and quenching.

3. Set up a salt bath like the one shown. Heat it to about $450^{\circ} \pm 10^{\circ}$F., stirring it gently. CAUTION: The molten salt can burn you badly. Do not let it come in contact with anything that can burn. Do not let water or any non-metallic substance fall into it.

4. Tie a piece of iron wire around four samples of the hardened rod. Be sure they are thoroughly dry. Hang them in the bath, up off the bottom with the wires hanging out. After five minutes take the first one out and wash it with water (rate of cooling is not important). Take three hardness readings. Record and average them. Mark the piece to avoid mixups.

5. In the same way raise the temperature of the bath to 550°. After five minutes at that temperature, take out a second piece of the steel, wash it, and test its hardness. Then do a piece at 650° and 750°. Mark each piece.

6. Record the colors of the clean surfaces on each piece of the steel after tempering. Use these names for the colors:

straw (yellow)
bronze (brown)
blue

7. Mount the untempered piece in the vise so that half of it sticks up. Taking care that there is nobody and nothing breakable in the way, give it a gentle blow with the hammer. If nothing happens, hit it a little harder. Record the results of this test as Bendability in your table: easily bent, tough, brittle, etc. Do the same for each of the tempered pieces. The sixth piece may be used to recheck any questionable result.

CONCLUSIONS:

Suppose you have four screwdrivers made from tool steel. After heat treatment one has the same color it had at first, another is yellow, one is bronze, and one is blue. If you used each screwdriver to pry off parts that were rusted in place, how might each look afterward?

UNIT 3. MECHANICS

FORCES AND MOTION.

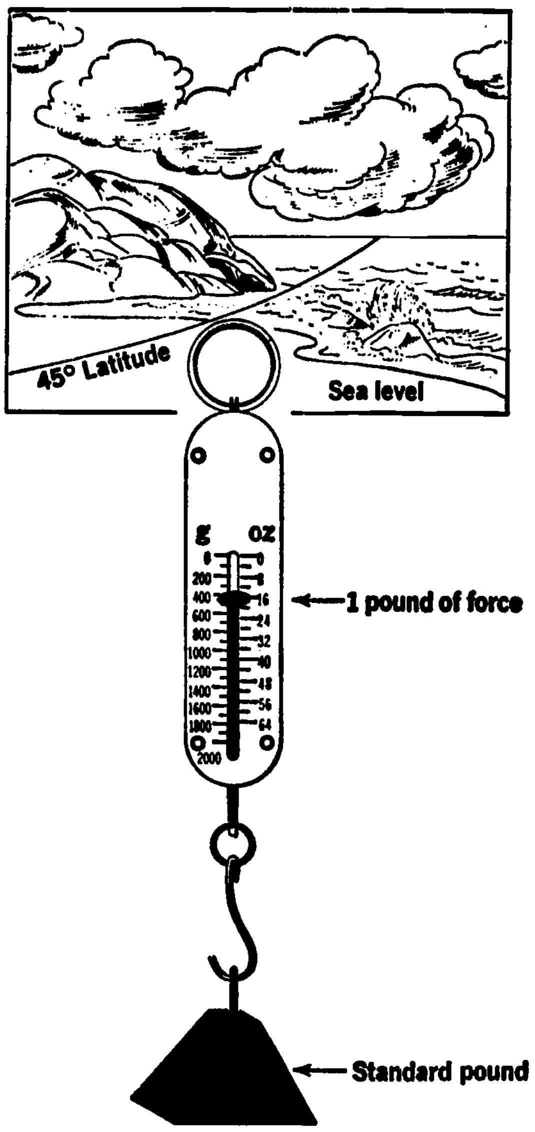
Force is a push or pull. It tends to make things move. If the thing can't move, then the force produces a stress that may bend or break the thing. You can see that force is what makes a car run. It also holds it together or breaks it up.

Forces can act on a thing without touching it. The earth's pull, gravity, even reaches to the moon and beyond. Generally, though, forces come from one thing pushing on another that it is touching.

Force is measured in pounds. The pull of the earth on a certain amount of matter is called one pound of force.

Force can be measured with a spring scale or some other device that tells how much something stretches or bends under a force.

Force not only has amount, but also direction. To show both kinds of information, an arrow can be used.



At 45° latitude and at sea level, one pound of force is needed to overcome the earth's attraction for the standard pound.

Fig. 3-1

Representing Forces by Arrows • Let an arrow (*A*) ¼-inch long represent a north force of 1 pound. (*B*) Then the arrow four times as long represents a north force of 4 pounds. (*C*) This arrow represents a northeast force of 6 pounds. (*D*) This arrow represents an east force of 3 pounds

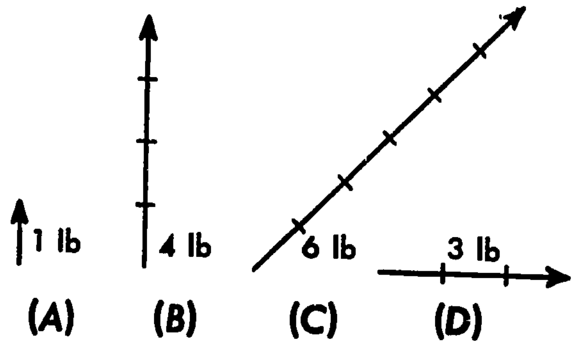
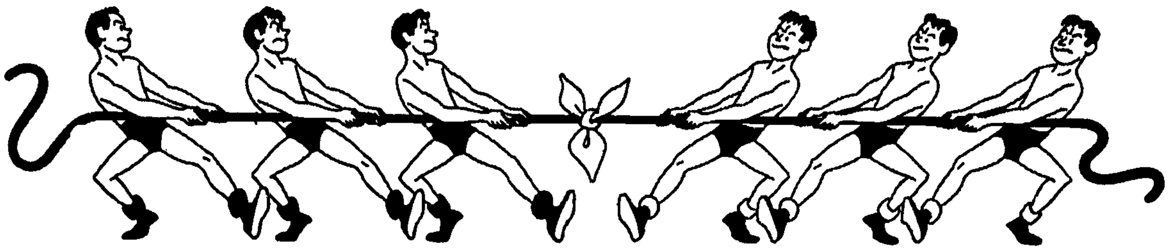


Fig. 3-2

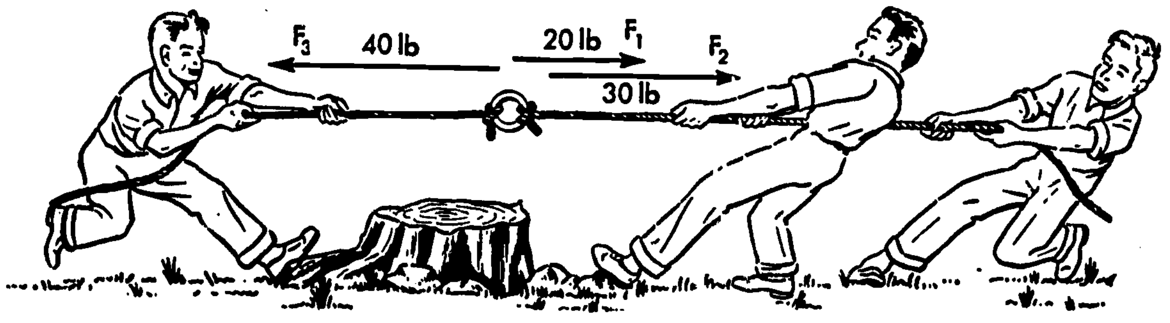
Sometimes more than one force is applied to a thing at the same time. If the forces are equal and in opposite directions, they balance each other.



A Tug of War • Balanced forces in equilibrium

Fig. 3-3

If they are not balanced, a <u>resultant</u> force acts. In Fig. 3-4, forty pounds of force pull to the left, while fifty pull to the right. The resultant force is ten pounds to the right.



Parallel forces.

Fig. 3-4

When the forces are not parallel, the resultant can be found by making a diagram with arrows, as in Fig. 3-5. If the arrows are proportional in length to the forces, and the angle is that of the forces, then the resultant is shown by the diagonal of the parallelogram.

A single force can be broken down into two component forces that have other directions. In towing a truck, as in Fig. 3-6, for example, the 750-pound force on the rope turns into a forward pull F_x (375 lbs.) and an upward pull F_y (530 lbs.).

The Arrows *OA* and *OB* Represent Two Forces • *OC* represents their resultant, the single equivalent force

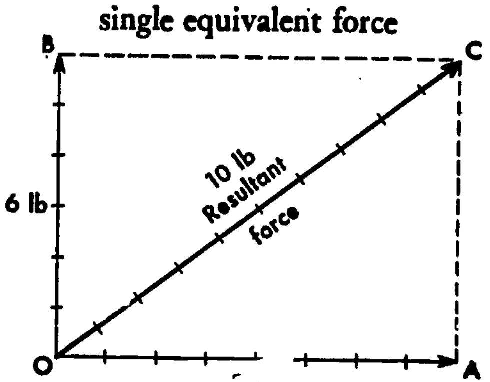


Fig 3-5

Illustration of force components.

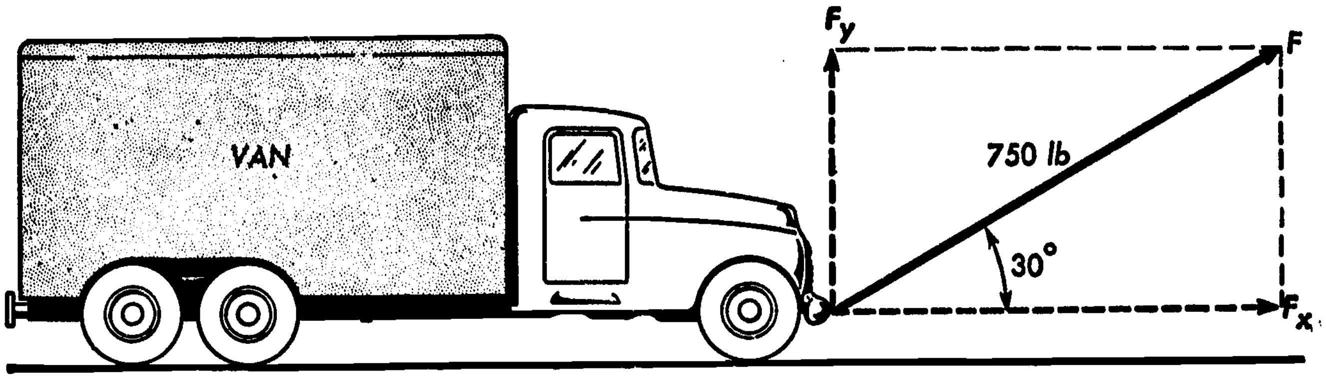


Fig. 3-6

Motion. When an object changes its place we call this motion. Motion can be in straight lines (like a piston) or rotary (like a crankshaft).

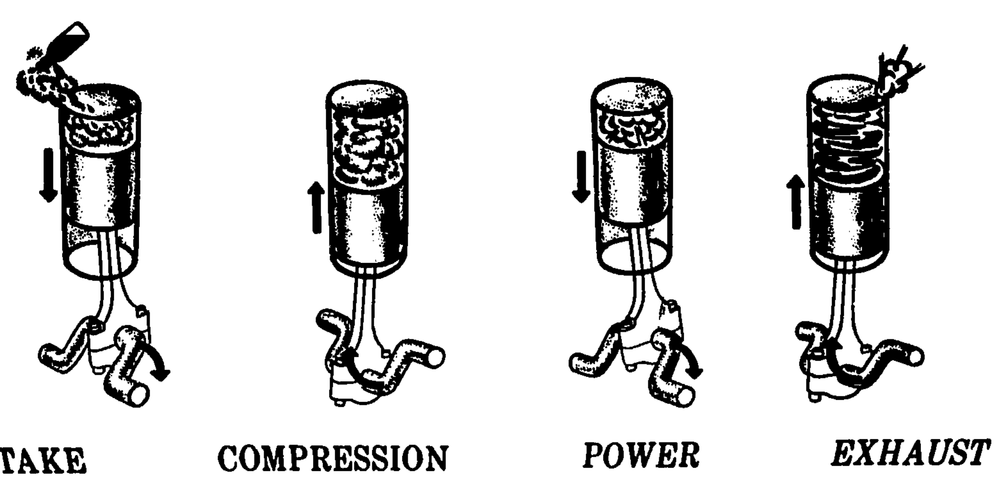


Fig. 3-7

Speed is a measure of motion--the distance traveled per second, per minute, or per hour. Motion also involves direction. For example, in telling about the movement of a piston, you not only say how fast it is going, but also its direction--whether up or down. Both speed and direction are expressed by velocity.

Rotary motion. Torque. The forces we talked about so far have tended to move things in straight lines--they are linear forces. When a force pushes on an object that is fastened at one place, it tends to make it go around or rotate. Such a rotary force is called a torque. Downward force on a piston (Fig. 3-10) turns into a torque at the crankshaft.

Torque is measured as the product of the force by the distance from the point where it is applied to the center of rotation. In testing the torque of a starter, as in Fig. 3-11, the torque is turned into a straight line force F, which is measured with a spring scale. The torque (F x D) will usually be reported in foot-pounds.

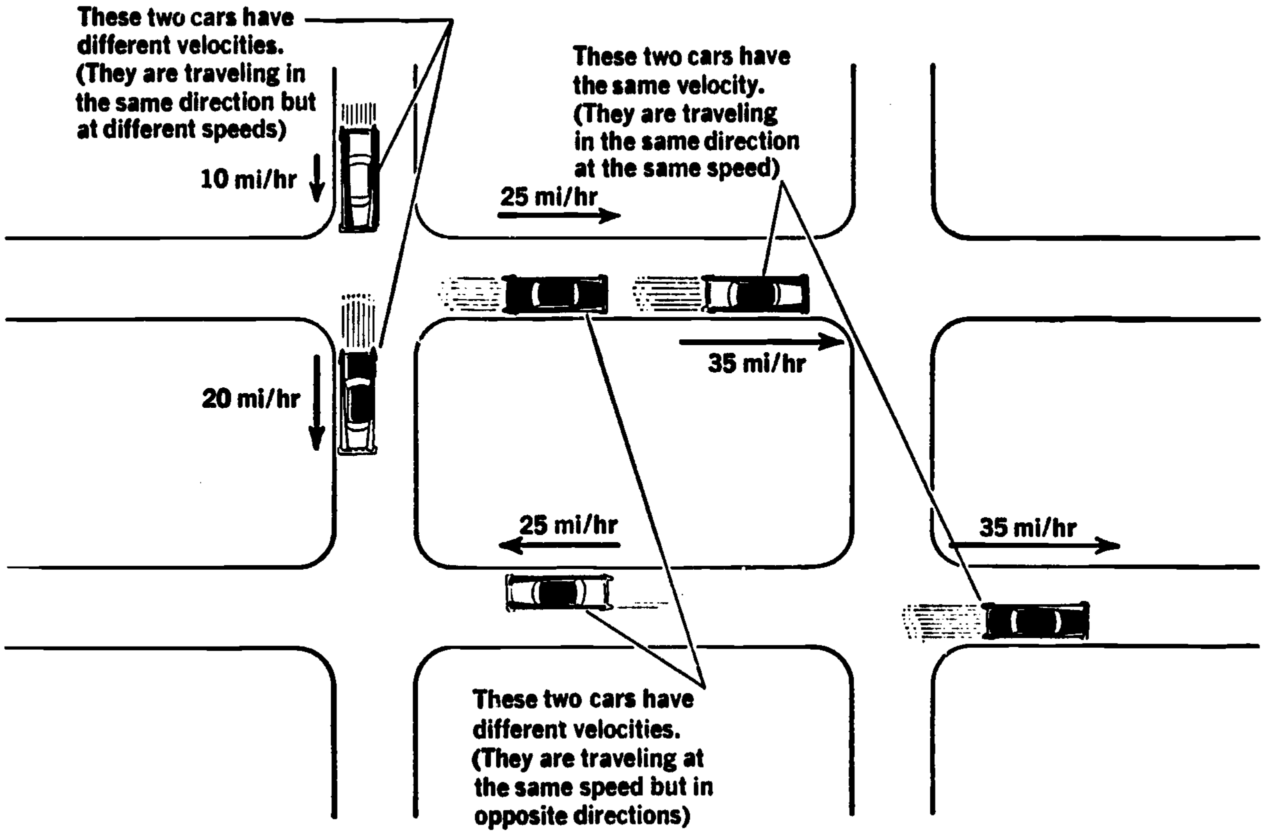
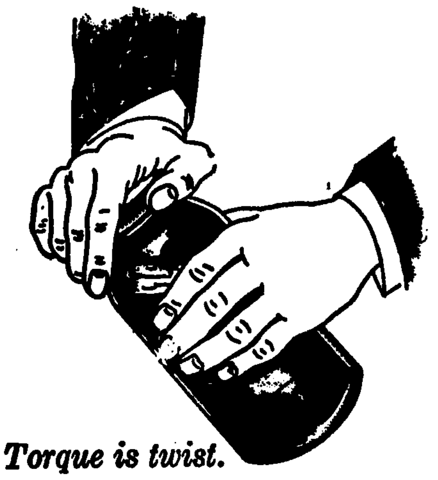


Fig. 3-8



Torque is twist.

Fig. 3-9

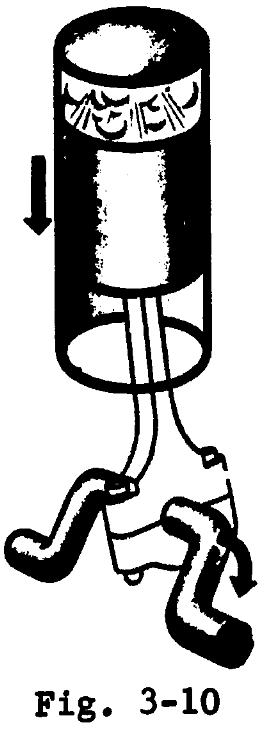
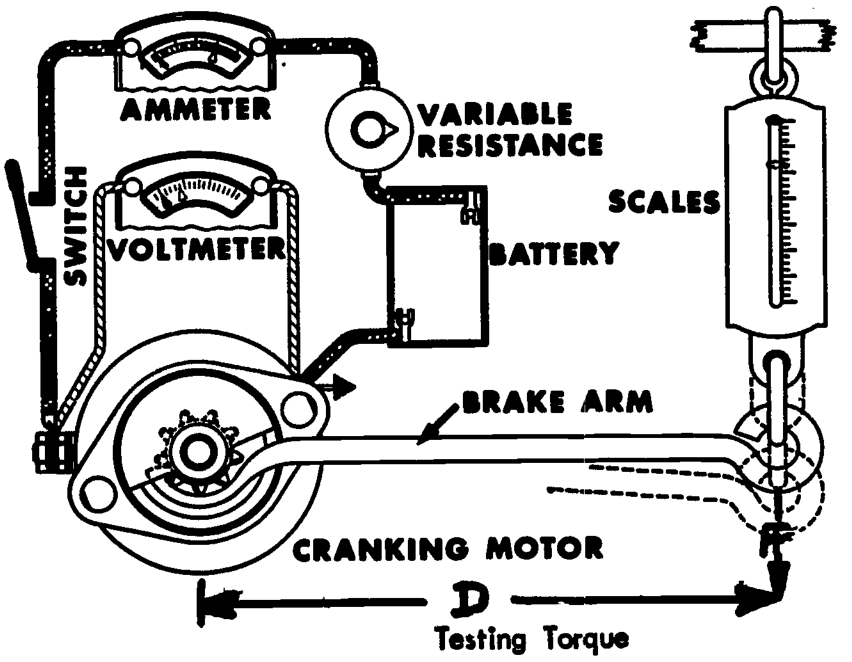


Fig. 3-10



Testing Torque

Fig. 3-11

Rotary motion also has both speed and direction. Rotary speed is generally given as revolutions per minute (rpm), but in a few cases, as with grinders where cutting depends on surface speed, it may be given in linear feet per second.

One other very common type of motion is the back-and-forth kind. This is called reciprocatry motion. Pistons in a cylinder go up and down this way. Bouncing of springs is the same kind of motion.

Back-and-forth motion is often called periodic, because there is a regular period of time for one complete swing or cycle. Periodic motion is described by its frequency--usually the number of cycles per second. Vibrations have a high frequency.

Many objects have natural periods of vibration or periodic motion. The pendulum is one example. Its frequency (Fig. 3-13) depends only upon its length; you cannot make it swing faster or slower by itself.

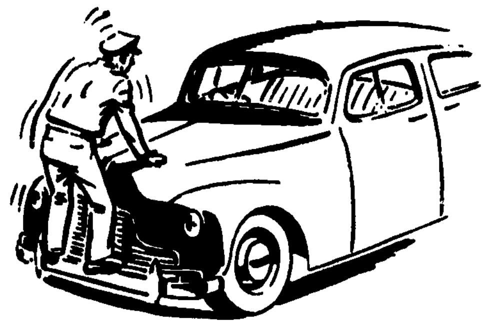


Fig. 3-12

To double the period of a simple pendulum the length must be increased fourfold.

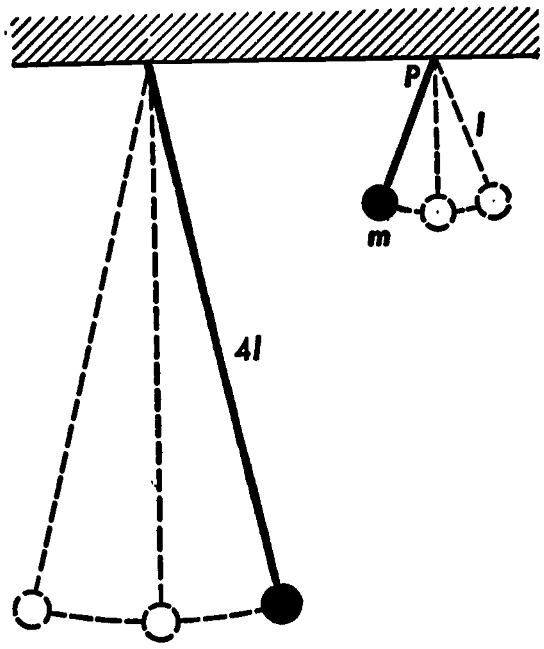


Fig. 3-13

Two types of spring pendulums.

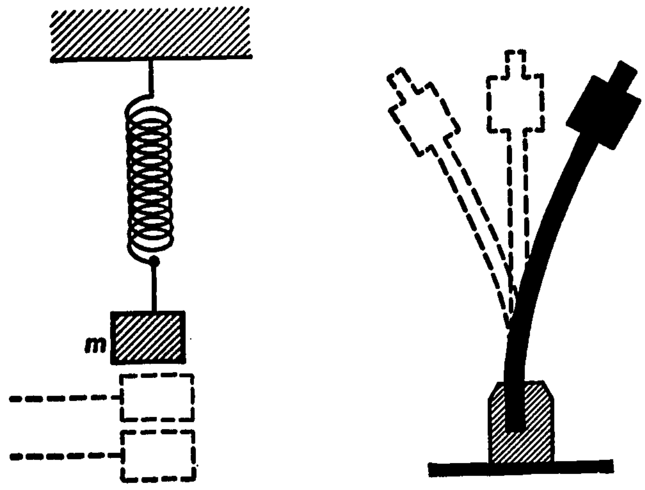


Fig. 3-14

When a load is put on a part that can stretch or bend, it acts like a "spring pendulum." It will have a natural period of vibration depending on its stiffness and weight.

Vibration permits small forces to do much more damage than they can do standing still. A crankshaft will vibrate, bending one way on the power stroke and the other way on the other strokes. This can build up more and more, if the engine is run at its natural frequency of vibration, until the shaft can break. A vibration damper (Fig. 3-15) is used to prevent this.

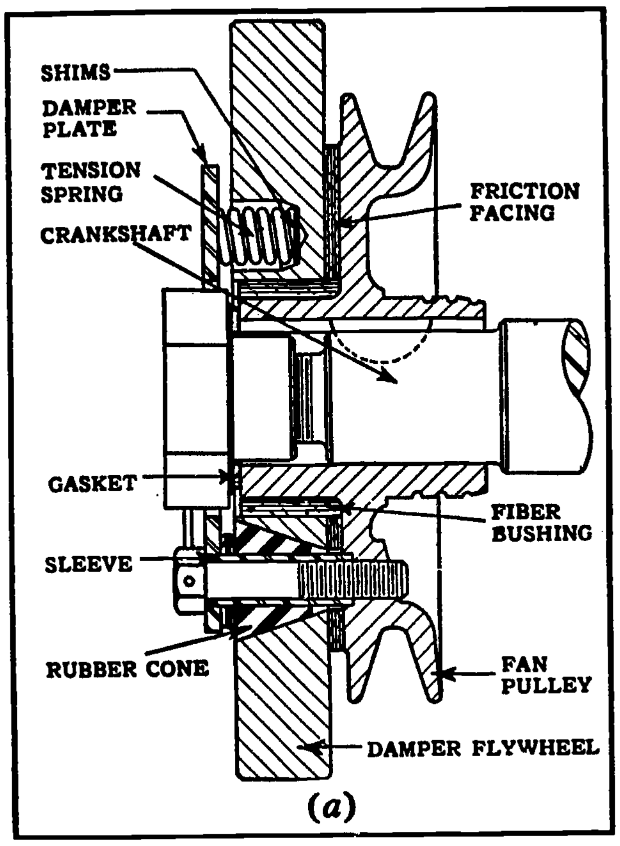


Fig. 3-15

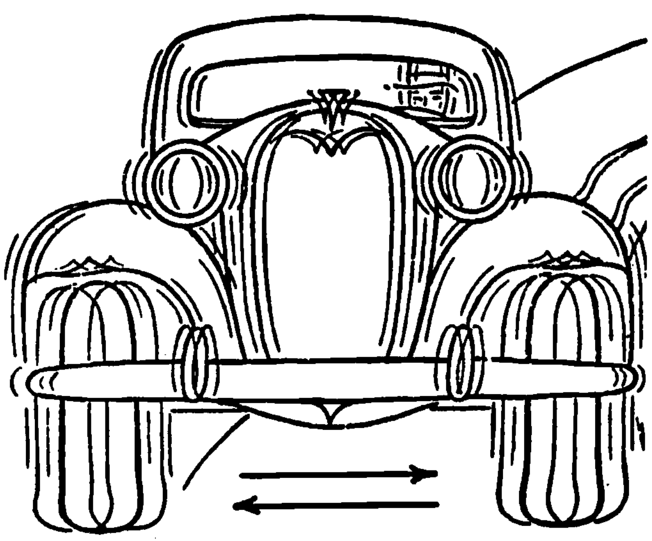


Fig. 3-16

Wheel shimmy is another example of vibration at a natural frequency.

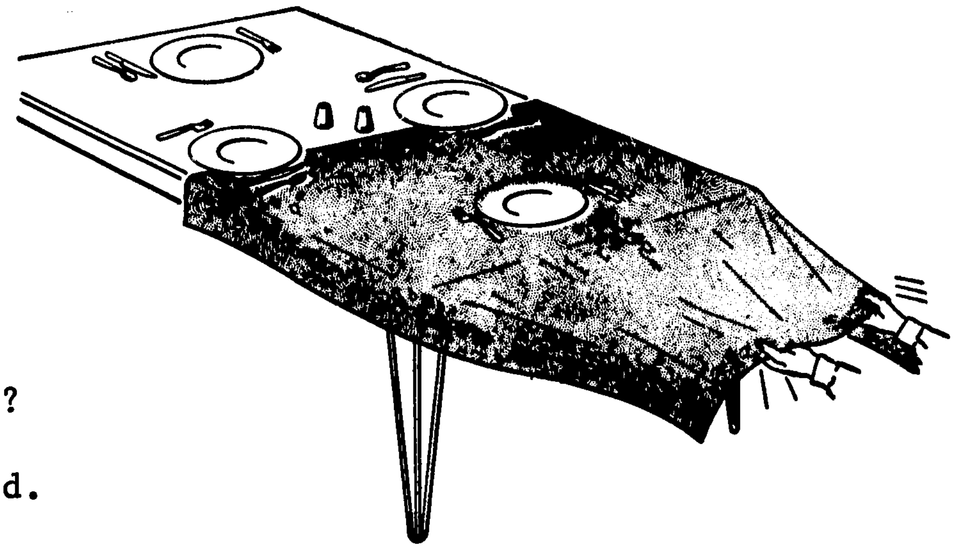
Vibration which may seem harmless can do damage in several ways. When a part is bent back and forth many times, it weakens. Over months and years a scratch can grow into a crack, and a crack into a break. Even parts that are flawless have a "fatigue limit."

Wear may come rapidly from vibration. Steering linkages which should move only when making a turn, have to move hundreds of times a minute when wheels shimmy. This causes ball joints and tires to wear much faster.

Noise is another effect of vibration. It is like a fever or sore throat--it may bother you, but it helps the doctor find out what's wrong. You have probably noticed that heavy parts vibrate slowly and give a low sound; light ones have higher frequencies--a rattle.

Inertia. The tablecloth trick that you see in Fig. 3-17 shows one of the most important facts about matter: it tends to stay where it is.

What happens to you when you are in a car that starts to move suddenly? Your body presses against the back of the seat. Why? Because it tends to stay where it is, even though the car has started.



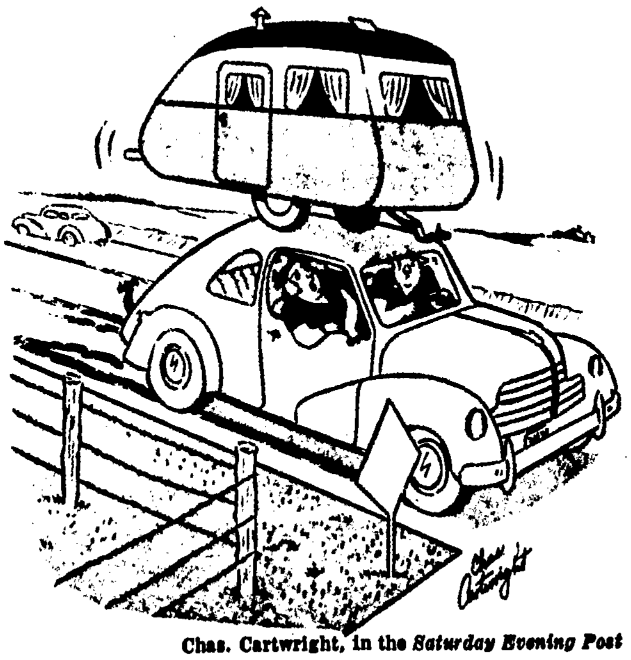
A tablecloth can be pulled from a table without dislodging the dishes.

Fig. 3-17

This tendency is called inertia. The inertia of a body is due to the mass (amount of matter) it contains. Since gravity's pull is proportional to the mass of a body, mass is usually measured as weight. The inertia of a resting body (here on the earth's surface) is equal to its weight.

Inertia also tends to keep things moving, once they have been started (Fig. 3-18). We say that a moving object has momentum.

What happens to you when you stop your car suddenly? Your body moves forward (it "wants" to keep moving) and may even strike the windshield if the stop is sudden enough.



Chas. Cartwright, in the *Saturday Evening Post*

"I Warned You about Stopping Too Quick"

Fig. 3-18

Momentum of a fluid (gas or liquid) can be used to run a turbine, which is a wheel with blades, as shown in Fig. 3-19. The momentum of the fluid, coming through the nozzle at high speed, pushes on the blades and forces the wheel around.

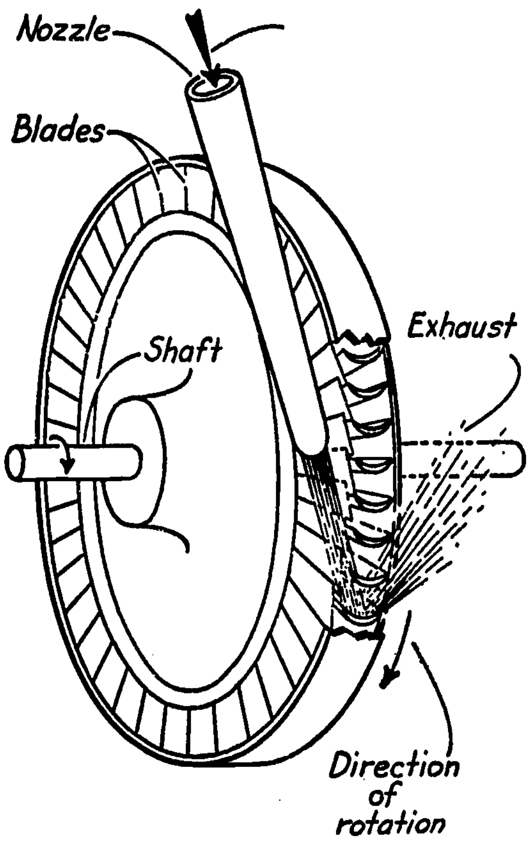


Fig. 3-19

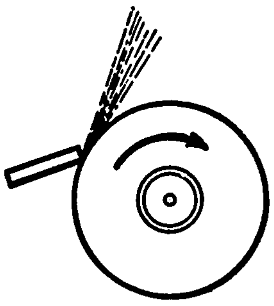
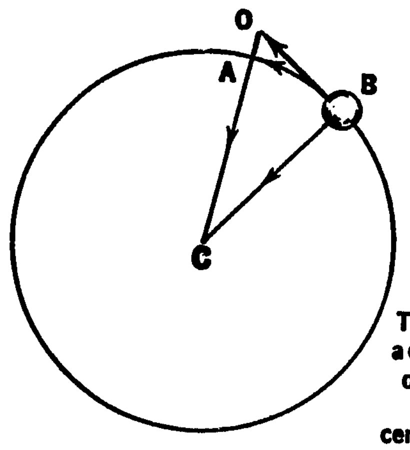


Fig. 3-20

Centrifugal force. A moving object tends to keep going in a straight line, like the sparks from a grinding wheel. If you tie a string on a ball and swing it in a circle, it tries to go off on a straight line OB. To hold it in a circle, you have to pull on the string. (Fig. 3-21) The inward pull (of the string) that holds the ball in its circle is a centripetal force. The outward pull of the ball on the string is a centrifugal force.



Ball B tries to follow path B O. String pulls it toward center

The string exerts a centripetal force on the ball. The ball exerts a centrifugal reaction on the string

The force of the string on the ball results in circular motion of the ball.

Fig. 3-21

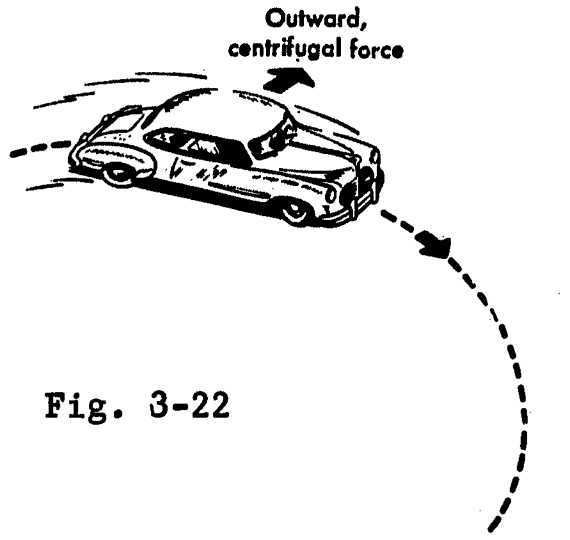

Outward, centrifugal force

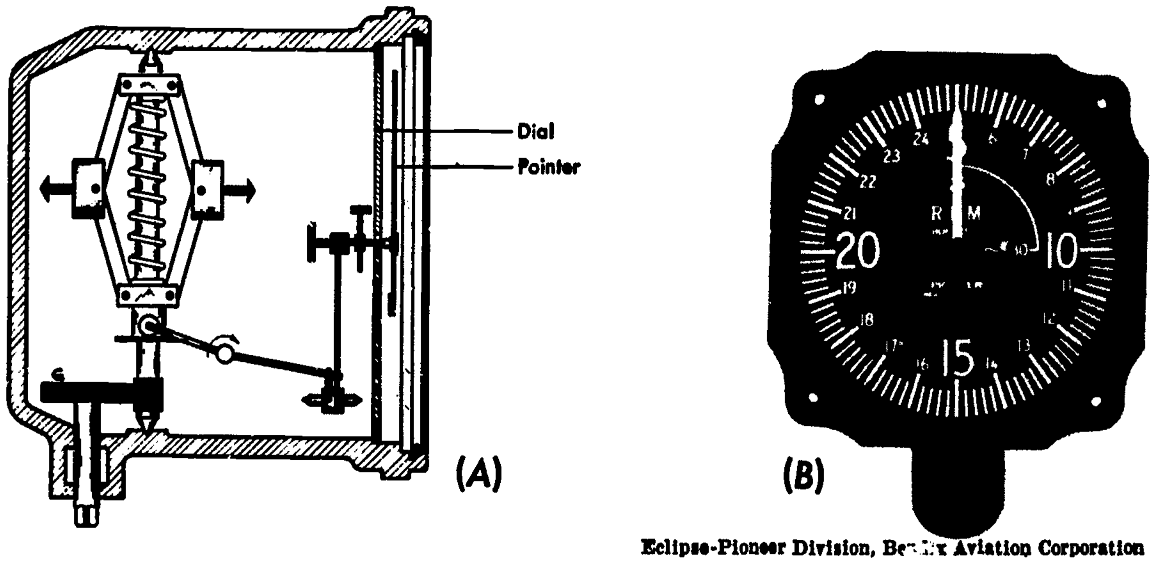
Fig. 3-22

In a car you experience centrifugal force every time you round a corner. You know how your body leans to the outside of the curve--it "wants" to continue moving in a straight line. You have to brace yourself to keep yourself upright.

The strength of centrifugal force increases as the square of the velocity:

$$\text{Centrifugal Force} = \frac{\text{mass x velocity}^2}{\text{radius of path}}$$

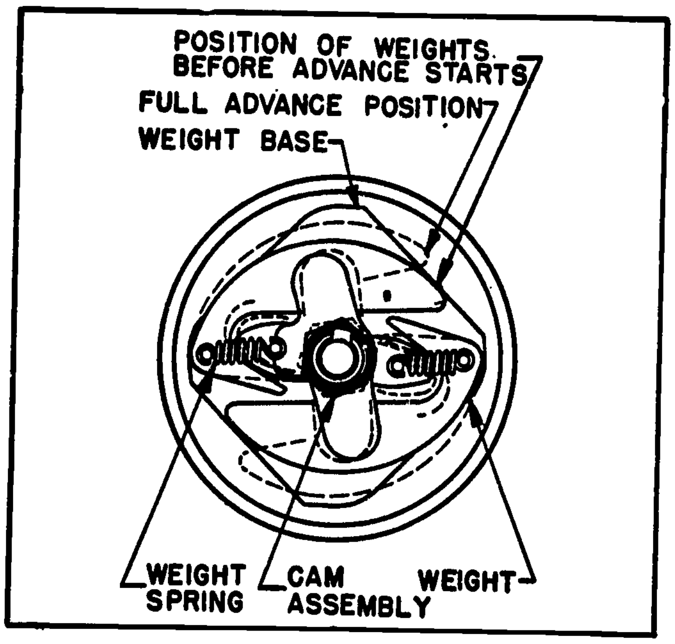
As example of the use of centrifugal force is the speed indicator shown in Fig. 3-23.



Eclipse-Pioneer Division, Be[illegible]x Aviation Corporation

Engine-Speed Indicator • As the speed increases, centrifugal force moves the metal weights apart, compressing the spring. A system of levers, pivots, and gears moves a pointer on the dial. (*B*) **The Dial Is Marked Off in Revolutions per Minute**

Fig. 3-23



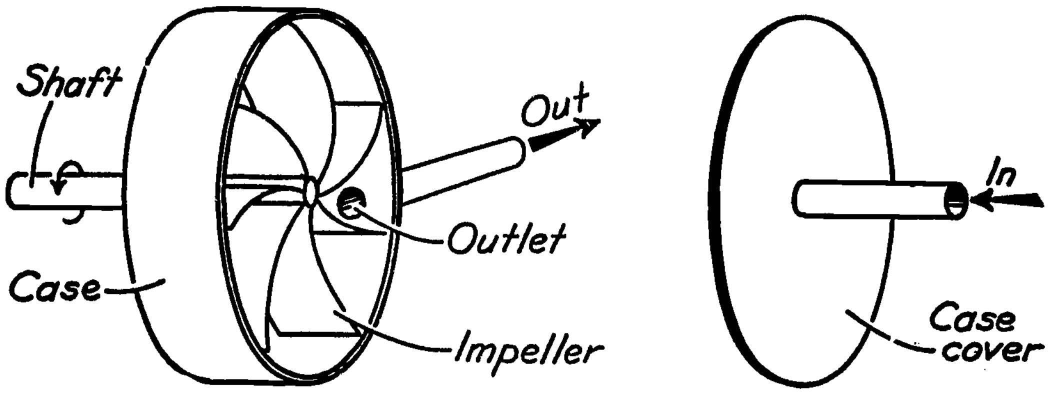
General Arrangement and Operation of a

Centrifugal force is used to advance the spark in the distributor assembly. As the distributor shaft rotates, the centrifugal weight levers are thrown outward causing the cam assembly to turn, thereby causing the spark to advance as the engine speed increases. The springs readjust the position of the cam assembly as the engine speed decreases.

Fig. 3-24

Centrifugal devices are also used to control spark advance, clutch pressure, governors in automatic transmissions, and other parts of a car.

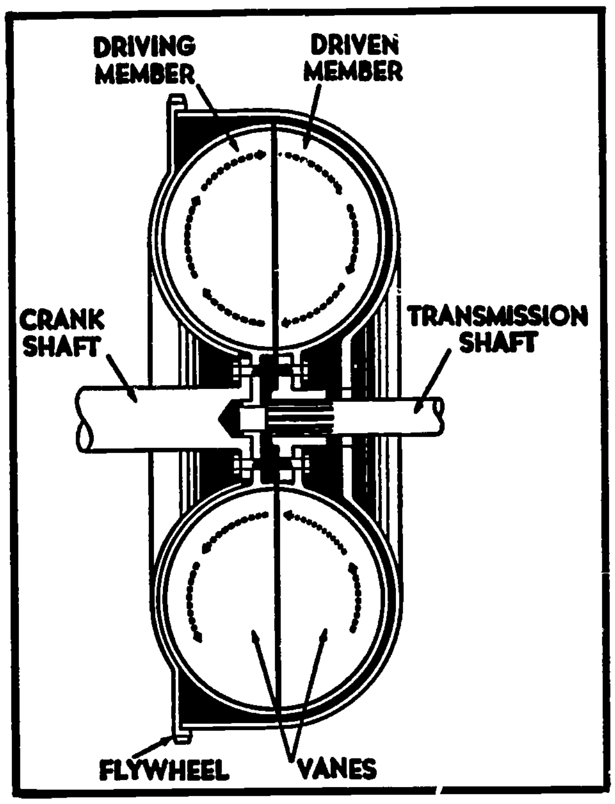
In the centrifugal pump, water enters at the center and is given a circular motion by the impeller. A centrifugal force is produced that pushes it through the outlet line.



The centrifugal pump.

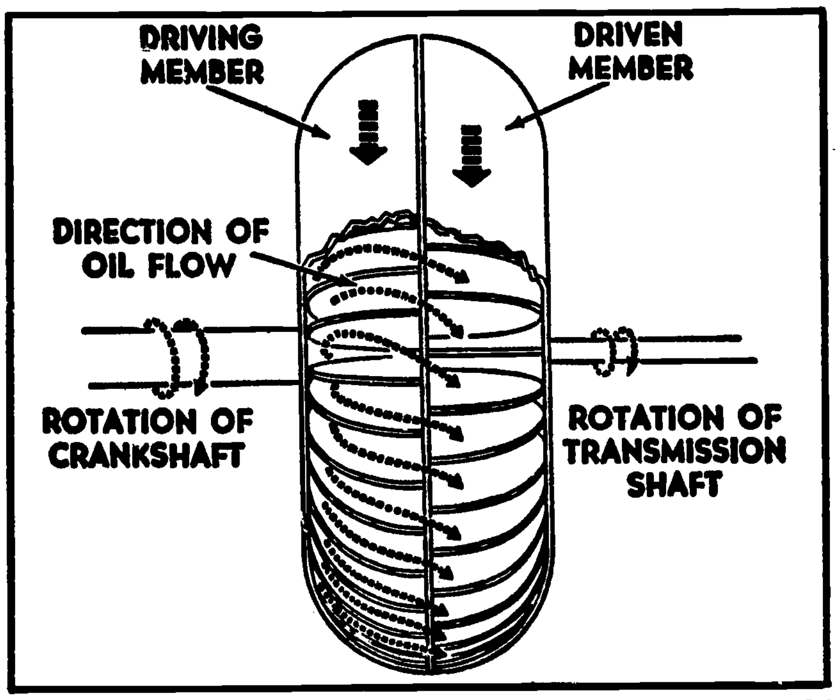
Fig. 3-25

Smooth clutch action in modern cars comes from a fluid coupling (Figs. 3-26, 3-27). It is like a hollow doughnut, sliced in two with blades or vanes in it, and filled with oil. One part (driving) is turned by the engine. Oil is thrown to the outside by centrifugal force. It passes across into the driven half, where its momentum pushes on the vanes and causes that part to turn. A torque converter works on the same principle.



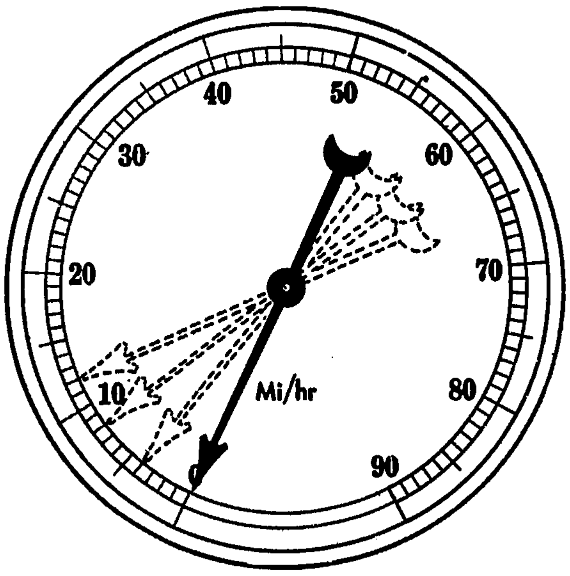
Cross-sectional view of a fluid coupling. (*Studebaker-Packard Corporation*)

Fig. 3-26



Fluid coupling in action. Oil is thrown from driving into driven member. Outer casings have been cut away so that vanes can be seen. (*Studebaker-Packard Corporation*)

Fig. 3-27



Acceleration • If the speedometer reading changes from 0 miles per hour to 12 miles per hour in 3 seconds, the car accelerates $12 \text{ mi/hr} \div 3 \text{ sec} = \frac{4 \text{ mi/hr}}{\text{sec}}$

Fig. 3-28

Acceleration. Change in velocity is called acceleration.

It is calculated from

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

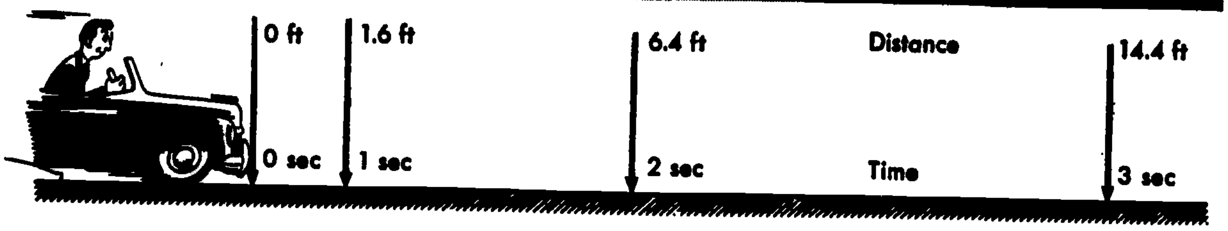
Its units are ft./sec./sec. or mi./hr./sec.

At a steady velocity, the distance covered is:

$$\text{distance} = \text{velocity} \times \text{time}.$$

If velocity increases, Fig. 3-29 shows how the distance traveled goes up as the square of the time:

$$\text{distance} = \tfrac{1}{2}\ \text{acceleration} \times \text{time}^2$$



Distance—Time • The car travels four times as far in 2 seconds as in 1 second. Distance traveled from rest varies as the *square* of the time

Fig. 3-29

Slowing down, or deceleration follows a similar rule. It takes a much longer time to decelerate from 60 m.p.h. to zero (full stop) than from, say, 40 m.p.h. to zero. Again, the distance traveled while decelerating varies as the square of the time. You can see why you need great distances between your car and any possible hazard when you are going fast.

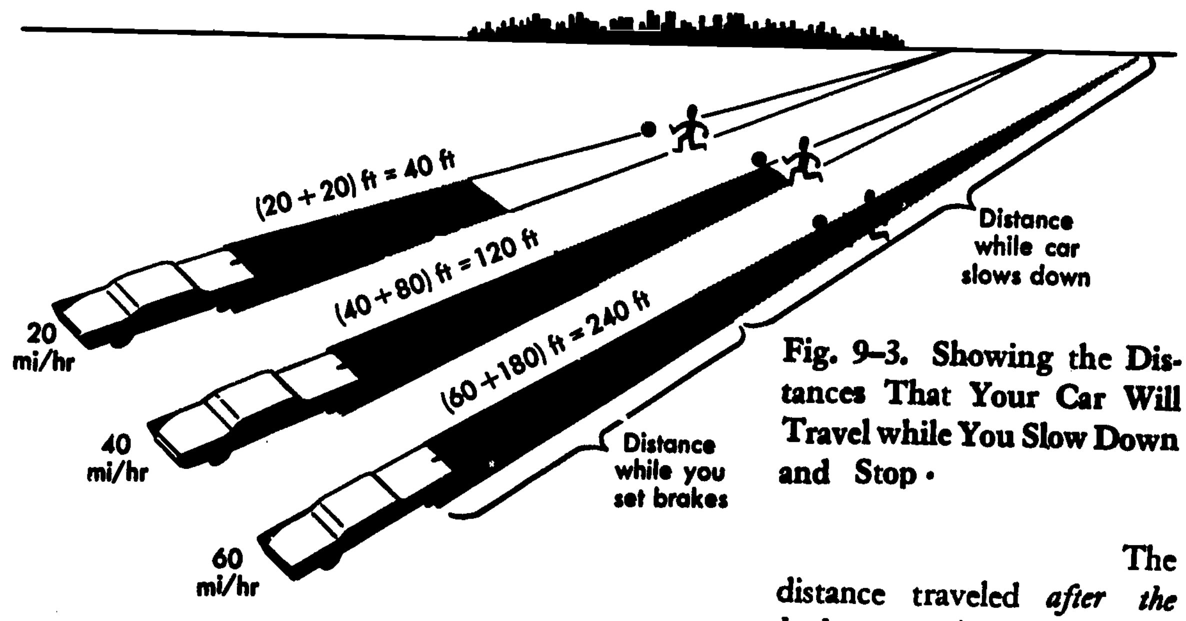


Fig. 9-3. Showing the Distances That Your Car Will Travel while You Slow Down and Stop • The distance traveled *after the brakes are set* is proportional to the square of the initial velocity

Fig. 3-30

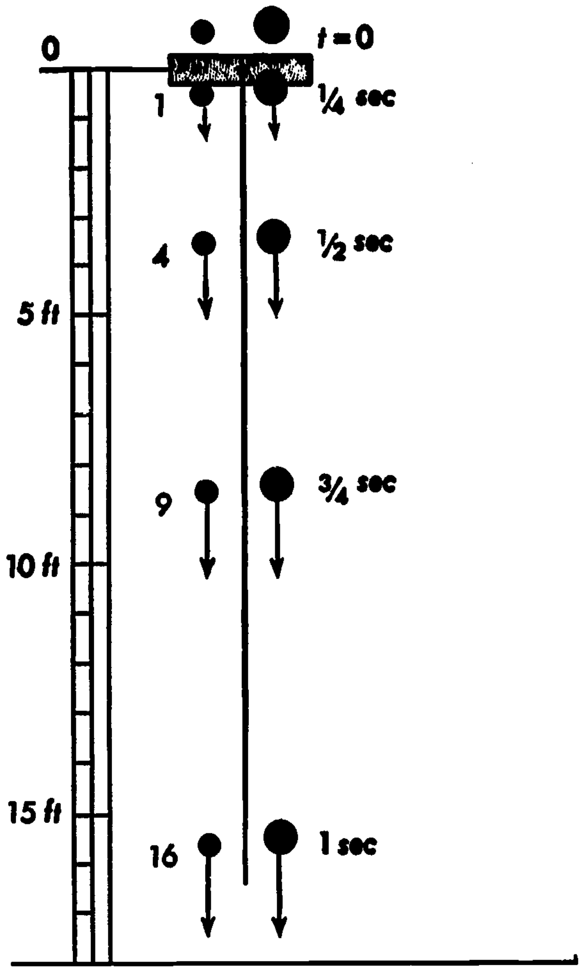
Force and acceleration. Perhaps you think that a heavy ball dropped from a high point will fall faster than a light ball. If you do, you are wrong. All freely falling bodies fall at the same rate--a constantly accelerating rate. Starting from rest, the rate of accelerating is 32 ft./sec./sec. This rate is given the name "g" (for gravity).

1 g = 32 ft./sec./sec.

When a force is applied to a body that is free to move, as in Fig. 3-32, it will produce an acceleration also. The relationship is given by the formula

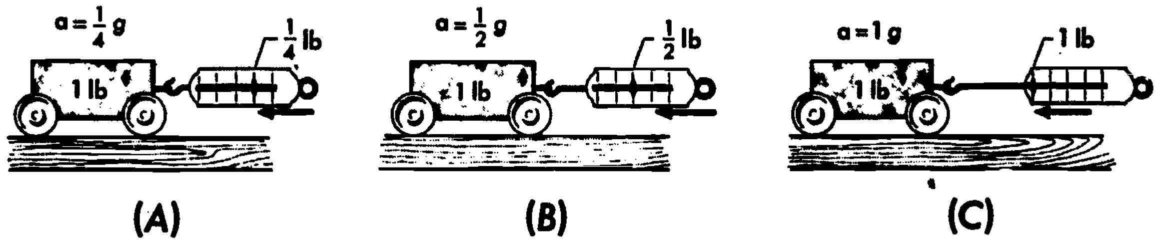
force = mass x acceleration
(lbs) (lbs) (g's)

As you can see from this formula, for any given object, a larger force will produce a faster acceleration. Also, as the weight (mass) of an object goes up, it takes more force to make it accelerate. When the number of pounds of force equals the weight of the object, the acceleration will be 1g, or 32 ft./sec./sec.



All bodies falling freely under the constant pull of gravity fall a distance of 16 ft in the first second.

Fig. 3-31



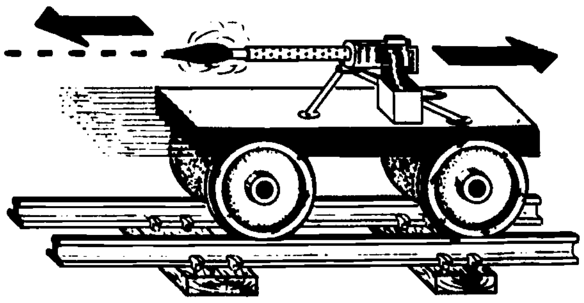
(A) (B) (C)

Acceleration Proportional to Force · (*A*) A force of $\frac{1}{4}$ pound accelerates a 1-pound car 8 feet-per-second per second, or $\frac{1}{4}$ *g*. (*B*) One-half pound accelerates it 16 feet-per-second per second, or $\frac{1}{2}$ *g*. (*C*) One pound accelerates it 32 feet-per-second per second, or 1 *g*

Fig. 3-32

Reaction. For every force acting anywhere, there is always an equal and opposing force. In other words, action equals reaction. The reaction, or "recoil" of a gun is equal to the force pushing the bullets (Fig. 3-33).

Reaction force of bullets on gun accelerates the gun toward the right

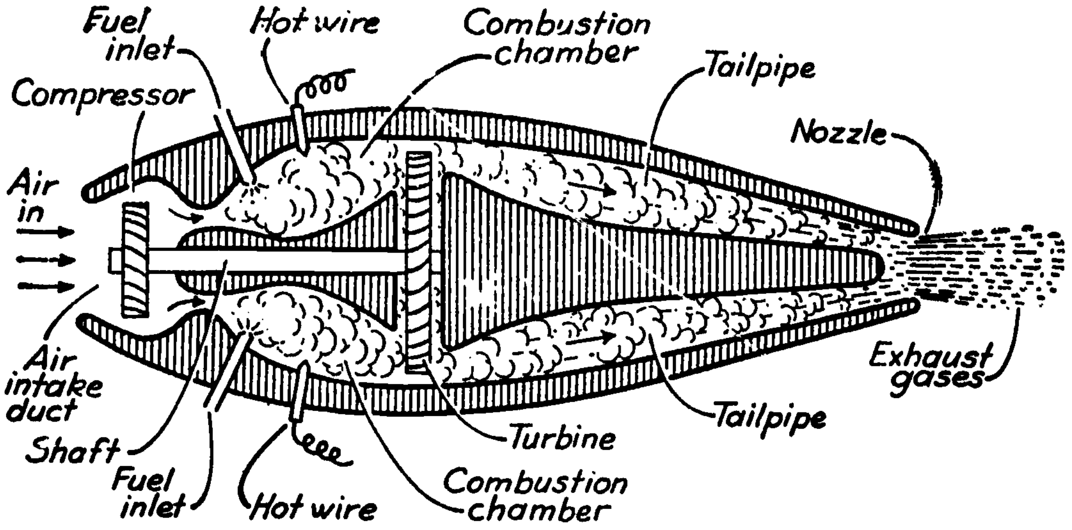


The unbalanced force of the bullets on the gun causes the gun to move toward the right with increasing velocity.

Fig. 3-33

If you suddenly let the air escape from a balloon, the balloon flies forward. What has happened? The air has rushed out with great force (the *action*), and the balloon flies in the opposite direction (the reaction). Jet planes work on this principle.

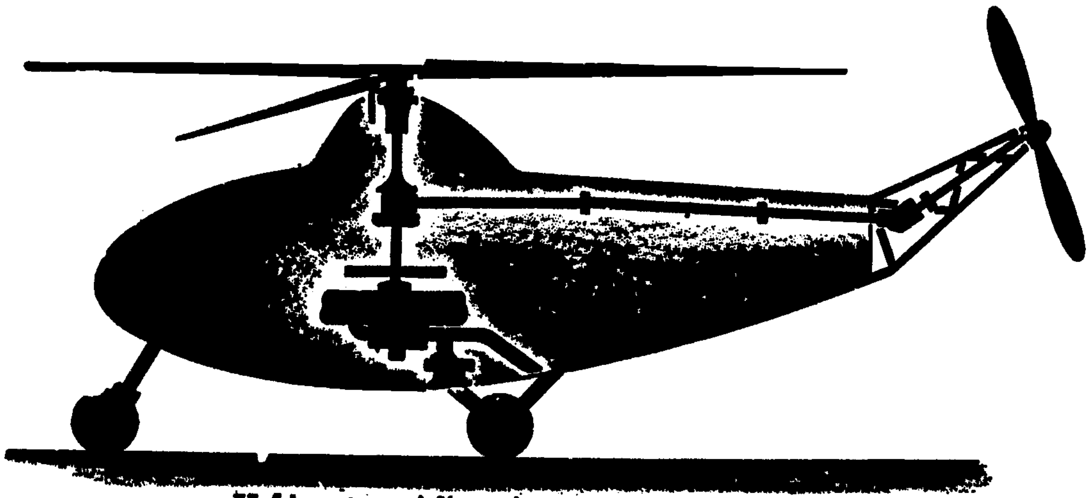
Jet engines push forward due to the reaction to the force of the exhaust gases leaving the rear nozzle at high velocity. Fig. 3-34 shows a jet engine in which the hot gases run a turbine. The turbine shaft runs a compressor which pumps in the tremendous volume of air needed to burn the fuel.



The turbo-jet engine.

Fig. 3-34

Torque reaction. When a torque is applied to cause rotation, a torque reaction pushes in the opposite direction. In a helicopter, the blade turning in one direction pushes on the 'copter, tending to spin it in the air. An anti-torque propeller can be used so the plane will stay headed in one direction.



Helicopter with anti-torque proveller.

Fig. 3-35

An engine has rubber mounts to absorb reaction torque. When the engine is raced, producing the force needed to give momentum to the rotating flywheel, the pistons and their shafts have a torque reaction that makes the engine lean to one side.

Fig. 3-36

This is the horizontal component of the force along the connecting rod. It also pushes the piston against one side of the cylinder (Fig. 3-36) and wears it egg-shaped.

EXPERIMENT 16. CENTRIFUGAL FORCE

Centrifugal force, the tendency of a spinning mass to move away from the center of rotation, is seen in many places on an automobile, from the distributor spark advance to unbalanced tires. If you spin a mass M on the end of a string, at a certain speed the centrifugal force will exceed the weight of F and lift it. This is how you will measure centrifugal force and relate it to the distance R and the speed of rotation.

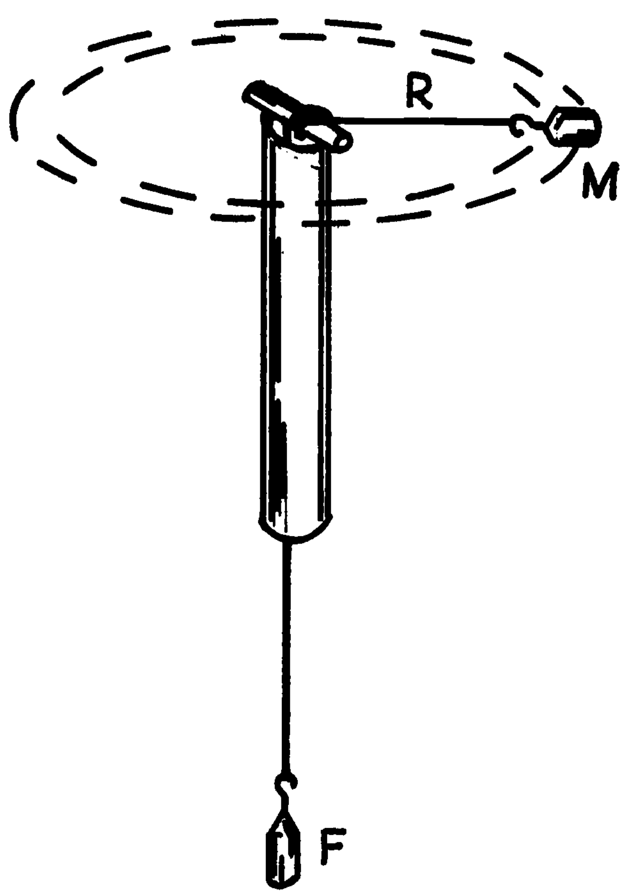


Fig. 1

MATERIALS: Metal tube ¼" or $\frac{3}{8}$" diameter, 5-6" long with flared ends; short metal rod or piece of pencil; hook weights--two 50-gram and one 100-gram; string; metric ruler; stopclock.

PROCEDURE:

1. In your notebook set up a page with a table like this:

M	F	R	V
(grams)	(grams)	(centimeters)	(turns/sec.)

2. Put a 50-gram weight on each end of the string, looping it around the rod or pencil as shown in Fig. 2, so that R is 10 cm. (from the center of the hole in the tube to the center of the weight). Spin the upper weight in a horizontal plane until it just lifts F up. Keeping this speed, with the stopclock measure how long it takes to make 10 turns and divide the time into 10 to get the velocity V (use 20 turns if 10 is too little time).

3. Slide the loop on the bar to make the length R 5 cm. from the hole in the tube to the center of the weight. Then repeat the test.

4. Replace the lower weight F by a 100-gram weight and repeat the tests at 5 cm. and 10 cm. in the same way as before.

5. Now put the 100-gm. weight on the upper loop and the 50 gm. weight on the lower end and do the tests at 5 cm. and 10 cm.

6. Try the experiment with the tube horizontal, the weight swinging in a vertical plane.

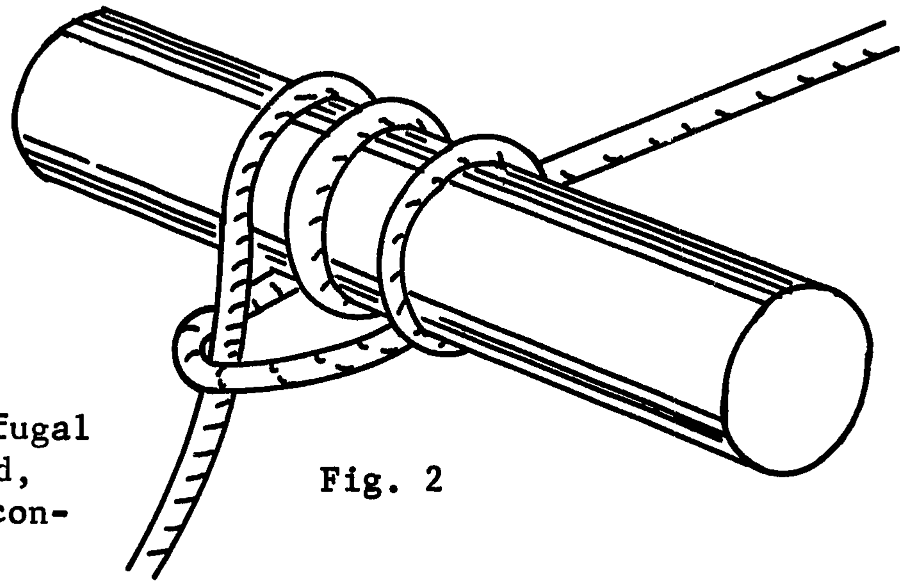


Fig. 2

CONCLUSIONS:

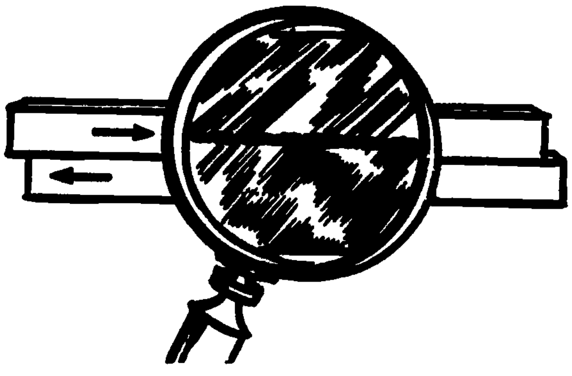
1. What would happen to centrifugal force if the radius were doubled, while speed and mass were held constant?

2. What is the effect if speed is doubled?

3. Which has more effect on centrifugal force, speed or radius?

4. In what plane must a part rotate for its centrifugal force to amount to anything.

2. FRICTION

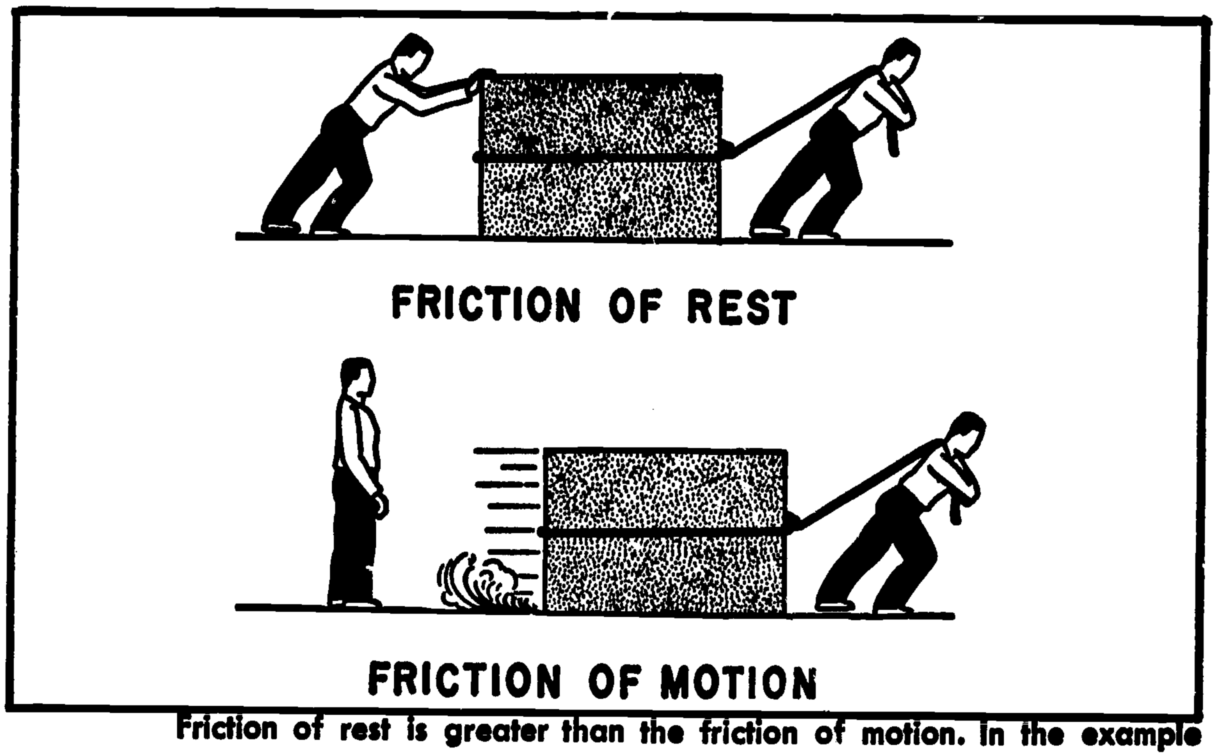


Dry metal surfaces that appear smooth to the eye, show tiny interlocking teeth when magnified.

Fig. 3-37

Friction is the resistance to motion between two objects that are in contact with each other. To make a car move, we depend on the friction of clutch and tires. To stop it, we need friction too, in the brakes and tires. So friction is needed in some places. But it has three side effects which are usually undesirable: (1) It causes wear (2) It produces heat (3) It uses up power.

The cause of friction is roughness of surfaces. When one surface slides over another, the little ridges catch on each other and cause drag.



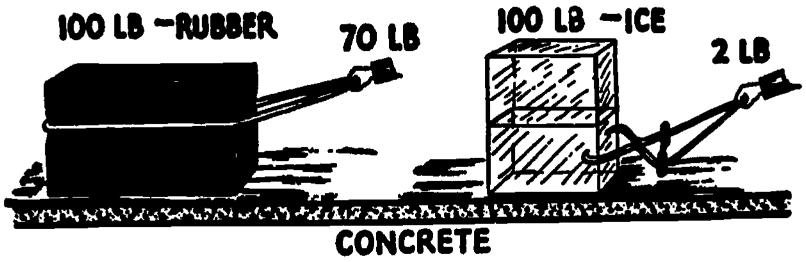
Friction of rest is greater than the friction of motion. In the example shown, it takes two men to overcome the friction of rest, but only one to overcome the friction of motion (after object starts moving). (*Pontiac Motor Division of General Motors Corporation*)

Fig. 3-38

Almost all surfaces are rough in some degree, so friction is very general.

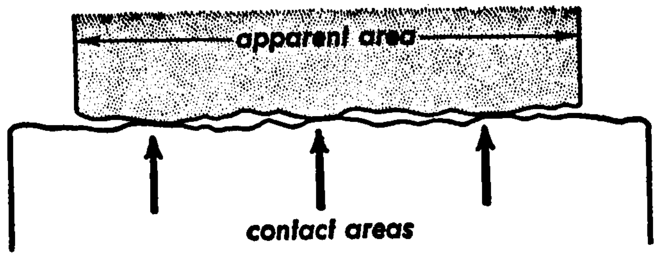
If two objects are pressed tightly against one another, quite a force may be needed to start them sliding. This is starting friction, or friction of rest. Once they start moving, less force is needed; this is sliding friction, or friction of motion.

The amount of force needed to make things slide is a matter mainly of (1) what the surfaces are like (rough-smooth, soft-hard) and (2) how much force presses them together. It does not usually matter how large the area of contact seems to be, but how large it actually is. (Fig. 3-40) As the load increases, however, so does the contact area.



Friction varies with the type of material.

Fig. 3-39



Illustrating the relatively small *contact areas* between two bodies having a much larger *apparent contact area.*

Fig. 3-40

The ratio of

$$\frac{\text{(f) friction force or drag}}{\text{(F) force pressing surfaces together}}$$

is called the <u>coefficient</u> <u>of</u> <u>friction</u>.

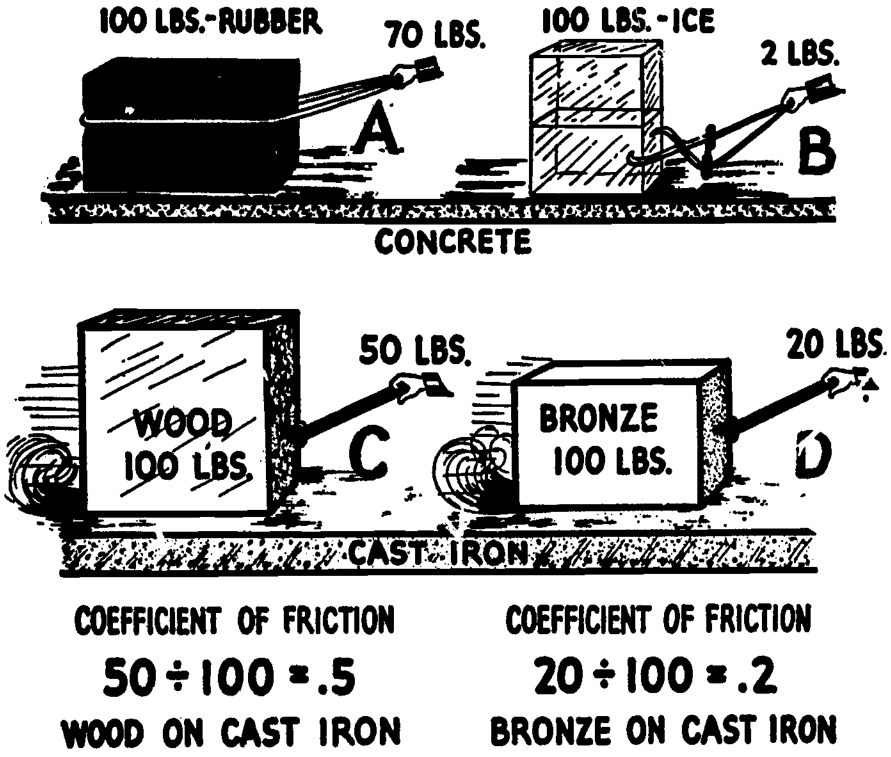
In Fig. 3-41 (a), it works out to

$$\frac{f}{F}=\frac{100}{500}=.20$$

and in (b) it is

$$\frac{f}{F}=\frac{200}{1000}=.20$$

In (c) the area of contact seems to be twice as large, but <u>F</u> is the same, and <u>f</u> is also the same.



Surface friction. Friction of motion. (Courtesy of Pontiac.)

Fig. 3-42

Sliding friction is proportional to the normal force pushing the surfaces together and independent of area of contact.

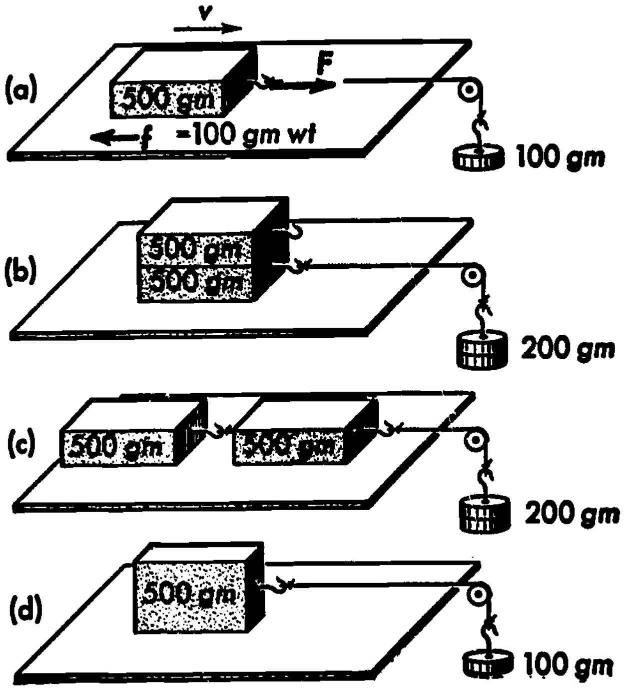


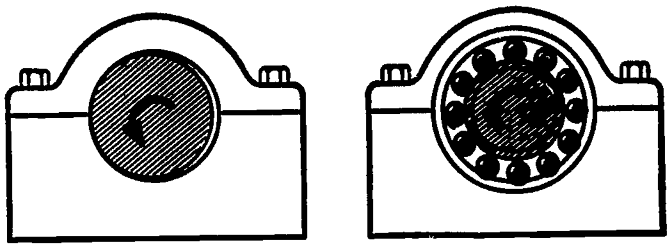
Fig. 3-41

Friction is affected by the condition of the surfaces that are rubbing. Rough surfaces have higher friction than smooth ones. Soft but strong materials, like rubber or brake linings, tend to develop a lot of friction. You would expect this, since they make contact at so many places.

Some coefficients of sliding friction that have been measured are:

rubber on concrete	.70
clutch and brake linings on steel	.50
steel on steel	.18
steel on concrete	.30
steel on babbit metal	.14
greased surfaces	.05
rubber on ice	.05

Rolling friction. When a round surface rolls over another, the rough spots do not catch on each other. This gives coefficients of friction as low as .002. Ball and roller bearings, when properly lubricated and clean of dirt, carry heavy loads, turn very easily, have extremely long life, allow very precise locating of parts, and permit high speeds.


(a) (b)

Sleeve bearings and ball bearings illustrate the two kinds of friction: (a) sliding friction and (b) rolling friction. (*Note*: the clearance in the sleeve bearing is exaggerated.)

Fig. 3-43

Wear is a result of friction. It varies with the amount of pressure between the surfaces, what the metals are (how smooth and hard), and how clean the surfaces are:

1. If the load is light, the little hills and ridges bend to let each other pass. Then they come back without wearing.

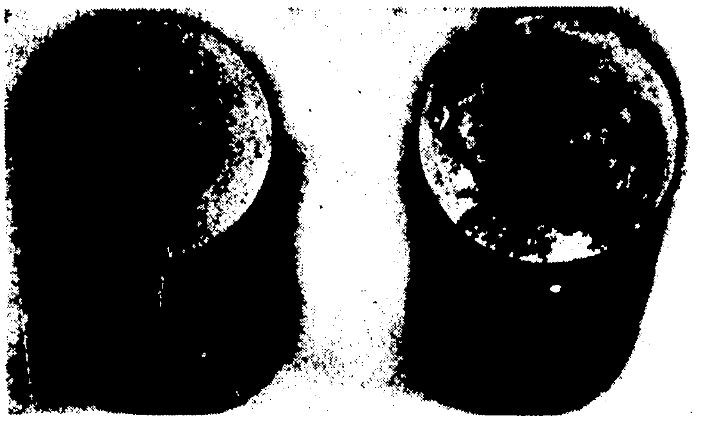

— Worn chain-drive sprocket.

Fig. 3-44

2. Heavier loads will polish metals which are plastic (soft). The surfaces are smoothed over mainly by plastic flow, but some metal rubs off, too. This is what happens when an engine is broken in.

3. Harder metals are less plastic. Under heavy enough loads, the ridges may break off as they slide.

4. Two pieces of the same metal can stick together under pressure if the surfaces are clean and free of oil or other material. Then if they are slid along, pieces are torn out. This is called seizing, galling, or spalling.


Good oil
Poor oil

— Effect of oil quality on spalling and wear of valve lifters.

Fig. 3-45

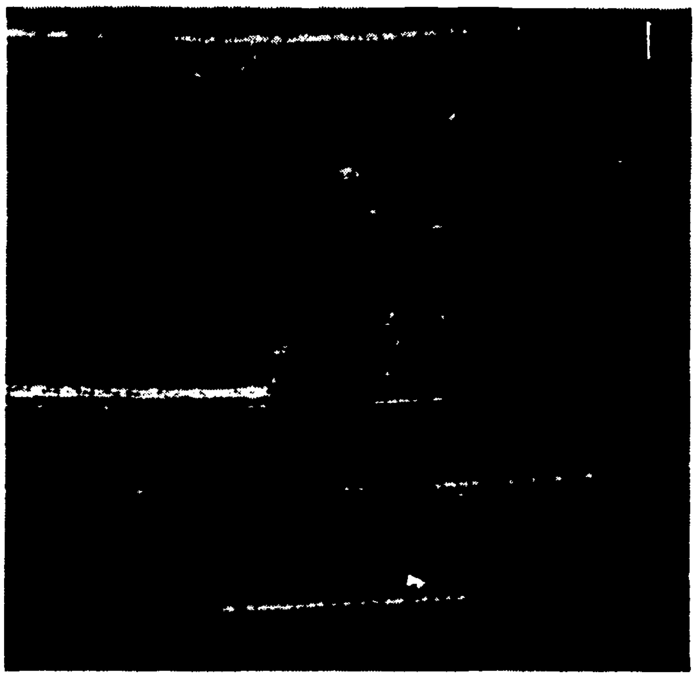


Fig. 3-46

5. Hard dirt particles between metal surfaces can dig out grooves, leading to very quick wear.

Lubrication. A material which is applied to surfaces to reduce friction is called a lubricant.

There are two main types of lubricant used in automotive equipment:

Oils, which are liquids and flow under their own weight. Viscosities from very thin (such as SAE 10 grade) to very thick (SAE 50 and even higher) can be had. Even the thick ones will leak out of small openings, so oils can be used only in closed systems, such as the differential in Fig. 3-47.


Fig. 3-47

When surfaces are coated with oil or grease, even very lightly, the little low places are partly filled. Friction between greasy surfaces is much less than between dry ones, but some wear of high points can still take place. A plain bearing (Fig. 3-48) wears a little on starting up.

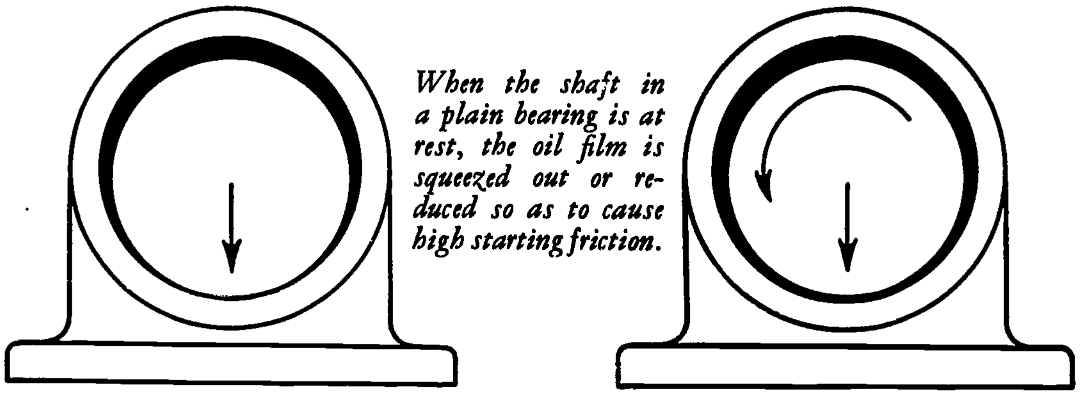
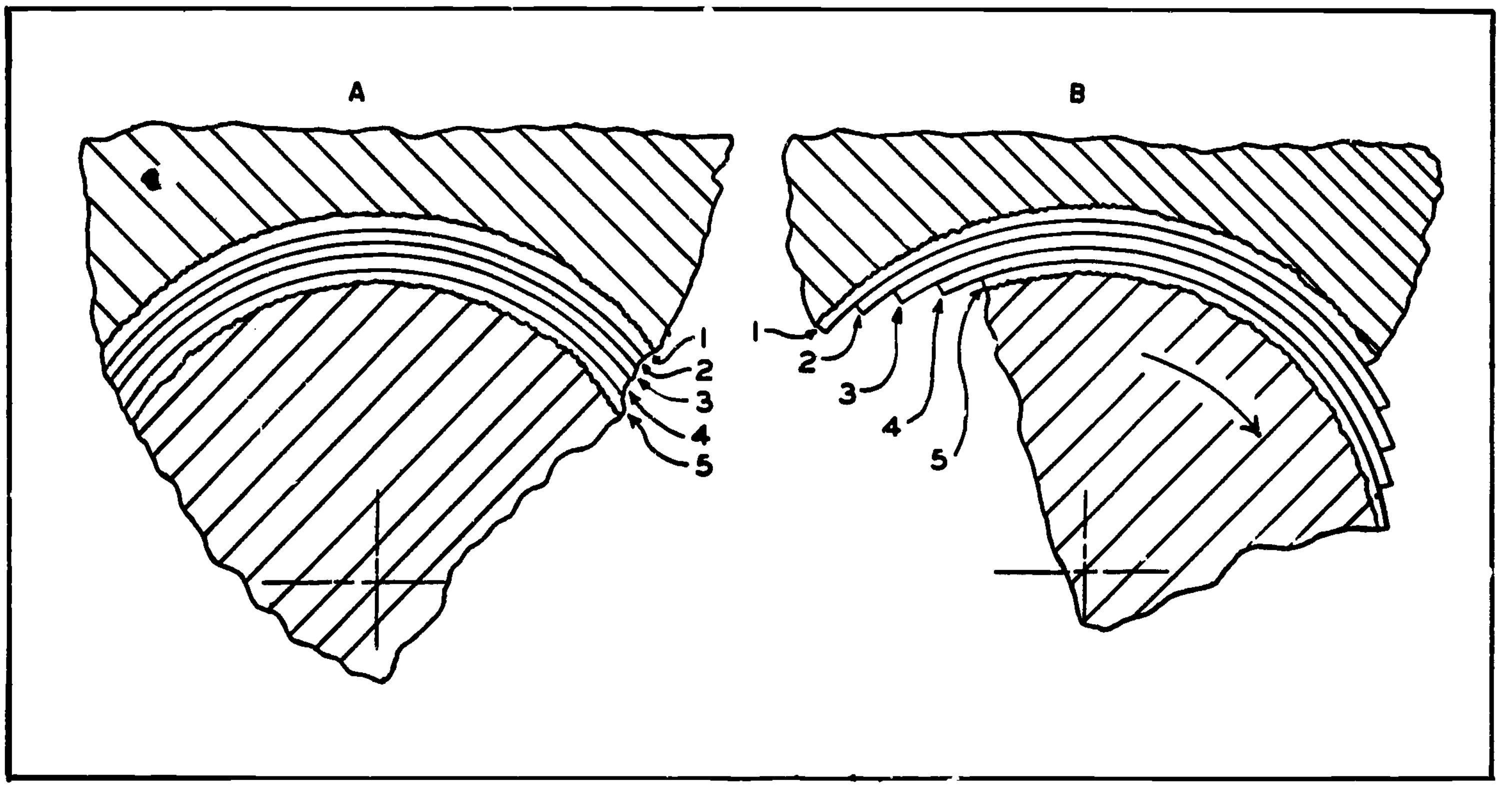


Fig. 3-48

To completely prevent wear, parts must be bathed in lubricant so that they do not touch at all. When a plain bearing is running in oil, friction takes place only between layers of the lubricant sliding past one another (Fig. 3-49).



Effect of Shaft Motion on the Oil Film Layers Built Up Between Bearing and Crankshaft

Fig. 3-49

Greases are semisolid mixtures of oil and soap. They do not flow under their own weight, so they can be used in open bearings where oil would leak out, as in the universal joint in Fig. 3-50. The viscosity of greases is high, so that it takes more power to move a part through grease than through oil.

Small amounts of other lubricants are used for special purposes. Graphite and molybdenum sulfide are slippery, dry solids which cut down friction. Because they are not liquid, they do not pick up dust as oils and greases do. Ordinary oils squeeze out of a bearing under high pressure. To make an extreme pressure (E.P.) oil, additives are put in which stick to the metal by chemical action. They form a permanent oily film.

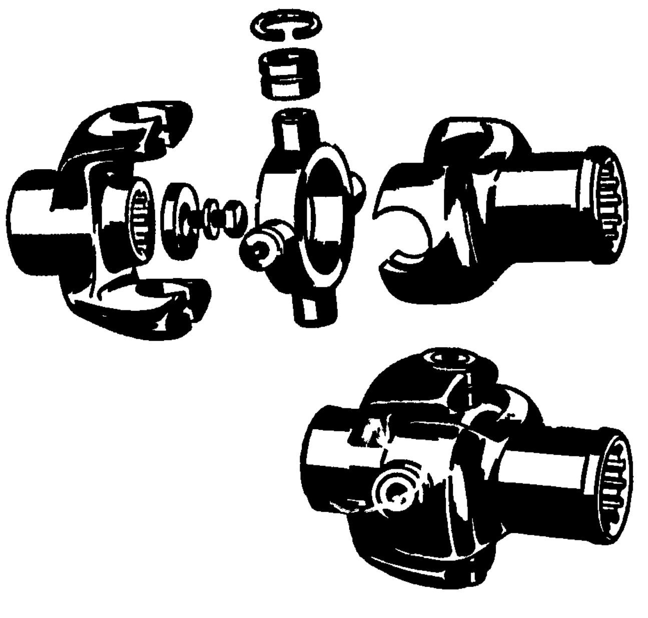
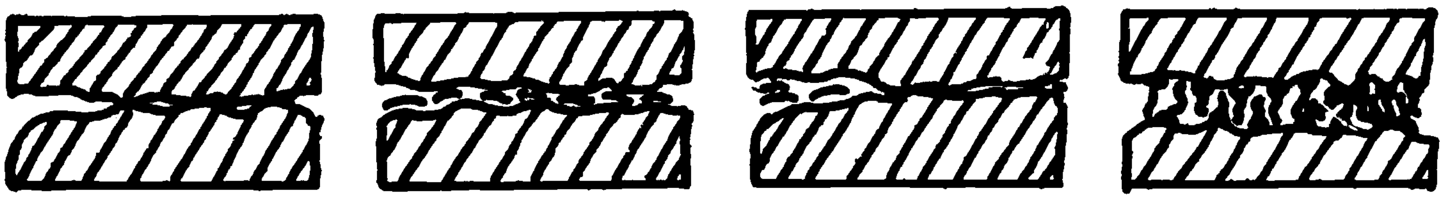


Fig. 3-50



No lubrication. Surfaces rub.

Oil keeps surfaces apart under light loads.

Oil lets surfaces rub under heavy loads.

E.P. oils keep surfaces apart under heavy loads.

Fig. 3-51

Gears transmit very high forces by sliding contact of very small areas of their teeth. Ordinary oils or greases would squeeze out, so transmissions and differentials usually call for extreme pressure (E.P.) lubricants.

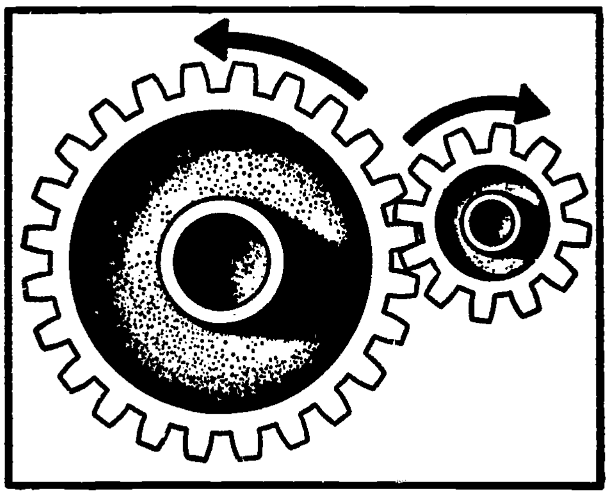


Fig. 3-52

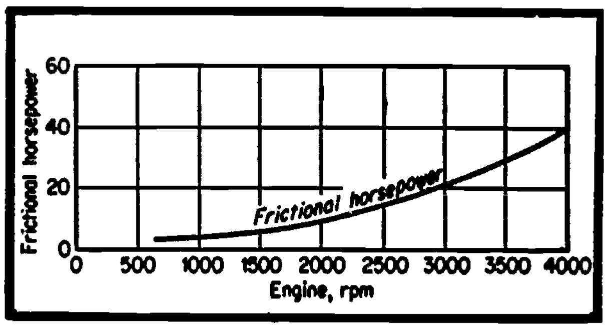
Cams also carry their load over a small part of their surface, so the pressure of this tiny area can be very high when the cam has to lift a valve spring at high speed. Fig. 3-54 shows how an engine oil containing antiwear or E.P. additive protects the cam while a plain oil (right) does not.

Fig. 3-53

— Effect of oil quality on cam nose wear.

Fig. 3-54

Friction in lubricants. Oil or grease can cut down wear to almost nothing. They also cut down the drag of friction, but only down to the viscosity of the lubricant. (Turn back to Fig. 3-49.) There is quite a lot of drag in various parts of an automobile. In the engine, for example, this friction uses up horsepower, as shown in Fig. 3-55, mainly due to the viscosity of the oil between piston rings and cylinder walls.



Friction-horsepower curve, showing relationship of flip to engine speed.

Fig. 3-55

Engine friction can be useful. In coming down hills, for example, shifting into low gear forces the engine to high rpm's so that it acts as a brake.

The frictional losses in the power train--transmission, differential, etc.--are even more than in the engine.

EXPERIMENT 17. FRICTION

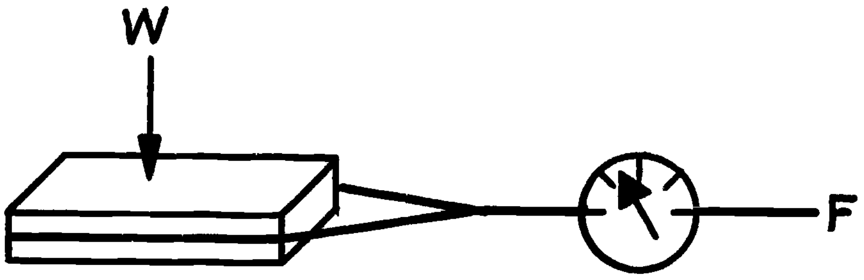
The drag between surfaces sliding past one another is friction. It can be useful: tires need it to grip the road, for example. But it can also be bad, leading to wear, heat, or wasted work.

In the study of friction we measure two quantities: the force pressing the two surfaces together (W), and the force needed to make one slide pass the other (F). The ratio of these, F/W, is the coefficient of friction. In this experiment you will use a simple apparatus like that shown, to measure the coefficient of friction and to find out what factors affect it.

MATERIALS: Smooth board; brick; wood, metal, and rubber-covered blocks; string; 1-kg. roller; balances--spring and beam.

PROCEDURE:

1. Prepare a page in your notebook with a data table like this, having about 15 lines:



Materials	Condition	W, gm.	F, gm.	F/W
Wood block on board, flat	standing			
Wood block on board, flat	sliding			
Wood block, board, on edge	standing			
Wood block, board, on edge	sliding			

2. Weigh the wood block. Record this as W.

3. Lay the board flat on the table. Fasten the string around the block and tie the spring balance to it as shown. Pull the block. How much force must be used before it begins to slide? (Record this as F in the first line.) How much is needed to keep it sliding (F in second line)? Divide out F by W and write the result in the last column.

4. Set the block on its narrow edge and repeat the test.

5. Add a 100-gram weight to the block in its flat position and repeat the tests.

6. Test the following combinations enough different ways so you can predict any which you do not actually try out: metal block, rubber-covered block, and roller on the wooden board and on brick or tile.

7. (Optional) Use steel on steel. Vary surfaces: wiped clean, cleaned with naphtha, cleaned with fine emery, oiled, greased, etc.

CONCLUSIONS:

1. How does the coefficient of friction depend on load?

2. How is it affected by area of surfaces in contact?

3. How does it vary with materials?

4. What can be done to get a high frictional force?

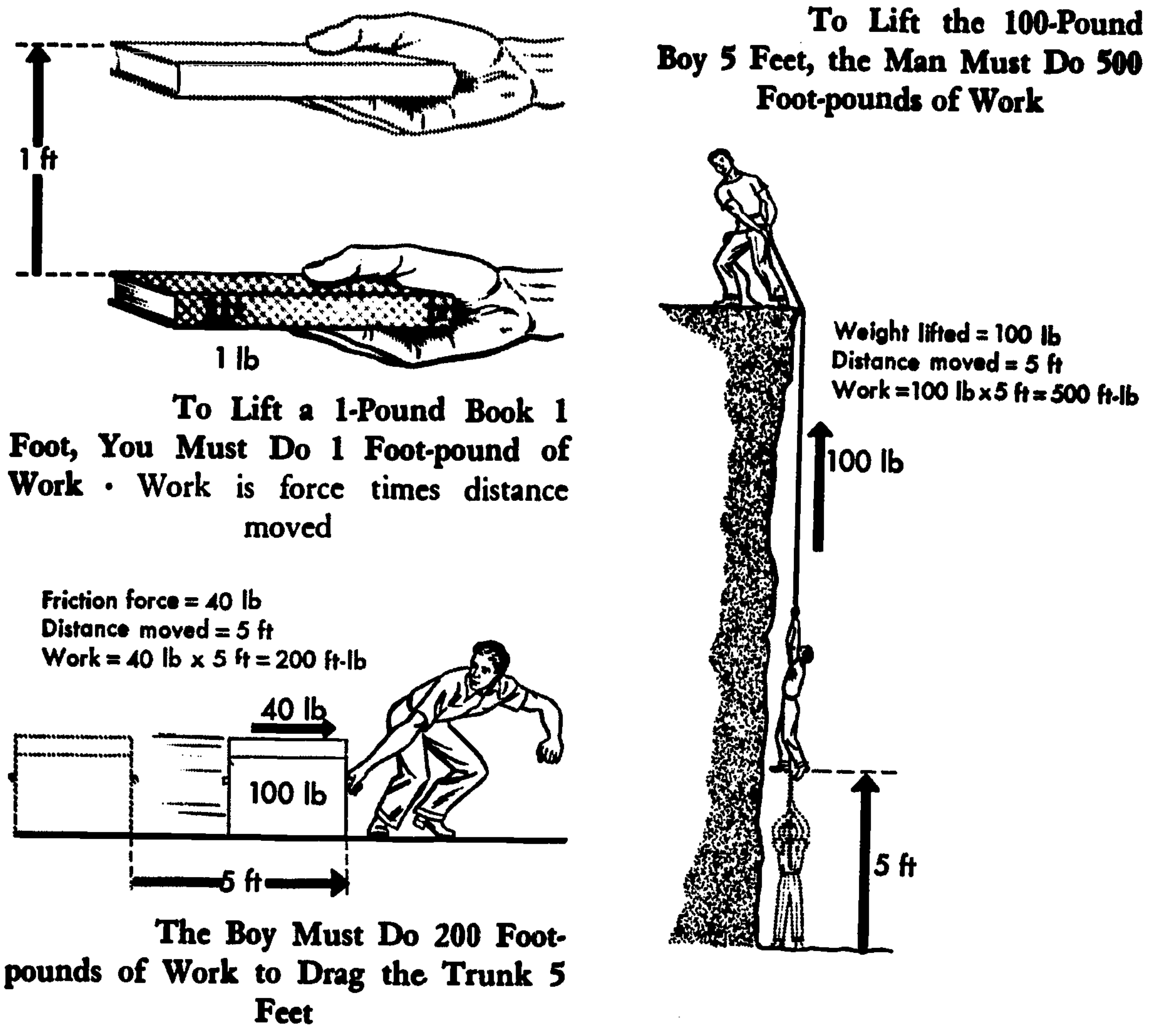
5. What two ways did you study that gave a low coefficient of friction?

3. WORK AND ENERGY

Work. In speaking of work, we often mean any kind of effort by body or mind. In physics, work is done when a force acts on something and moves it. The amount of work is:

$$\underset{\text{(foot-pounds)}}{\text{work}} = \underset{\text{(pounds)}}{\text{force}} \times \underset{\text{(feet)}}{\text{distance}}$$

through which the force acts. Some examples of work are shown in Fig. 3-56.



To Lift the 100-Pound Boy 5 Feet, the Man Must Do 500 Foot-pounds of Work

To Lift a 1-Pound Book 1 Foot, You Must Do 1 Foot-pound of Work · Work is force times distance moved

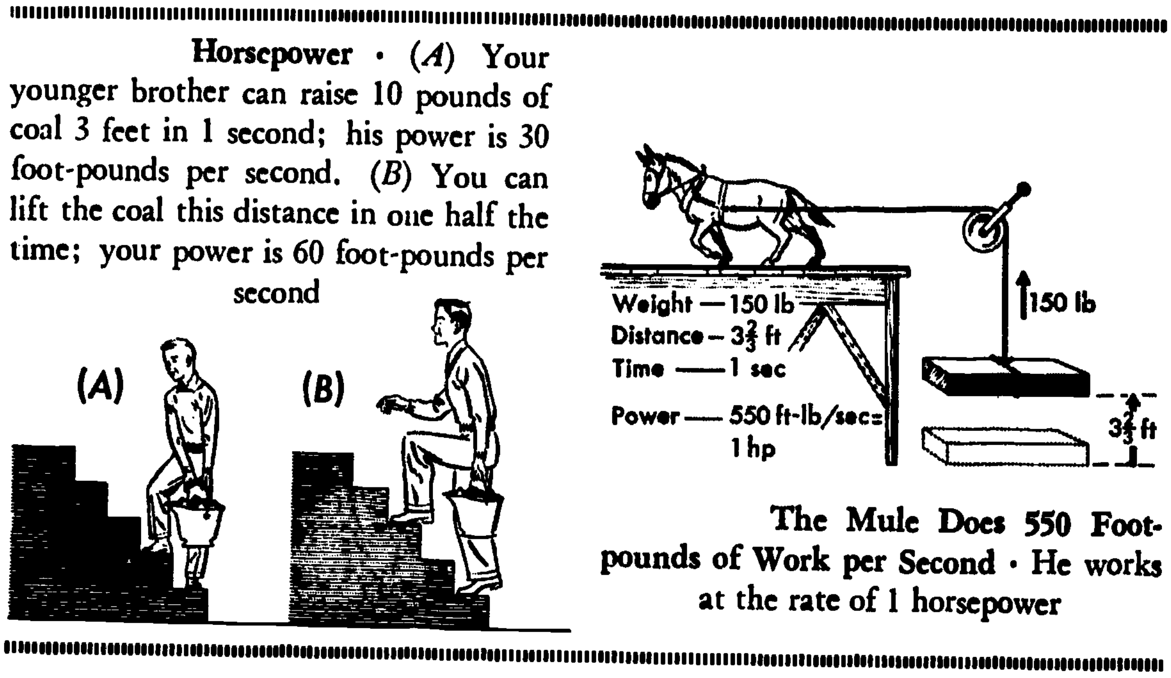
The Boy Must Do 200 Foot-pounds of Work to Drag the Trunk 5 Feet

Fig. 3-56

Power. The rate of doing work is called power.

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

Power can be expressed in foot-pounds/second. One horsepower is equal to 550 foot-pounds per second.

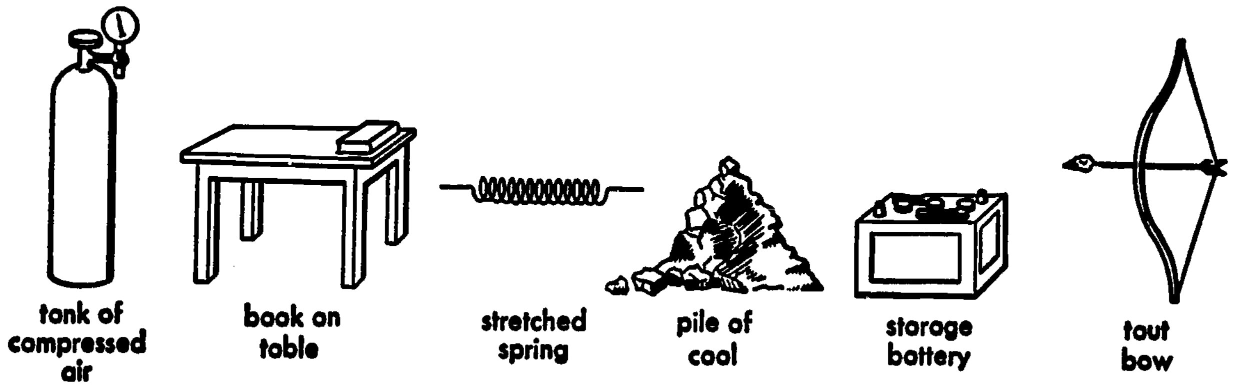


Horsepower · (*A*) Your younger brother can raise 10 pounds of coal 3 feet in 1 second; his power is 30 foot-pounds per second. (*B*) You can lift the coal this distance in one half the time; your power is 60 foot-pounds per second

The Mule Does 550 Foot-pounds of Work per Second · He works at the rate of 1 horsepower

Fig. 3-57

Energy. The capacity to do work is called energy. It is found in many different forms. Several kinds of "stored" or potential energy are shown in Fig. 3-58.



Examples of potential energy.

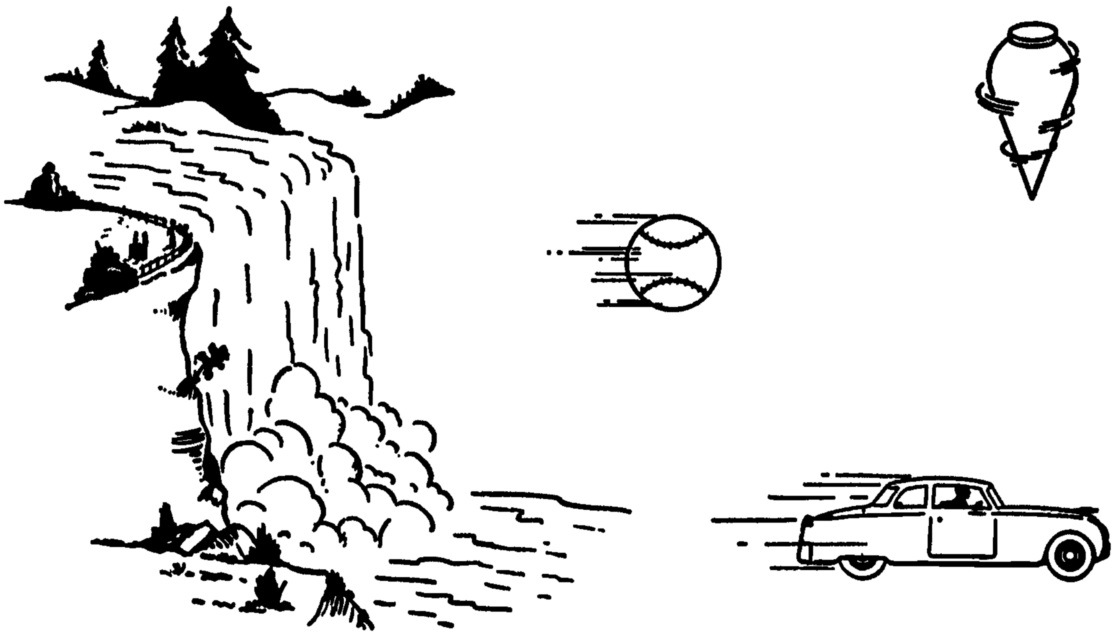
Fig. 3-58

Another important type is energy of motion, or kinetic energy.

The various forms of energy can be changed into one another, but energy cannot be made out of nothing, nor can energy be destroyed.

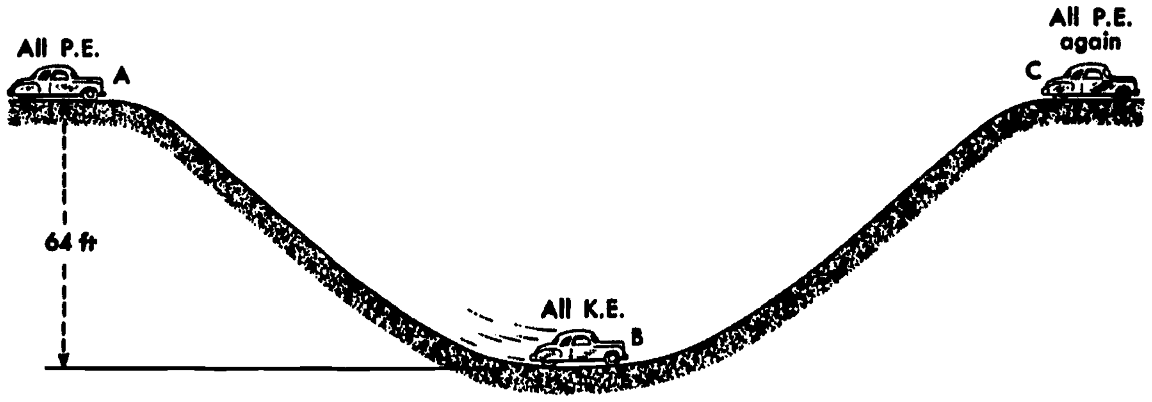
In practical work, when energy is changed from one form to another, some of it always turns into heat--which is still another form of energy, but which is generally not what is wanted.

Fig. 3-60 shows an example of energy conversion. The car in the illustration is coasting.



Examples of kinetic energy.

Fig. 3-59



The Potential Energy, at *A*, of the Car Is Transformed into Kinetic Energy at *B*, Then into Potential Energy at *C* • Actually, will the car coast as high at *C* as it was at *A*?

Fig. 3-60

If the car will not coast as high at C as it was at A, what happened to the "extra" energy?

The automobile is basically made to change the potential energy of fuel into the kinetic energy of motion. In a car there are very many changes of energy. As one example, kinetic energy moving the push rod, (Fig. 3-61) becomes potential energy in the spring as it is compressed.

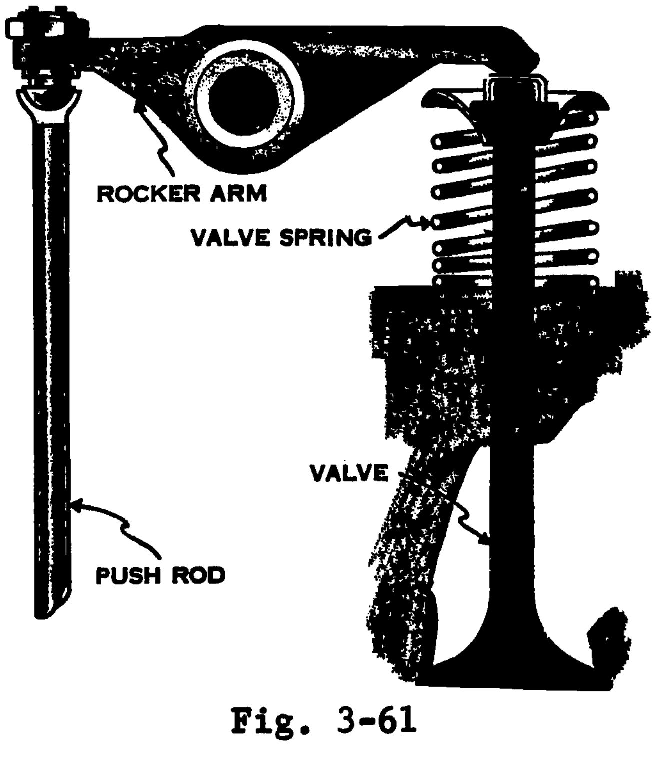
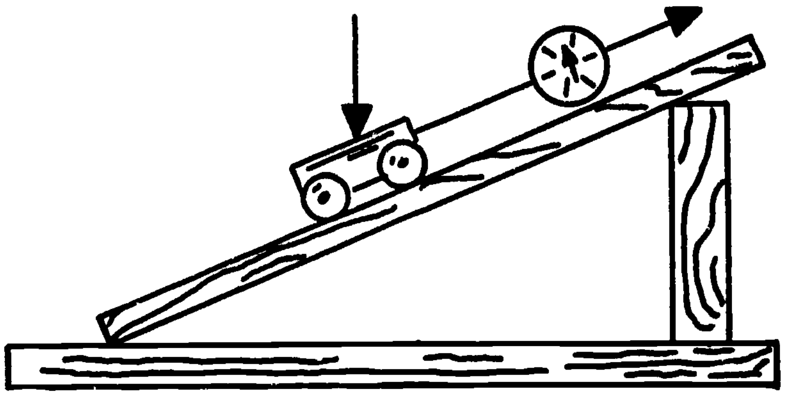


Fig. 3-61

EXPERIMENT 18. THE INCLINED PLANE

The inclined plane is a simple machine. To study it in the laboratory you will use a board propped up at an angle, as in the picture. The little car is pulled up the board by a force that is measured by a spring balance.



If the pull on the string is less than the weight of the car with its load, the plane has a mechanical advantage. But as you will see, you get no more work out of it than you put in.

Work is calculated by multiplying a force by the distance through which it moves.

Work = F x d

Input work will be the input force (pull on the spring balance) times the distance along the board that the car moves. Output work, the work actually accomplished, is the weight of car and load times the height it is raised.

In every machine some work is wasted, due to friction. The ratio

$$\frac{\text{output work}}{\text{input work}}$$

is the efficiency of the machine. It is usually multiplied by 100 to give percent efficiency.

MATERIALS: Inclined plane, spring balance, car, friction box, weights, meter stick.

PROCEDURE:

1. Prepare a page in your notebook with a table like this:

Input			Output			Percent Efficiency	Mechanical Advantage
Force	Distance	Work	Force	Distance	Work		

2. Set the inclined plane at an angle of about 30^{o} by propping one end up on a brick, a pile of books, etc.

3. Weigh the car. Record this. (In which space?)

4. Hook the spring balance to the front of the car. Read the force in grams needed to pull it up the plane, and record it.

5. Measure and record the distance that the back of the car travels, from the lower end (where it touches the table top) to the point where the car is at the end of the board. Measure and record the height from the table top straight up to the same point. Calculate the input and output work, the percent efficiency, and mechanical advantage.

7. Put a weight (1000 or 2000 grams) in the car and get a new set of data.

8. Run the experiment with a friction box loaded with 500 grams of weight, in place of the car.

9. Optional. Change the angle of the plane and do one or two of the tests outlined above.

CONCLUSIONS:

1. Why is an inclined plane useful?

2. If you put more work in than you get out, where did the rest go?

3. Is dragging a box up an inclined plane easier than lifting it?

4. Where a long ramp is used to get a heavy object up on a platform, what could you do to make the work as easy as possible.

4. MACHINES

Uses of machines. From earliest times man has used machines to help him do things. A machine is a device to which mechanical energy is applied at one point and delivered in a more useful form at another.

1. It can change the direction of forces.

2. It can change the amount or speed of forces.

3. It can change the distance through which forces act.

A machine is driven by a prime mover, which changes energy from one form to another. Engines, electric motors, and horses are examples of prime movers. Your arm or foot could be a prime mover.

All machines, no matter how large, are combinations of simple machines.

1. The lever and its special forms--pulley, gear, and wheel and axle.

2. The inclined plane and its special forms, the screw and the wedge.

Ideal machines follow this rule:

Input work (force x distance) = output work (force x distance)

In practice, all machines waste some work as heat caused by friction, so

Total input work = output work + wasted work (friction).

Efficiency. In actual machines we find that input work is always more than output work, due to friction. The ratio of these is called efficiency. It is usually given as a percent

$$\text{percent efficiency} = \frac{\text{output work}}{\text{input work}} \times 100$$

The Lever. A rigid bar that is free to turn about a fixed point or fulcrum is called a lever. In Fig. 3-62, an effort force F_E lifts a resistance F_R. The input work is the force F_E times the distance it moves, s_E. The output work is $F_R \times s_R$. Experiments show that

$$F_E \times s_E = F_R \times s_R$$

input work = output work

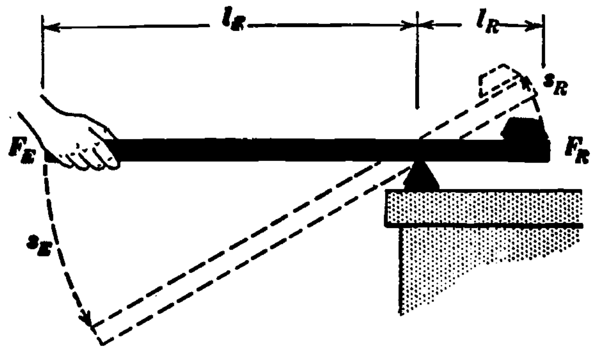


Fig. 3-62

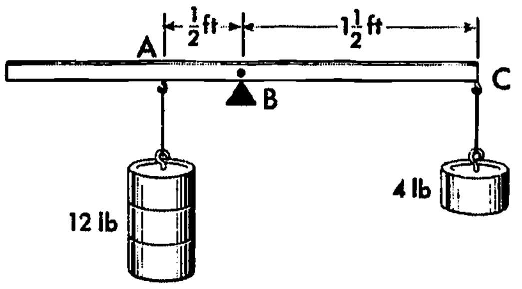


Fig. 3-63

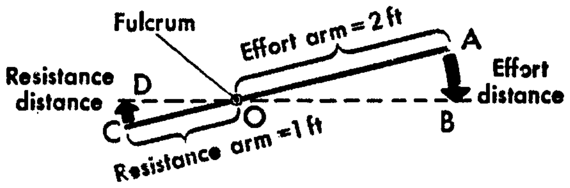
This lever uses a small effort force to lift a heavy resistance. This increase in force is shown by a number, the mechanical advantage (M.A.). The mechanical advantage of any machine is the ratio of

$$\frac{\text{resistance force}}{\text{effort force}}.$$

For example, the M.A. of the lever in Fig. 3-63 is $\frac{12}{4} = 3$.

When a lever is used to multiply a force, it always does so at the expense of distance or speed. In other words, a small force may move a large resistance, but the force will have to move through a much greater distance than the resistance moves. (See Fig. 3-62)

On the other hand, a large force moving through a small distance can, by means of a lever, make a small resistance move through a much larger distance. In this way a lever can be used to increase speed.



Effort Arm and Resistance Arm of a Lever • Its mechanical advantage = effort arm ÷ resistance arm

Fig. 3-64

On a lever it is much easier to measure the length of the arms than it is the distance that the forces move (See Fig. 3-64). Actually, the two are always in proportion; so it works out that

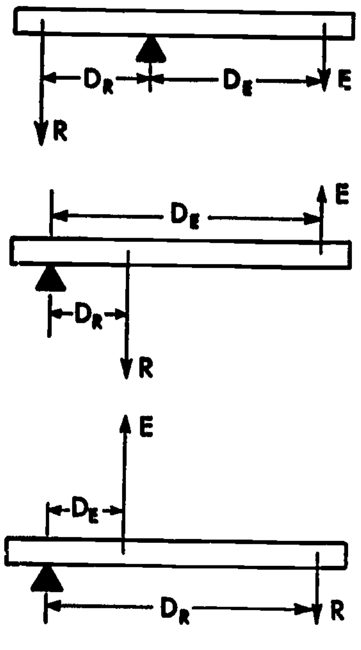
effort force x effort arm = resistance force x resistance arm.

Since torque is force x distance (arm length), we can say of a lever that

input torque = output torque.

The purpose of a lever is to carry torque around a fixed point. The torque comes from an input force at one point and gives an output force (equal to the resistance) at another point.

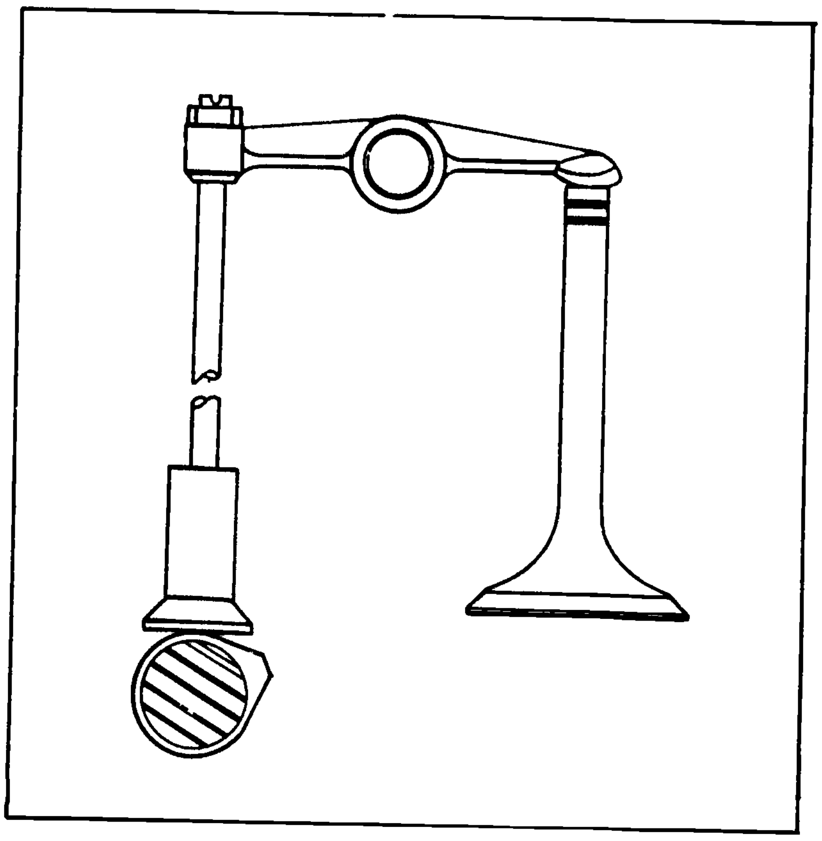
Levers can be arranged different ways to do different things, as shown in Fig. 3-65.



Types of levers.

Fig. 3-65

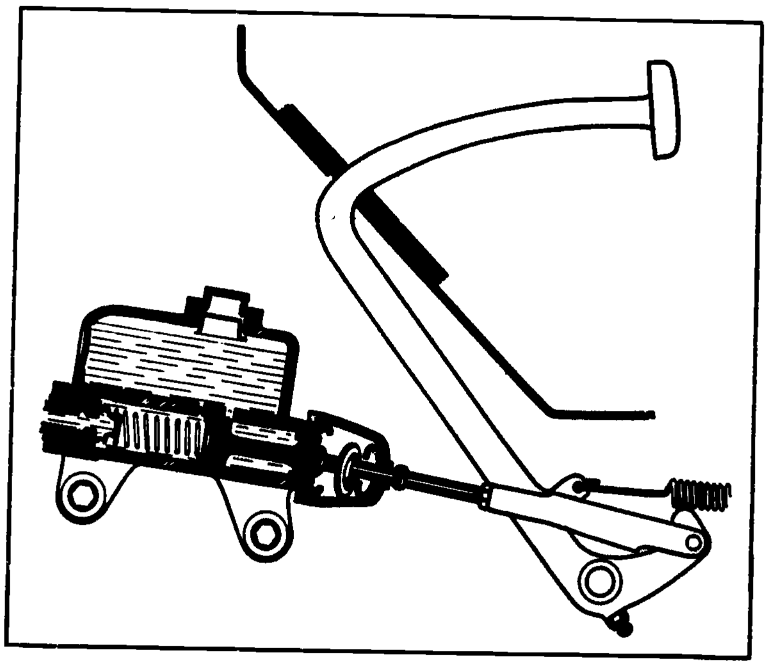
A lever can change direction of motion, as the rocker arm does.



Rocker Arm

Fig. 3-66

It can increase force, as the foot brake does.



Foot Brake Fig. 3-67

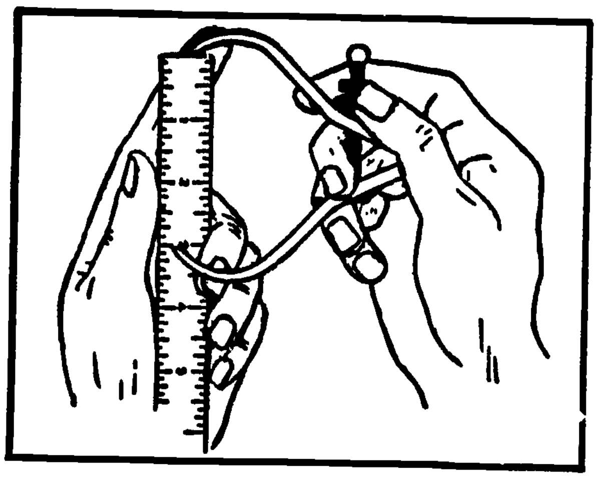


Fig. 3-68

It can increase distance of movement and speed: the little screw on the caliper in Fig. 3-68 opens the ends rapidly.

Rotating levers. Common levers, like the wrench in Fig. 3-69, cannot always be free to go around in a full circle. A lever can be mounted to turn freely, though, like a yoke on a universal joint. Its purpose, like that of any lever, is the carry torque.

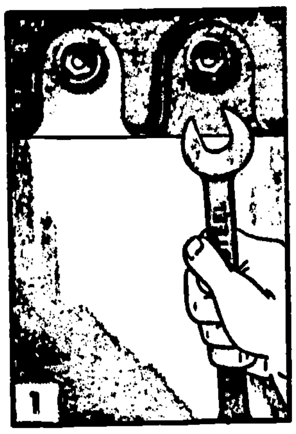
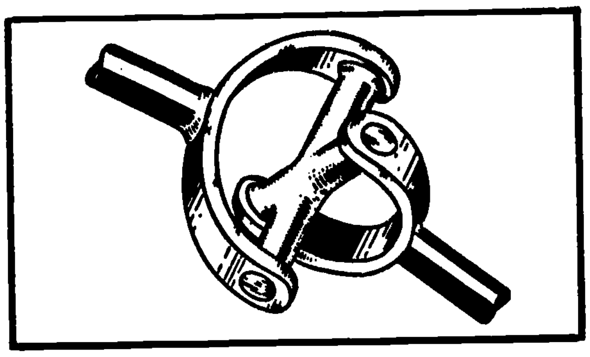


Fig. 3-69

We might say the principle of the lever this way:

Whenever two parts are locked together so they rotate together, the torque will be the same at all points.

This is the principle of the friction clutch simplified in Fig. 3-71, only the lever has lost the shape of a stick and is now round.



A simple universal joint.

Fig. 3-70

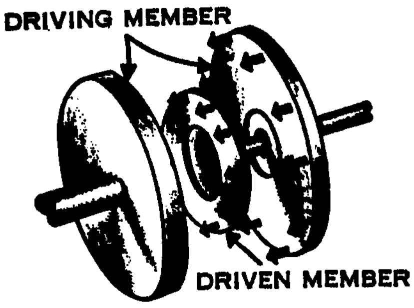


Fig. 3-71

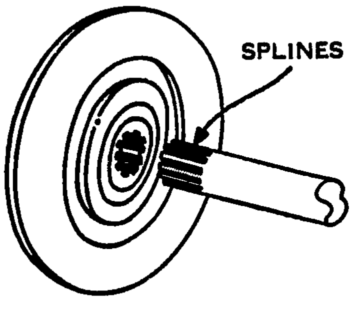


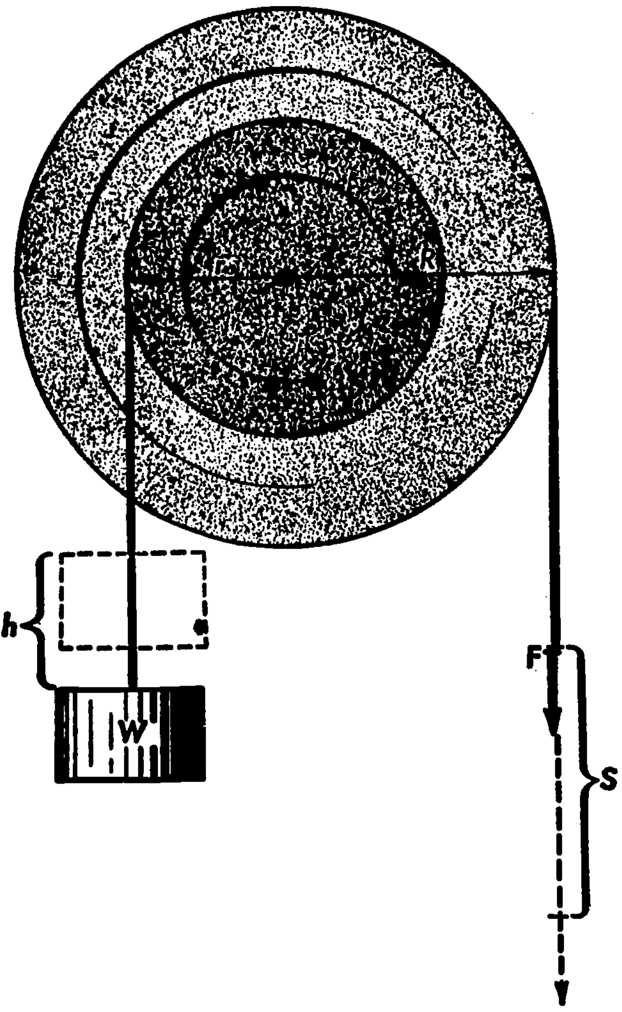
Fig. 3-72

A splined shaft also carries torque without changing it.

These devices are all examples to show that while we usually think of a lever as turning only part of a circle, its principle applies just as well to objects that can go all the way around.

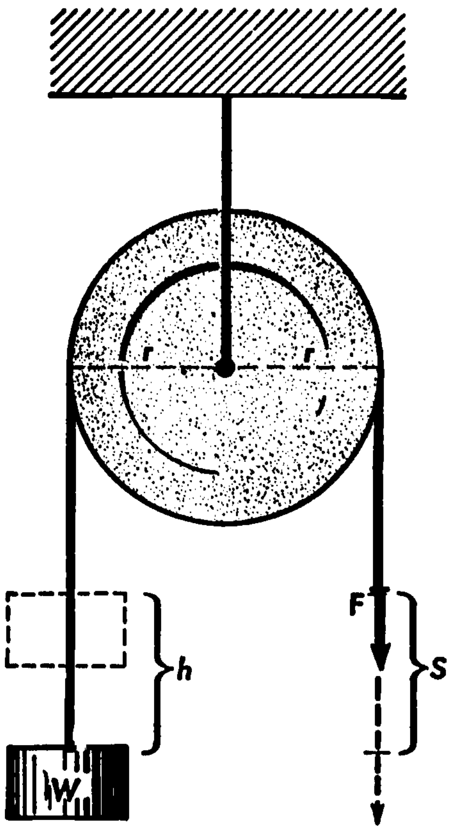
By applying a force at one radius and a resistance at another, the wheel and axle can gain or lose force or speed just like any other lever. In Fig. 3-73, a force at radius R lifts a resistance weight at a smaller radius r.

The large radius is twice the small one, so the effort F moves twice as far, but it only has to be half as strong.



Wheel and axle.

Fig. 3-73



A fixed pulley.
Fig. 3-74

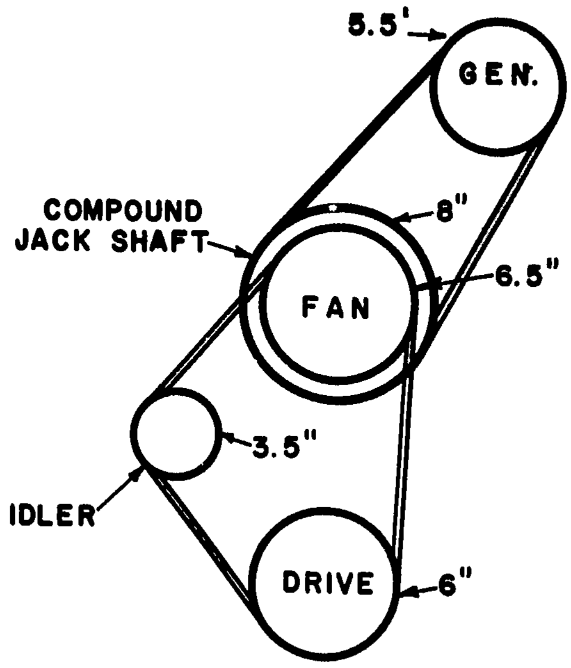


Fig. 3-75

A simple fixed <u>pulley</u> moves the effort and resistance equal distances, so its mechanical advantage is <u>one</u>. This type of pulley can be used simply to change the direction of the motion (<u>idler pulleys</u>) or to drive a shaft.

Pulley drives depend on friction. To deliver high power they need high friction.

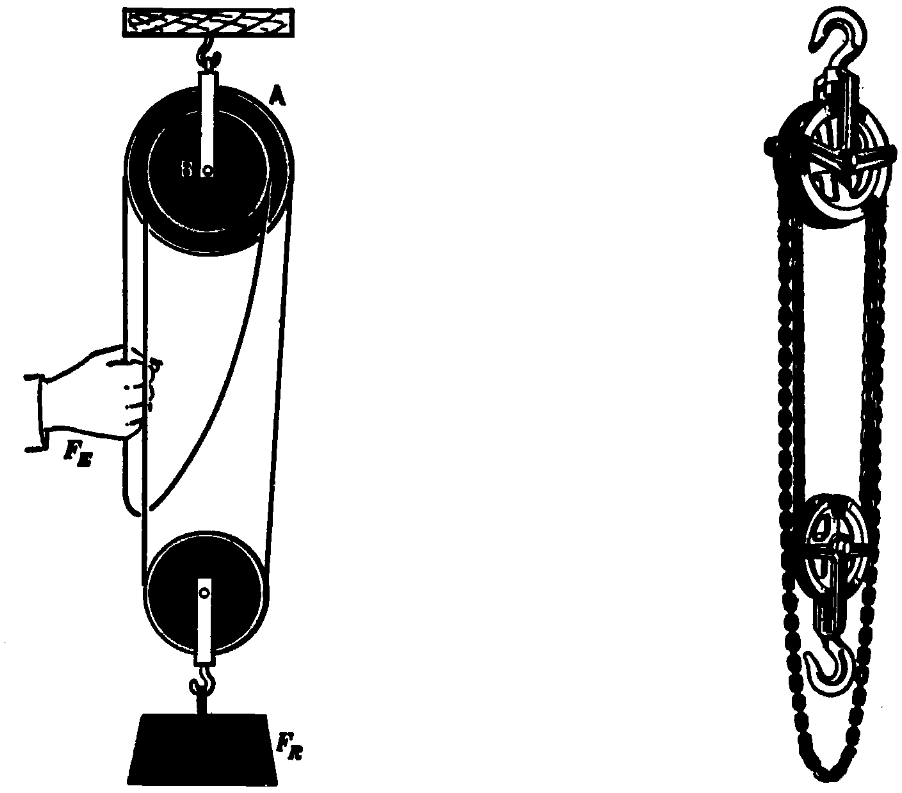
V-belt pulleys are used to drive the generator, fan and water pump on many cars because the rubber V-belt has high friction.

When the forces are so great that a rope or belt would slip, chain can be used instead.

Chain pulleys or <u>sprockets</u> have notches on which the links catch.

When one pulley drives another of the same size by a rope, belt, or chain, the speeds of the two pulleys will be the same, and the output power will be the same as the input power. When a small wheel drives a big wheel, however, the big wheel will make less than a full circle when the small wheel makes a full circle. There is a loss in speed, but a gain in power.

In general, pulleys of different sizes have a mechanical advantage equal to the ratio of their sizes, but what they gain in torque they lose in speed, and vice versa.



Left, a diagram of a differential pulley; right, a commercial chain hoist.

Fig. 3-76

<u>Gears</u>. A gear can be thought of as a wheel made of little levers, as in Fig. 3-77.

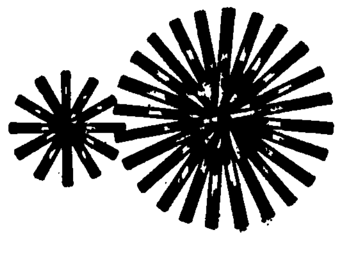


Fig. 3-77

Suppose we had some little 10-inch sticks firmly mounted at the centers on a shaft. On another shaft we mounted some 20-inch sticks at their centers and with the same space at the ends as the short ones have. A torque of 500 pound-inches on the first shaft would give a force at the end (five inches from the shaft) which can be figured by using:

$$\text{Torque} = \text{Force} \times \text{Distance}$$

$$\text{Force} = \frac{\text{Torque}}{\text{Distance}} = \frac{500 \text{ lb.-in.}}{5 \text{ in.}} = 100 \text{ lbs.}$$

This force applied on the ends of the 20-inch sticks, (10 inches from the shaft) would give a torque:

$$100 \text{ lbs.} \times 10 \text{ in.} = 1000 \text{ lb.-in.}$$

Each tooth of a gear is like the end of a stick. Thus the small gear in Fig. 3-78 drives the large one, giving it double the torque. But the large gear has twice as many teeth, so it will take twice as long to make a complete revolution. Notice also that the two gears turn in opposite directions.

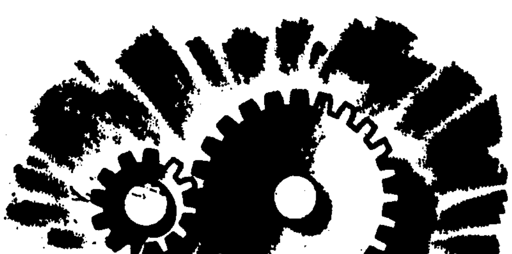


Fig. 3-78

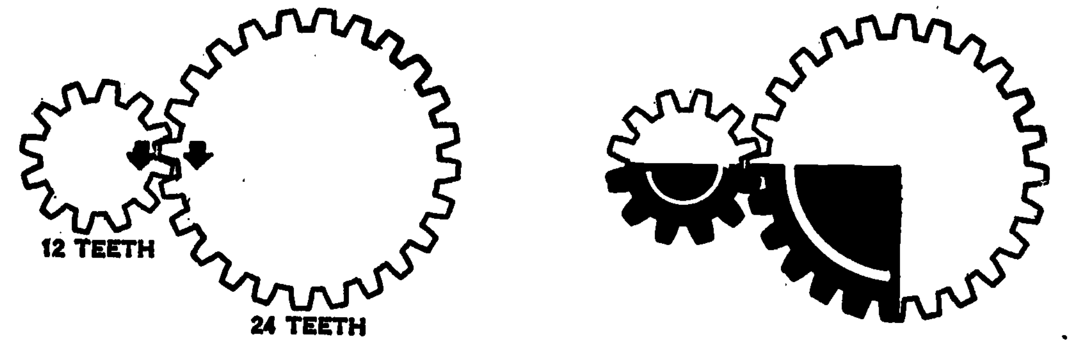


Fig. 3-79

A pair of gears has a mechanical advantage (gain in torque) equal to the ratio of the number of teeth on the gears, but whatever is gained in torque is lost in speed.

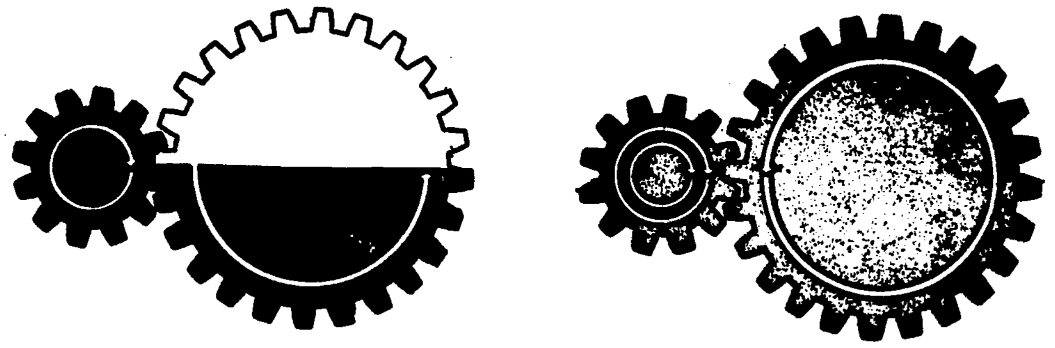
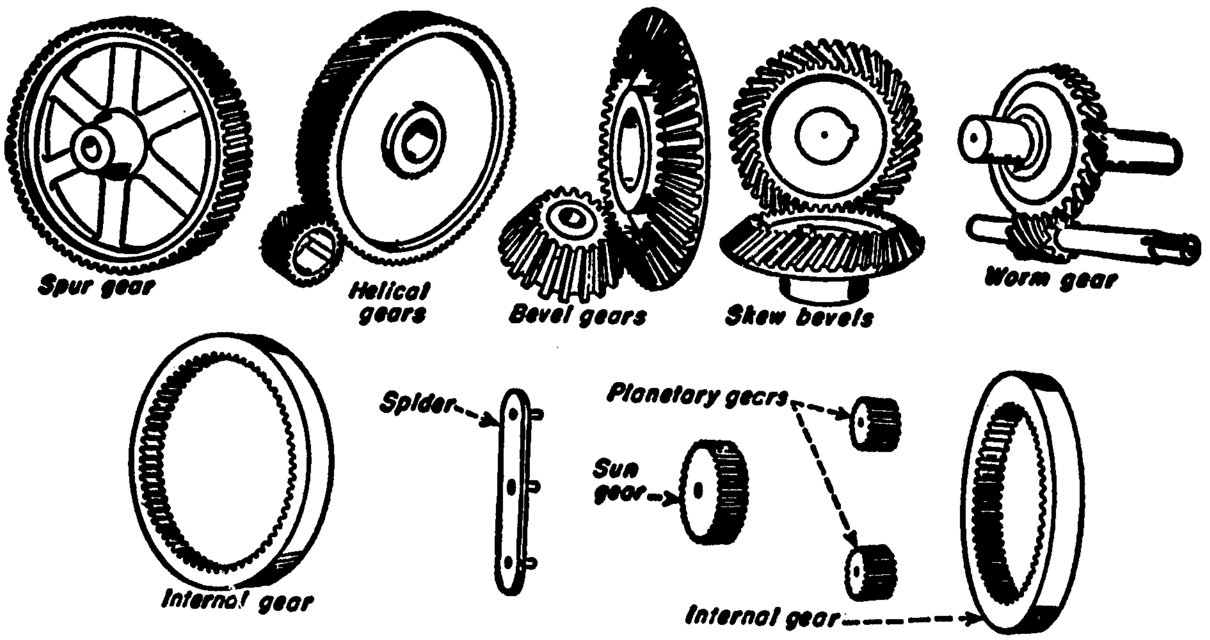


Fig. 3-80

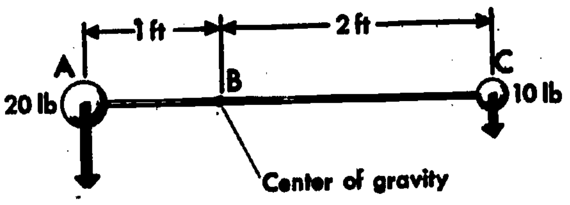
An automobile has in it not only simple spur gears like those shown in the drawings above, but other types, some of which are shown in Fig. 3-81.



Various types of gears. The disassembled view of a planetary-gear system above shows the relationship of the spider, sun, two planetary, and internal gears. Planetary gears are used in overdrives and automatic transmissions. The "spider" is also called a planet-pinion cage.

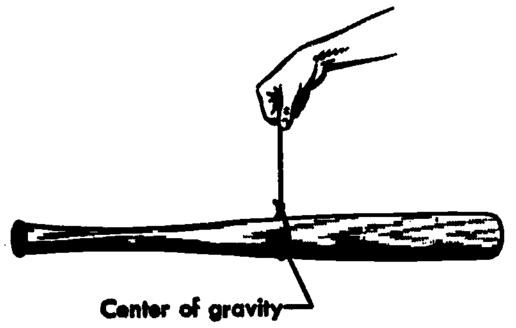
Fig. 3-81

Center of gravity. If several weights are put on a stick, as in Fig. 3-82, the stick can be balanced by hanging or pivoting it at a certain point. This point, where the clockwise and counterclockwise torques are equal, is called the center of gravity. It is easy to find the center of gravity in objects, even if they are odd-shaped (Fig. 3-83), because the center of gravity of any free-hanging, balanced object lies directly under the point where it is hung.



Center of Gravity · It is at *B*, where the system balances. We can assume that the weight of the two spheres acts at *B*

Fig. 3-82

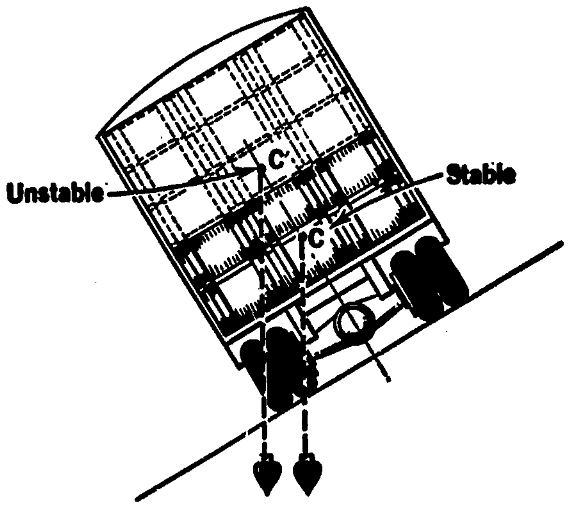


How Can You Find the Center of Gravity (Point of Balance) of This Baseball Bat?

Fig. 3-83

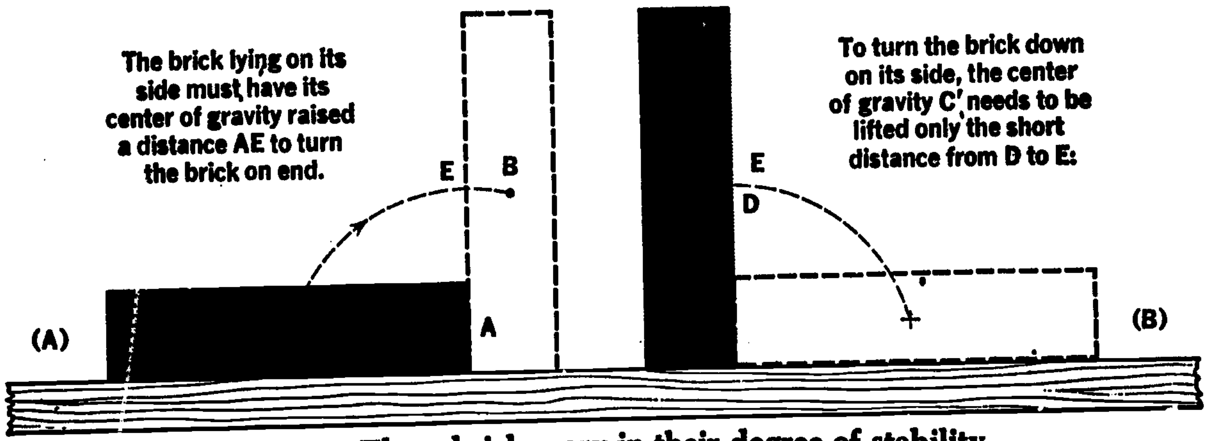
When the center of gravity of an object is directly over the base, the object is stable; if a vertical line dropped from the center of gravity falls outside the base, then the object is unstable and can easily tip over.

By lowering the center of gravity or widening the base we can make an object more stable.



The truck is stable when a plumb line dropped from the center of gravity falls within the area described by the wheels.

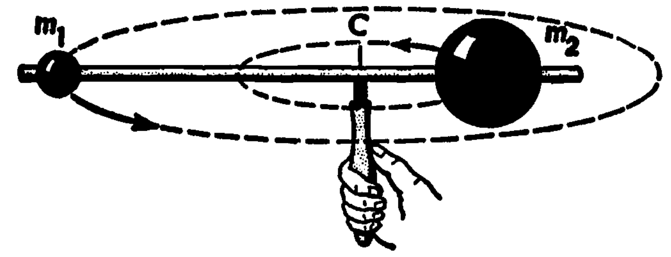
Fig. 3-84



These bricks vary in their degree of stability.

Fig. 3-85

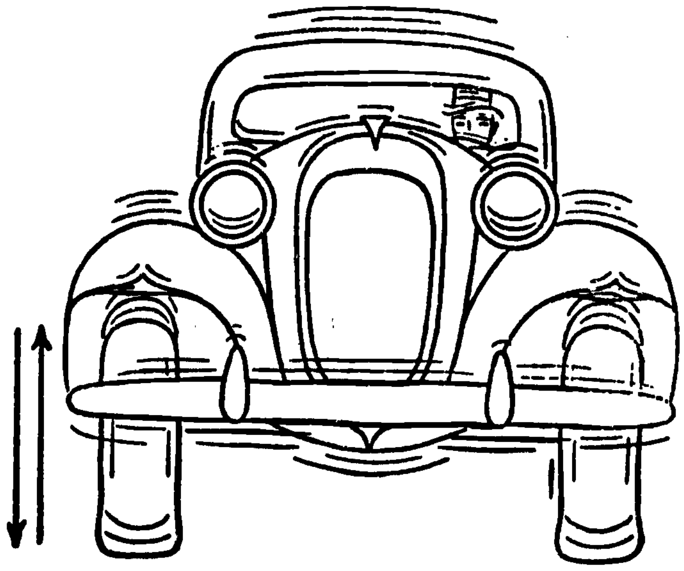
Balance in rotation. A body tends to rotate smoothly (in balance) around its center of gravity, like the rod and weights in Fig. 3-86.



Illustrating the smooth rotation of two bodies

Fig. 3-86

If a body is mounted on a bearing, it is balanced when its center of gravity is at the axis of the bearing. It will then rotate smoothly. If the wheel of a car is unbalanced, the center of gravity is not at the axis. When it rotates around the axis, it may have enough centrifugal force at high speed to lift the wheel in a "hop."



Unbalance Causes Wheel Hop

Fig. 3-87

A crankshaft has counterweights. The center of gravity of the piston, connecting rod and counterweight, taken as a unit,must be at the true axis of the shaft. For this reason pistons are weighed accurately in designing a good engine.

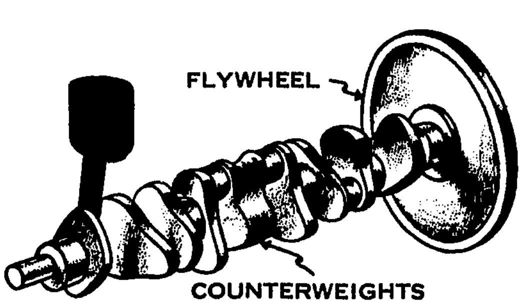
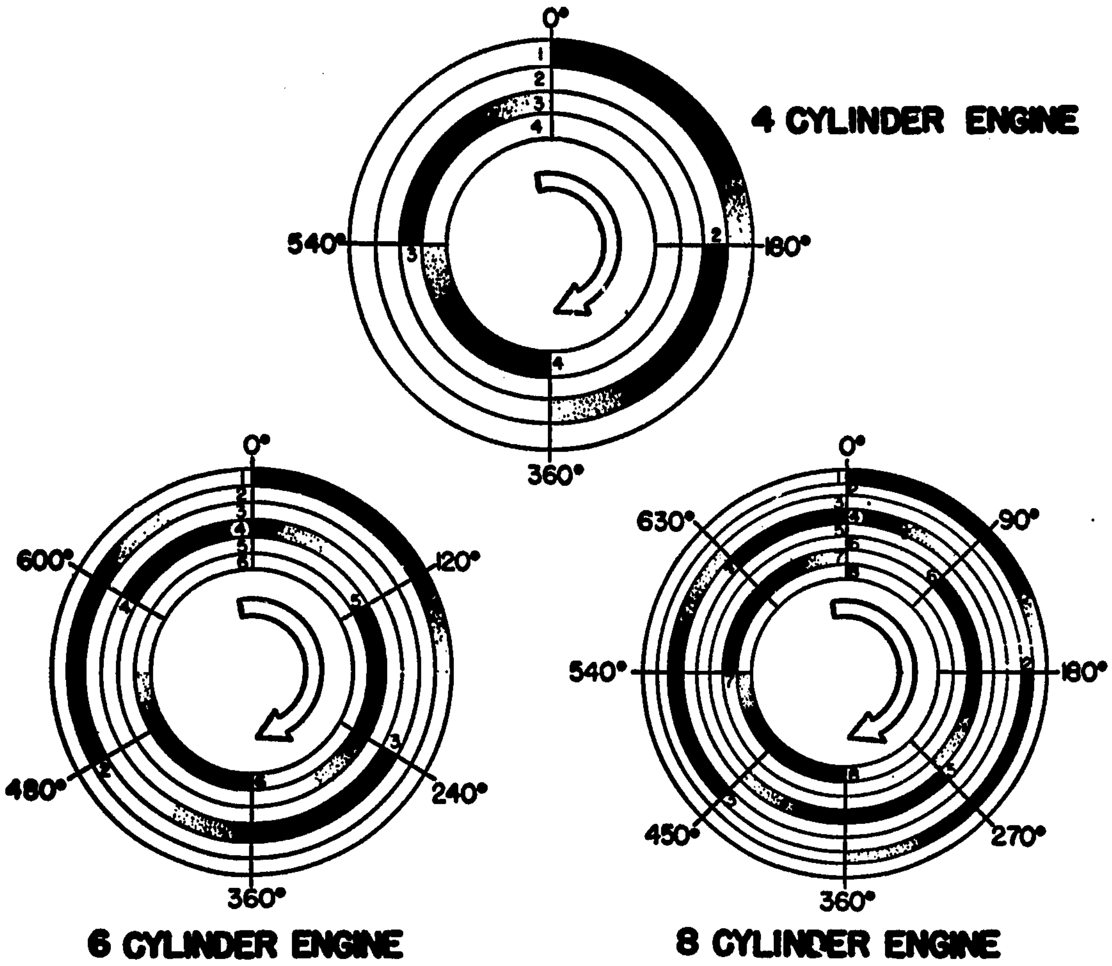


Fig. 3-88

Rotational momentum. A body in rotation tends to continue in rotation about its axis at the same speed unless acted upon by an unbalanced torque.

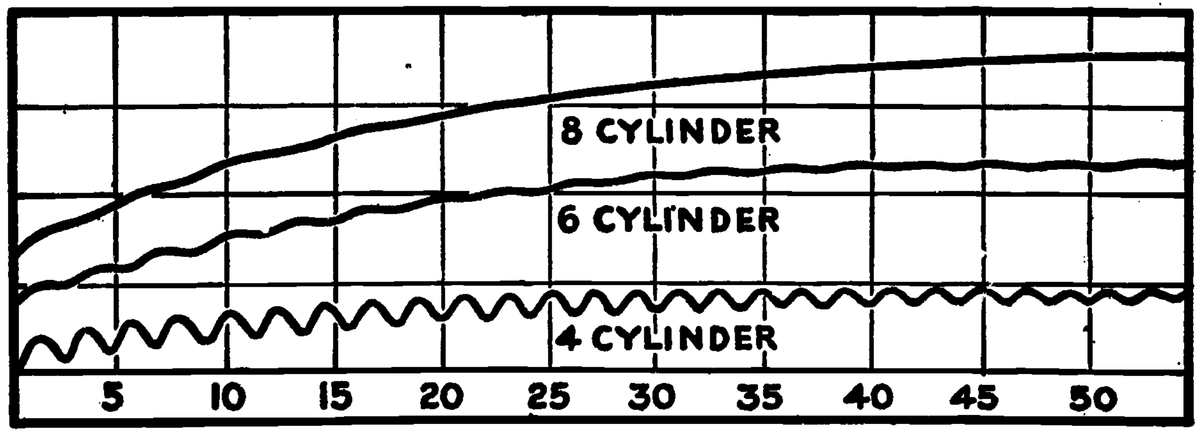
An engine gets its power from sudden explosions of gasoline, so the rotation of the crankshaft tends to be uneven (Figs. 3-89, 3-90).

The power strokes of six-and eight-cylinder engines overlap, giving smoother torque.



Power impulse in four-, six-, and eight-cylinder engines during two crankshaft revolutions. The complete circle represents two crankshaft revolutions, or 720 degrees. Less power is delivered toward the end of the power stroke, as indicated by lightening of shaded areas that show power impulses. Note power overlap on six- and eight-cylinder engines.

Fig. 3-89



Graph showing relative continuity power flow for four-, six-, and eight-cylinder engines at speeds up to 60 m.p.h.
Fig. 3-90

To give more even power, a heavy flywheel is attached to one end of the crankshaft. The momentum of the flywheel does not change much with any one power stroke, but each one can change it a little bit. As the power strokes on an "eight" overlap a little on each revolution it can have a lighter flywheel than a six.

"Pick-up" of speed means giving momentum to the car as a whole. This depends upon the momentum given to the rotating mass in the engine--pistons, rods, counterweights, and flywheel. Aluminum pistons, having less mass than castiron, give an engine less momentum. This improves pick-up, makes it easier to slow down, and cuts down gas use.

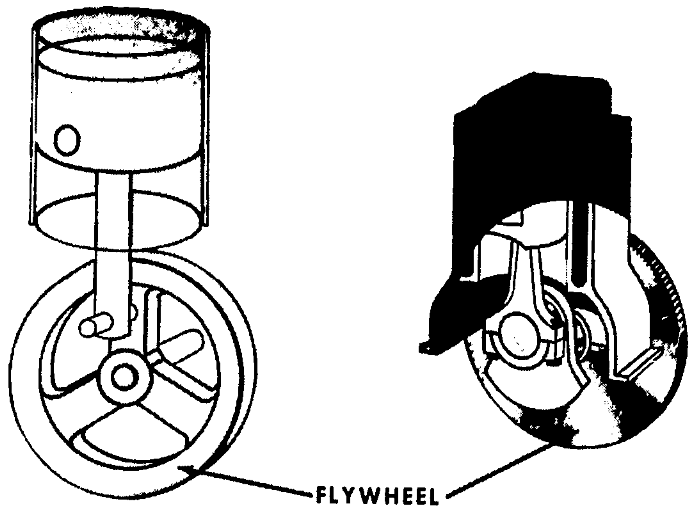
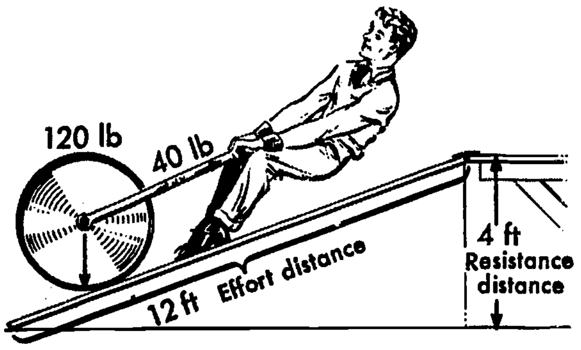


Fig. 3-91

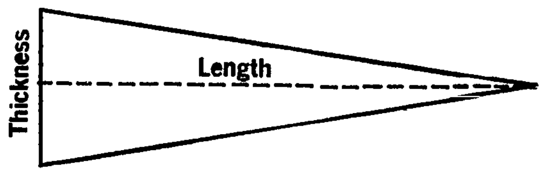
The inclined plane is the oldest and simplest machine. The boy in Fig. 3-92 finds it easier to move a 120-pound roller up on a 4-foot platform by using a 12-foot plank. Instead of 120 pounds of force, he needs only 40 pounds. The input work, 12 ft. x 40 lbs., equals the output work, 4 ft. x 120 lbs.



An Inclined Plane · The boy exerts a small force, acting through a long distance, up the plane. Thus he lifts a heavy load through a smaller vertical distance. M.A. = length of plane ÷ its height

Fig. 3-92

A wedge is an inclined plane. Instead of the resistance moving along the plane, the wedge is usually the part that is moved.



The wedge is a double inclined plane.

Fig. 3-93

Most cutting tools, like the hacksaw shown here, are forms of the inclined plane.

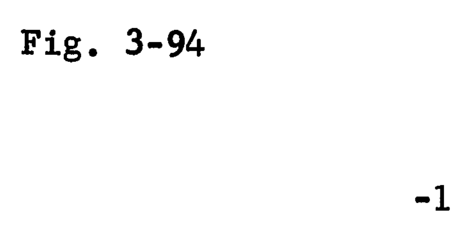
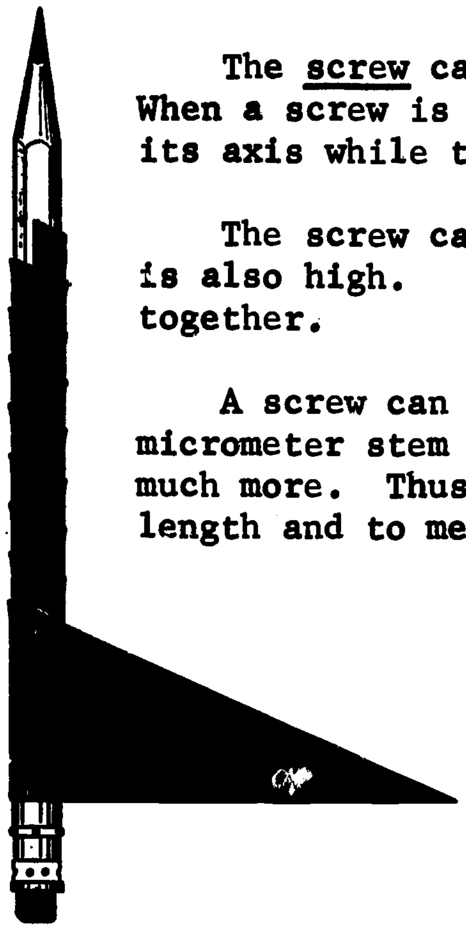


Fig. 3-94

The screw can be thought of as an inclined plane wound on an axis. When a screw is turned, the resistance moves a short distance along its axis while the effort force moves a long distance (Fig. 3-96).

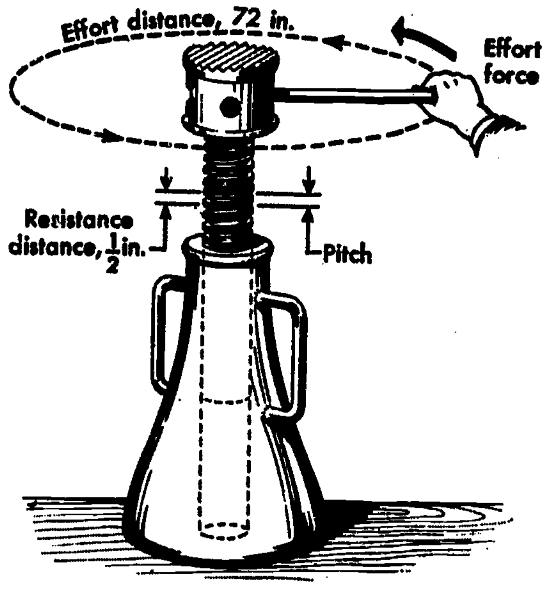
The screw can develop a high mechanical advantage, but friction is also high. This is an advantage if the screw is to hold things together.

A screw can be used to "magnify" motion. In Fig. 3-97, the micrometer stem moves a tiny distance endways while the thimble turns much more. Thus it is possible to make very fine adjustments in length and to measure them accurately.



The screw is an inclined plane wound on an axis.

Fig. 3-95



A Jackscrew • The effort force acts through a great distance, around a circle, to lift the load through a small distance. M.A. = circumference ÷ pitch of the screw

Fig. 3-96

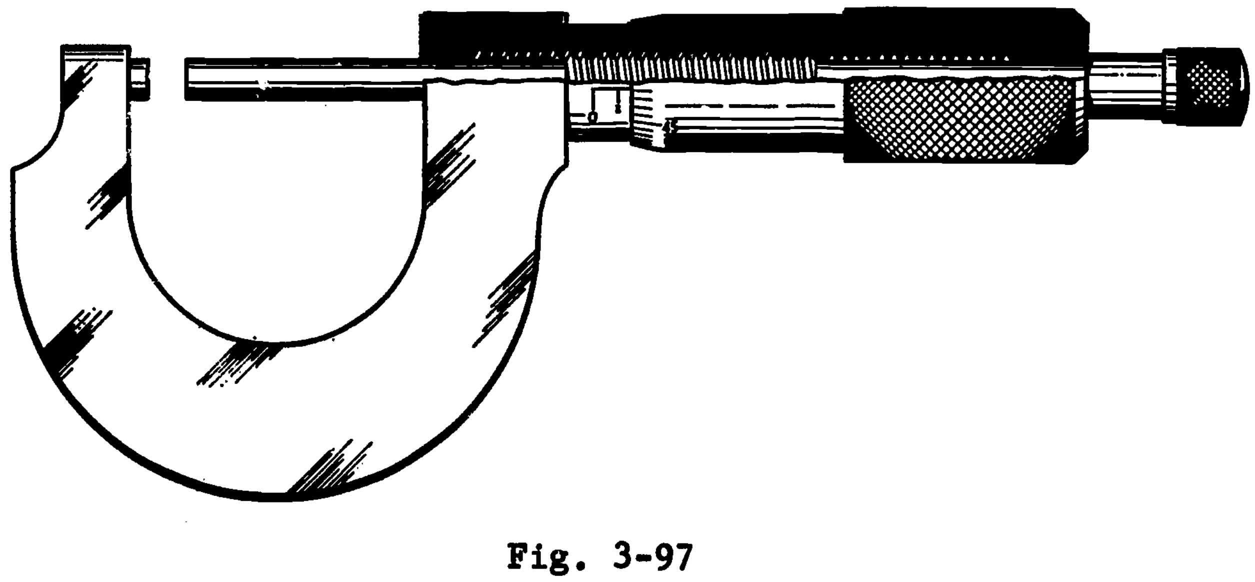
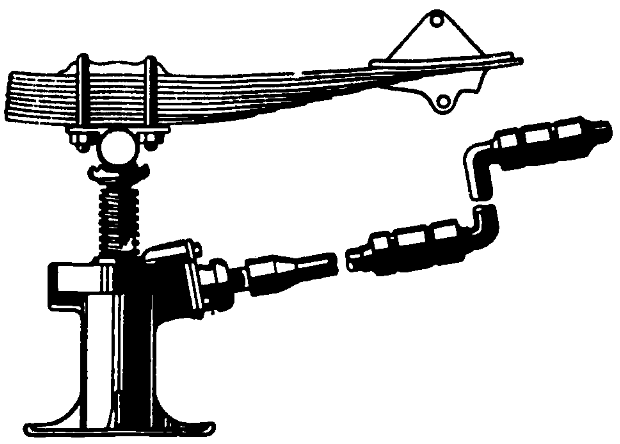


Fig. 3-97

Adjustments on carburetors, brakes, and other parts have to be fine. Screws are used for this purpose, so that a good amount of turn gives a tiny bit of end-travel.

Compound machines. When a number of simple machines are put together, they form a compound machine. The jack in Fig. 3-98, for example, combines a screw with a handle that works as a wheel and axle.

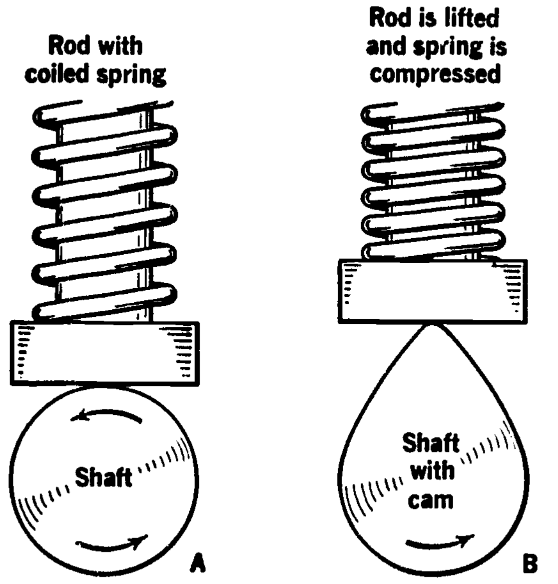


Screw Jack

Fig. 3-98

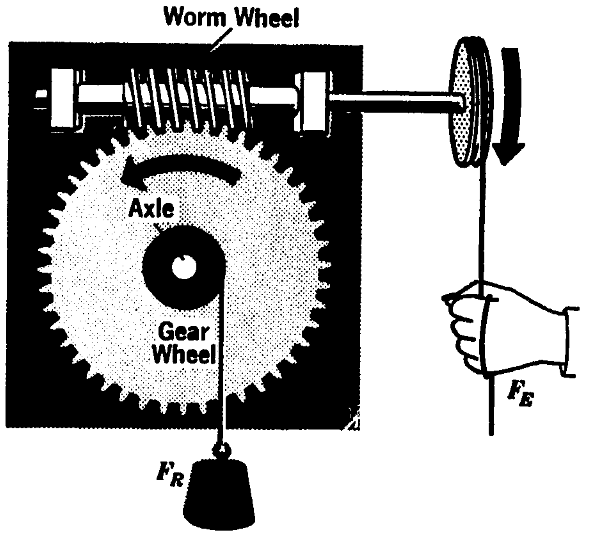
The cam is an inclined plane on a shaft.

The worm gear is a screw turned by a shaft and driving a gear.



Rotary motion is changed to reciprocating motion by means of a cam.

Fig. 3-99



The worm wheel has a high mechanical advantage, but friction may lower its efficiency.

Fig. 3-100

How many simple machines can you count in the transmission inFig. 3-101?

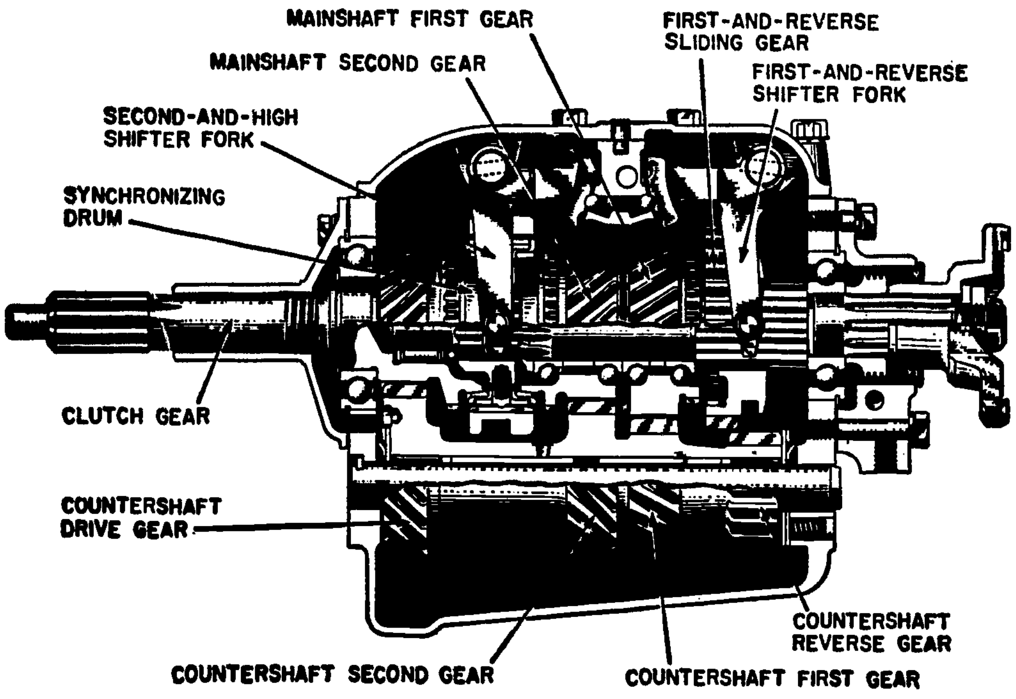


Fig. 3-101

EXPERIMENT 19. THE LEVER

A lever is a stiff bar or rod that turns around a fixed point or fulcrum as a force pushes on it. The force times its distance from the fulcrum gives you torque. When a small effort force at the end of a long arm can overcome a large resistance force at the end of a small arm, you have a large mechanical advantage. Mechanical advantage is the ratio of resistance force to effort force, or

$$M.A. = \frac{\text{Resistance}}{\text{Effort}}$$

MATERIALS: meter stick, support, 4 saddles, hook weights, balance.

PROCEDURE:

1. Prepare a page in your notebook with a data table like the following:

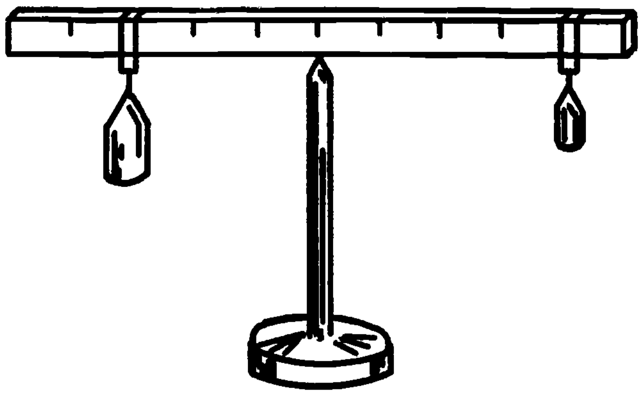
Counterclockwise			Clockwise			Mechanical Advantage
Force	Lever arm	Torque	Force	Lever arm	Torque	

2. Balance the meter stick on the knife-edge support.

3. Weigh one saddle on a laboratory balance. Hang it on the stick at some point such as 20 or 30. Note that it tends to turn the stick in a counterclockwise direction; its weight is the first counterclockwise force. Under "lever arm" write how many centimeters the center of the saddle is from the knife-edge fulcrum. Multiply to get the torque.

4. Weigh another saddle. Mount it on the other side of the knife edge, where it will balance the stick. Write down the data for this on the same line, under "clockwise." Are the torques equal?

5. Hang a 100-gram weight on one of the saddles. Record the force (sum of the weight and the saddle), lever arm, and torque.



6. On the other saddle put a different weight. Move it until the stick balances again. Fill in the data for this side. Are the torques on the two arms the same?

7. Divide the larger force (weight plus saddle) by the smaller, to calculate the mechanical advantage or leverage.

8. On one side of the lever mount a second saddle. Put a weight on it also. On separate lines record the data for these two loads. Calculate the torques and write the sum of the two in the next line. With a single saddle and weight on the other side, balance the stick. Put these data on the third line, opposite the total torque of the other side of the lever.

9. <u>Optional</u>. Mount the stick with the fulcrum at about 30. Put a saddle and weights somewhere on the short arm to balance it. The center of gravity, where the entire weight seems to act, is at the center (50). What force at that point would give a torque equal to that of the saddle and weight? How much does the stick seem to weigh? Check it on the laboratory balance.

CONCLUSIONS:

1. When a lever is in balance, what can be said of the torques?

2. When two torques act in the same direction, what is their effect?

3. In step 9 which of the forces is assumed to be the effort force? Is this always the case? Cite practical examples for your viewpoint.

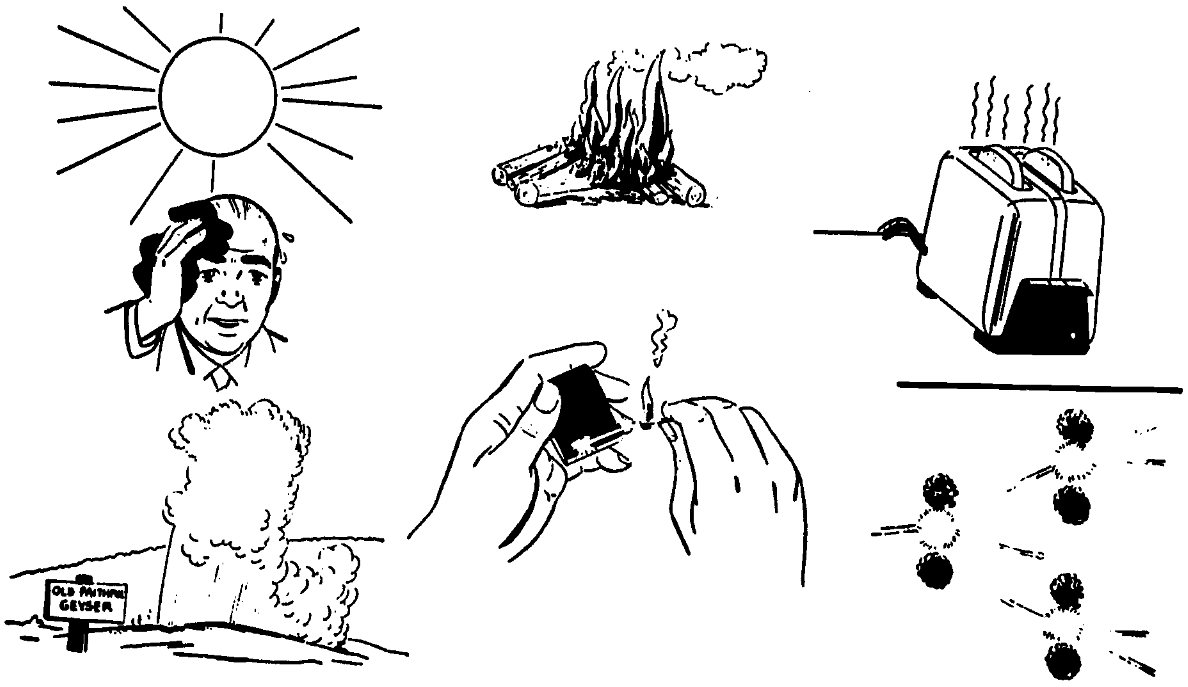
4. Why didn't the weight of the lever enter into our calculations of torque in the early part of this experiment?

5. Could you ever have a mechanical advantage of less than 1?

UNIT 4. HEAT

1. WHAT IS HEAT?

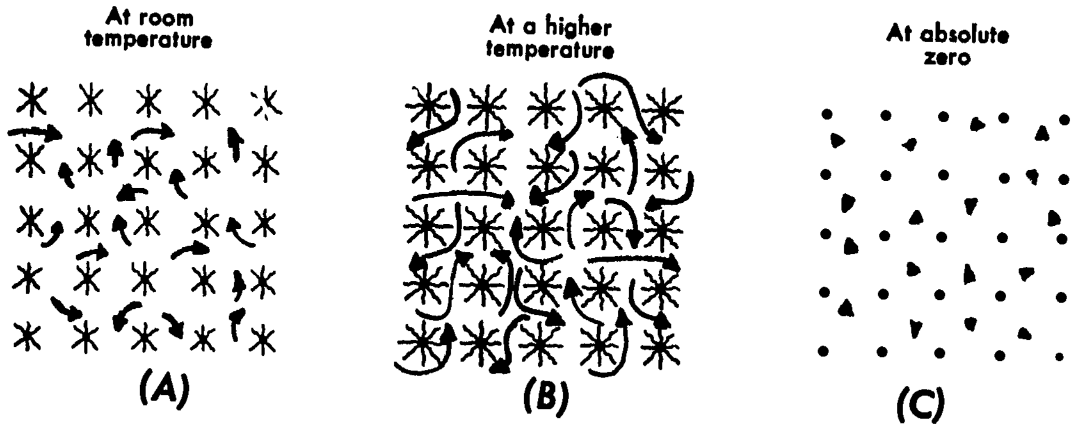
We all know that the heat of burning gasoline drives a car. Rubbing things together heats them. Electric current makes heat. It can also be gotten from under the ground, from the sun, or from nuclear reactions.



The six most important sources of heat. Can you identify each?

Fig. 4-1

Heat is a form of energy--called thermal energy--the kinetic energy of atoms and molecules in motion. Heat motion has no special direction. (Fig. 4-2). The atoms in a piece of iron stay in place but vibrate in all directions and electrons move freely around and between them. These movements average each other out, so the piece of iron as a whole does not seem to move.



A Diagram of Atoms in Iron. (A) At room temperature they vibrate. (B) At a higher temperature they vibrate more vigorously. (C) At the lowest possible temperature (absolute zero) they do not vibrate at all. At higher temperatures molecules have greater kinetic energy. Electrons (arrowheads) also move at various rates.

Fig. 4-2

We have already seen how the molecules of gases and liquids, and the electrons in a metal, are moving all the time. The temperature of something is simply a measure of the average energy of motion of the electrons, atoms, and molecules in it.

2. THERMAL EXPANSION AND MEASUREMENT

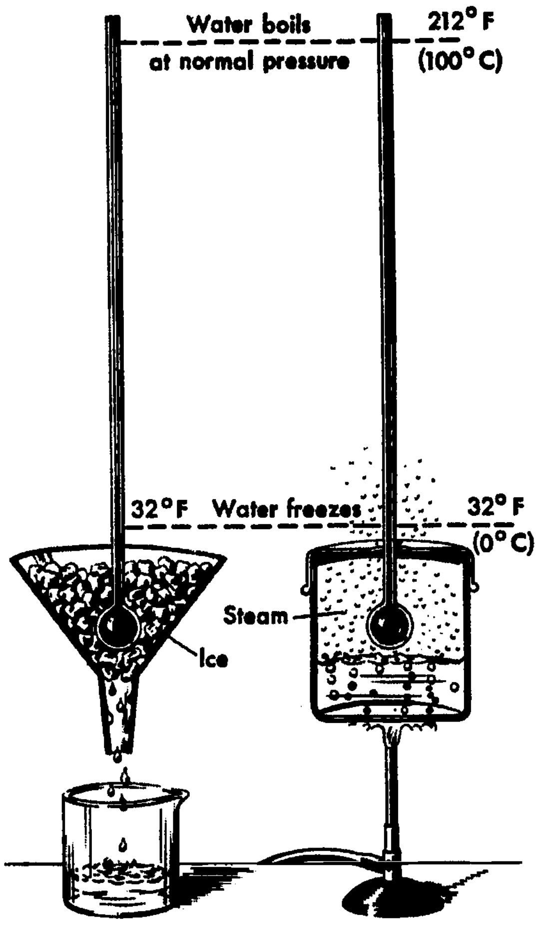
Whenever something is heated, the atoms or molecules shove each other more violently, taking more space between them. This makes the object larger, and we say it expands. When it is cooled, it contracts, or gets smaller.

Solids, liquids, and gases all expand when heated, contract when cooled. The change in volume is proportional to the change in temperature.

The expansion of gases (Charles' Law) has already been taken up.

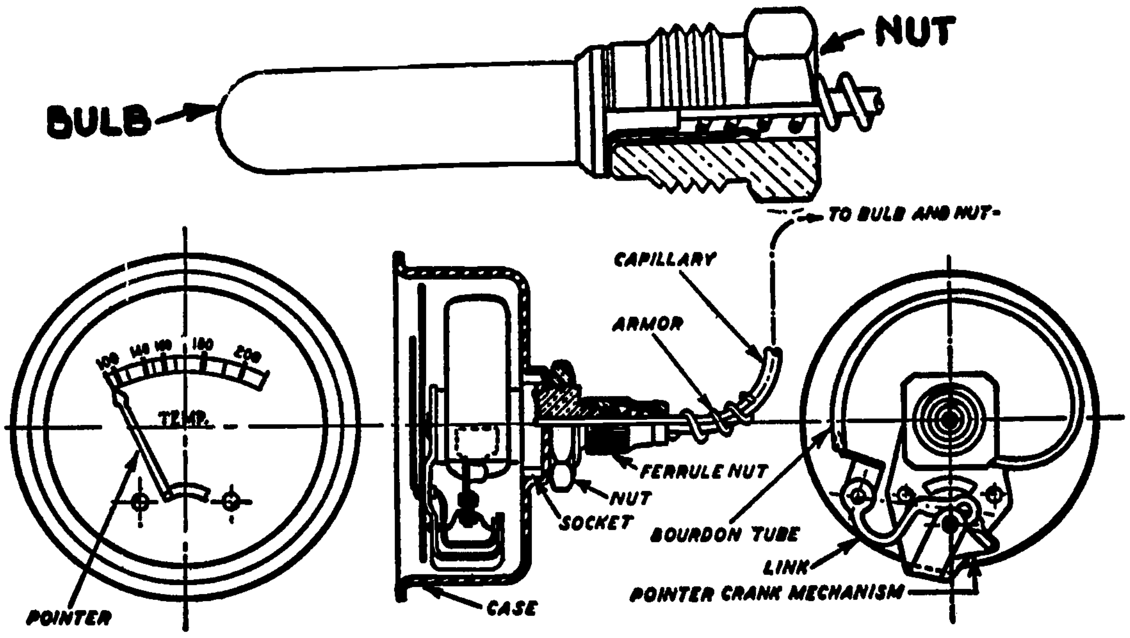
Expansion of liquids is actually used to measure temperature. In the ordinary thermometer, mercury in the bulb expands and contracts. Its volume is measured on a scale which has been set against certain exact temperatures, such as the freezing and boiling points of water (Fig. 4-3).

Expansion of a liquid, measured by a Bourdon tube like the pressure gauge we studied earlier, operates one kind of temperature indicator (Fig. 4-4).



Locating the Freezing Point and the Boiling Point on a Thermometer

Fig. 4-3



Engine-temperature indicator.

Fig. 4-4

Solids also expand when heated:

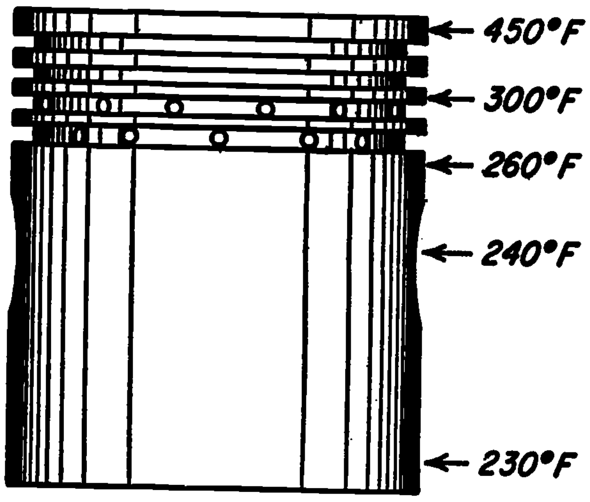
change in length = constant x change in temperature x length

The constant of expansion depends on the material. Here are the constants for some metals:

Aluminum	.000012/°F.
Brass	.000010
Copper	.000009
Cast Iron	.000007
Steel	.000006

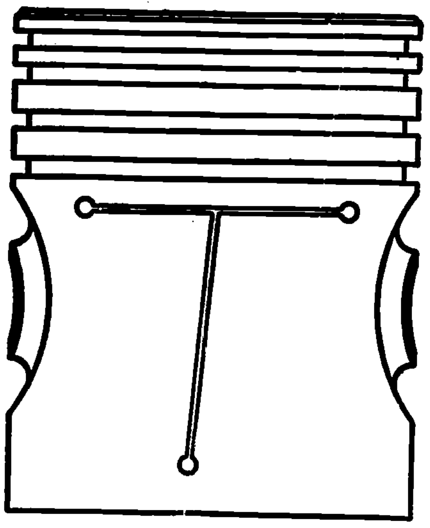
Expansion of metals takes place in many parts of a car. For example, automobile pistons have to work under a wide range of temperatures, from 0°F. in a cold engine in winter, to 450°F. (Fig.4-5). This would give a four-inch aluminum piston a change of .000012 x 450 x 4 = .0216 inches.

The piston would have to be .02 inches under size when cold so it could fit in the cylinder when hot. This would be very loose and noisy when cold.



Typical operating temperatures of various parts of a piston. (Muskegon Piston Ring Company)

Fig. 4-5



Piston with horizontal and vertical slots cut in skirt. Horizontal slot reduces path for heat travel, and vertical slot allows for expansion without increase of piston diameter.

Fig. 4-6

There are several ways to make a piston that can expand. For example, the piston in Fig. 4-6 has a slot to allow for expansion.

Another part that expands when an engine runs is the valve stem. Fig. 4-7 shows a valve with the adjustment nut used to give proper clearance. There must be enough clearance so that even when the valve gets hot and expands, it will rest on the valve seat on each cycle.

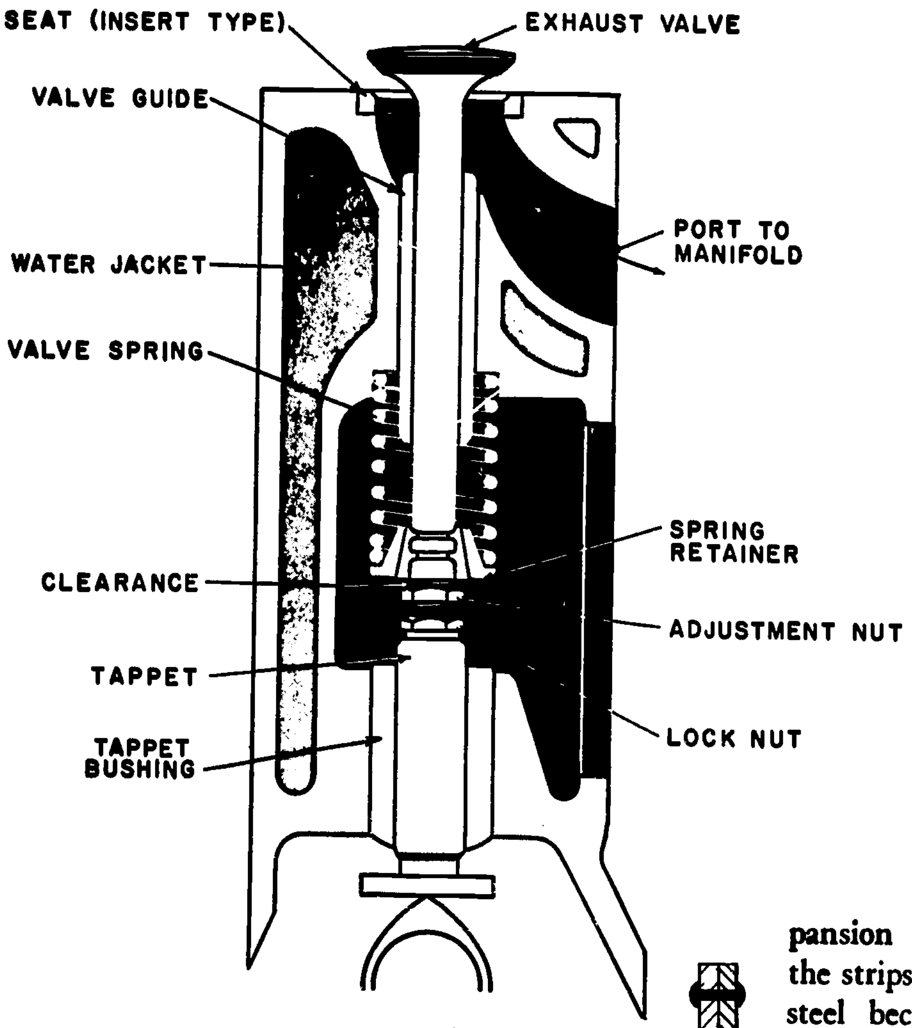
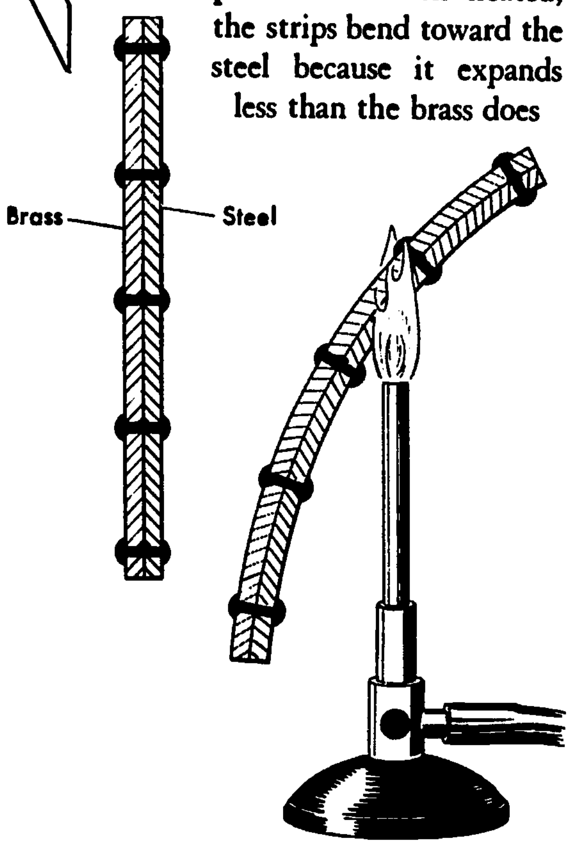
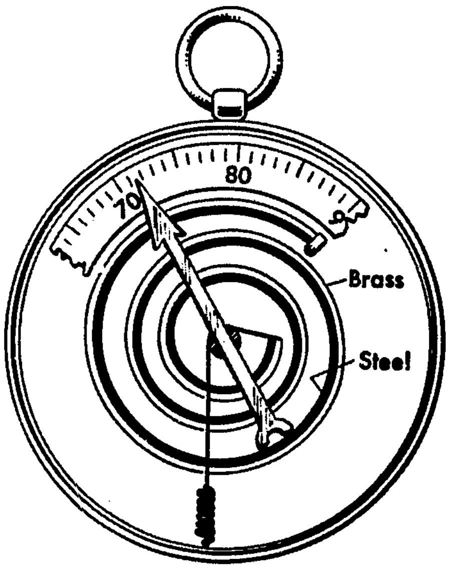


Fig. 4-7

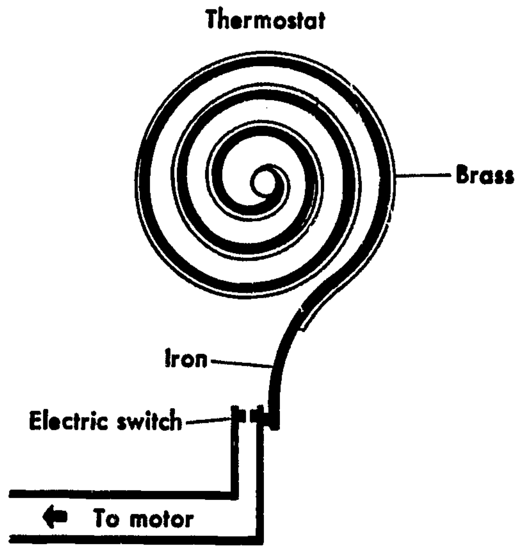
Expansion of metals can be quite useful. As we have seen, each metal expands at its own rate (measured by its "constant"). When two metals are made into a bimetal strip, as in Fig. 4-8, the strip bends when heated because of the unequal rates of expansion of the two metals. A bimetal strip can be coiled into a spiral; with an indicating needle it becomes a bimetallic thermometer. With electric contacts, it becomes a thermostat or control device.



Unequal Expansion • When heated, the strips bend toward the steel because it expands less than the brass does



A Bimetallic Thermometer • As the temperature rises, the spiral double strip unwinds and moves the pointer on the scale

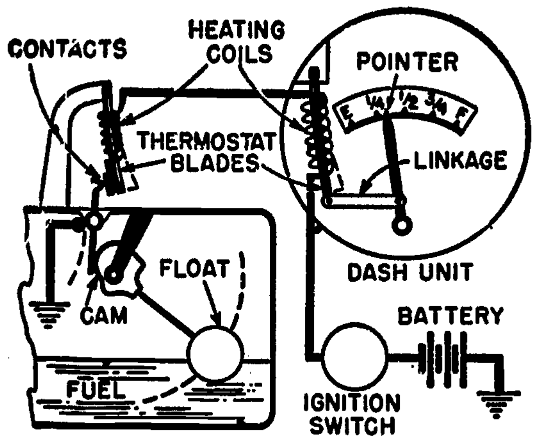


A Temperature Control •

Fig. 4-8

Thermostats are used in dashboard fuel and temperature gauges (Fig. 4-9) although temperature can also be measured by other methods, as it affects vapor pressure, resistance, or the voltage between metals.

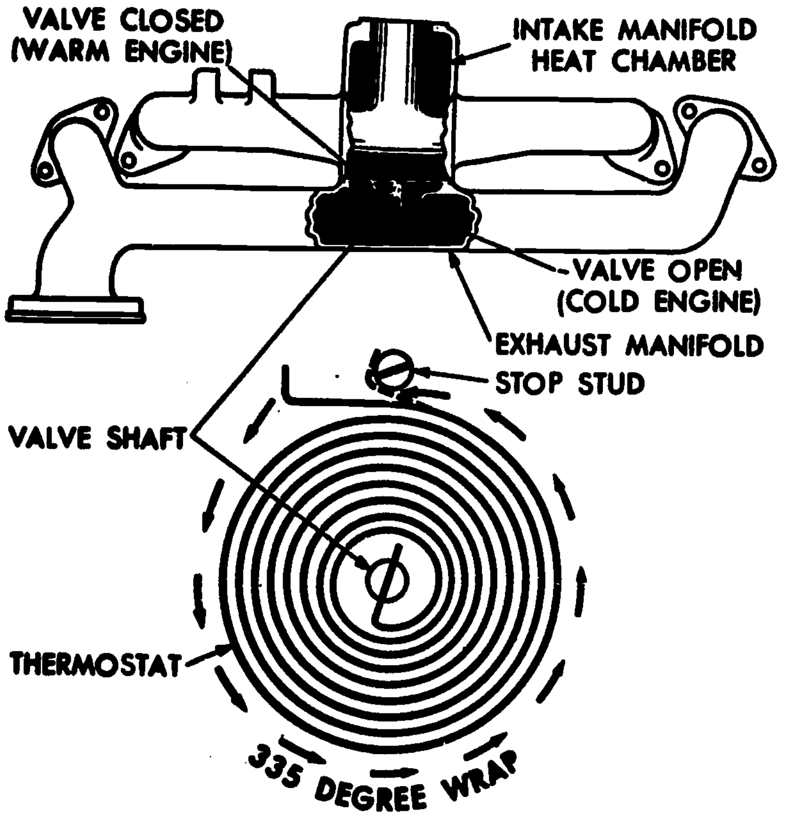
Chokes and manifold heat-control valves (Fig. 4-10) also use expansion of a bimetal spiral.



Schematic wiring circuit of thermostatic fuel-gauge indicating system.

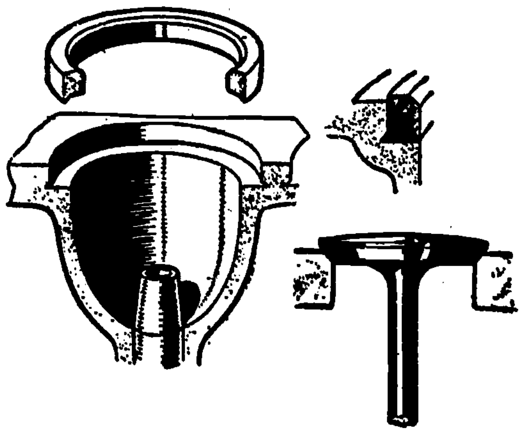
Fig. 4-9

The principle of expansion is used to fit valve seats, like that in Fig. 4-11. They are shrunk by cooling in dry ice, then put in place. Then they warm up and expand to fit tightly in place.



Manifold Heat Control Valve

Fig. 4-10



Valve-seat insert.

Fig. 4-11

EXPERIMENT 20. THERMAL EXPANSION

When metals or other materials are heated, they get larger. This is called thermal expansion. ("Thermal" means "caused by heat.") In the automobile this fact is useful in some places while it makes problems in others.

In this experiment you will study thermal expansion to see what factors determine how much a metal will expand. You will work with sections of pistons.

MATERIALS: Section of aluminum piston or other U-shaped specimen as shown, $\frac{1''}{8}$ to ¼" thick and approximately 3" across; section of iron piston of same size; section of smaller aluminum piston, 1" to 2" across; hot plate; oil; pan for heating oil; ring stand; clamp; thermometer (to 600° F.) 2" and 4" micrometers.

PROCEDURE:

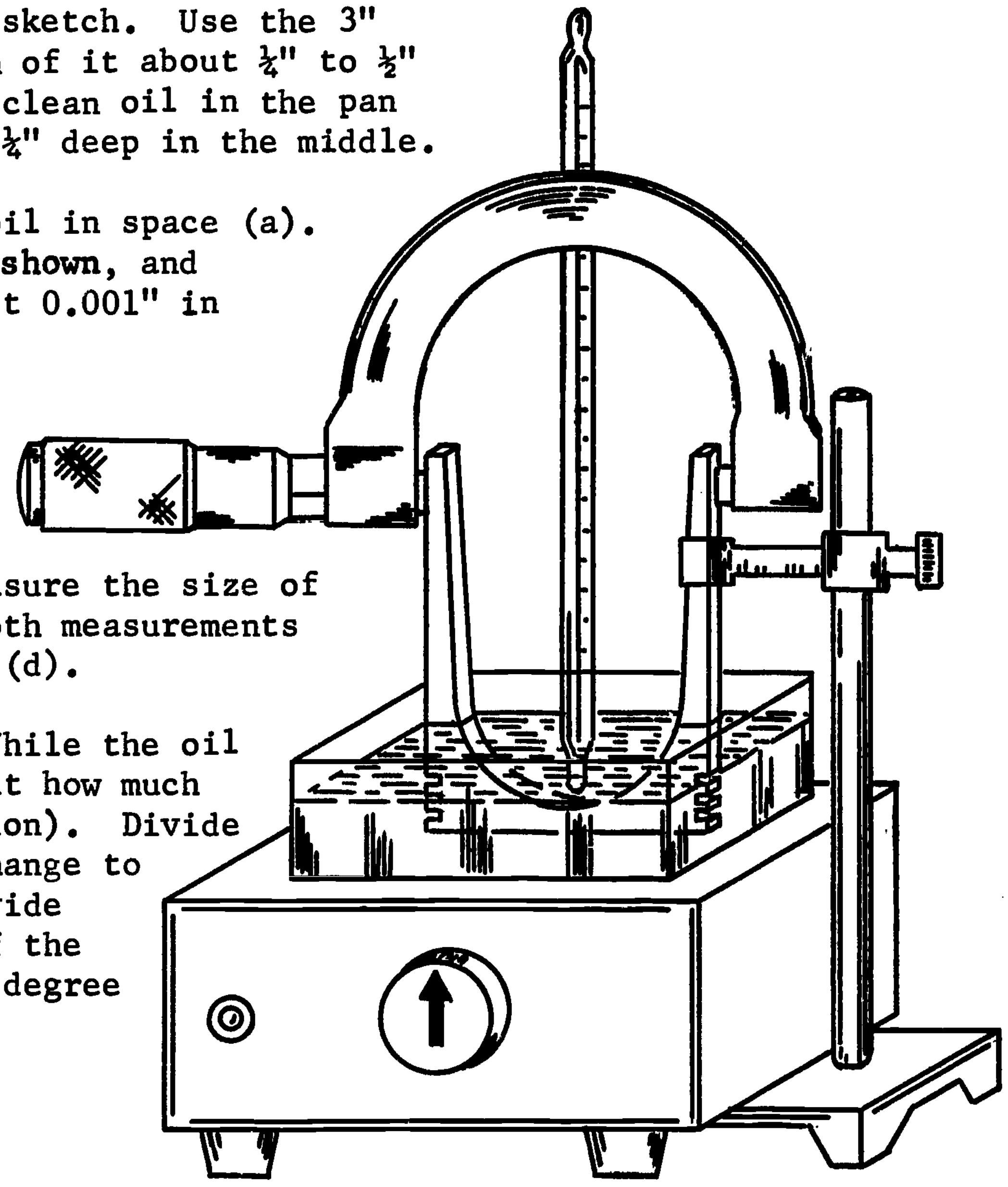
1. In your book prepare a page for the data, having a table like the one shown on the following page. Do not copy the letters in the spaces.

2. Set up the apparatus as in the sketch. Use the 3" aluminum specimen. Have the bottom of it about ¼" to ½" above the bottom of the pan. Pour clean oil in the pan until it covers the specimen about ¼" deep in the middle.

3. Record the temperature of the oil in space (a). Measure the specimen carefully, as shown, and record this dimension to the nearest 0.001" in space (b).

4. Heat the oil to between 200° and 300°, stirring it with care, so as not to break the thermometer. Turn off the hot plate. Again measure the temperature. Measure the size of the specimen carefully. Recheck both measurements quickly and record them in (c) and (d).

5. Turn on the hot plate again. While the oil is heating up to 400°-500°, find out how much the specimen expanded (by subtraction). Divide the expansion by the temperature change to find the expansion per degree. Divide this result by the original size of the specimen to find the expansion per degree per inch.



Specimen No.	1		2	3
Material	Aluminum		Aluminum	Iron
Temperature °F.	a	a		
Inches	b	b		
Temperature	c	e		
Inches	d	f		
Expansion, inches				
Expansion per °				
Expansion/°/in.				

6. When the oil has reached between 400° and 500°, turn off the hot plate and get a new set of measurements. Then cautiously take the piece from the hot oil and set it on a paper towel to cool.

7. Measure the smaller aluminum specimen accurately at room temperature. Record the temperature and width. Clamp it in the hot oil (around 400°-500°) like the first piece, wait 2-3 minutes, and measure it again. Record the temperature and size again. Calculate the expansion as you did for the first piece.

8. Do the same with the iron piece.

CONCLUSIONS:

1. What are the three factors that determine how much an object expands on heating?

2. Based on this experiment, what is your opinion of aluminum for automobile pistons?

EXPERIMENT 21. THE THERMOSTAT

To control the temperature of an engine, a thermostat is put in the water flowing to the radiator. This type of thermostat is a metal device with a bellows filled with a certain liquid whose vapor pressure makes it stretch when hot, opening a valve that lets the water through. In this experiment you will see how one works and will check the temperature at which it opens.

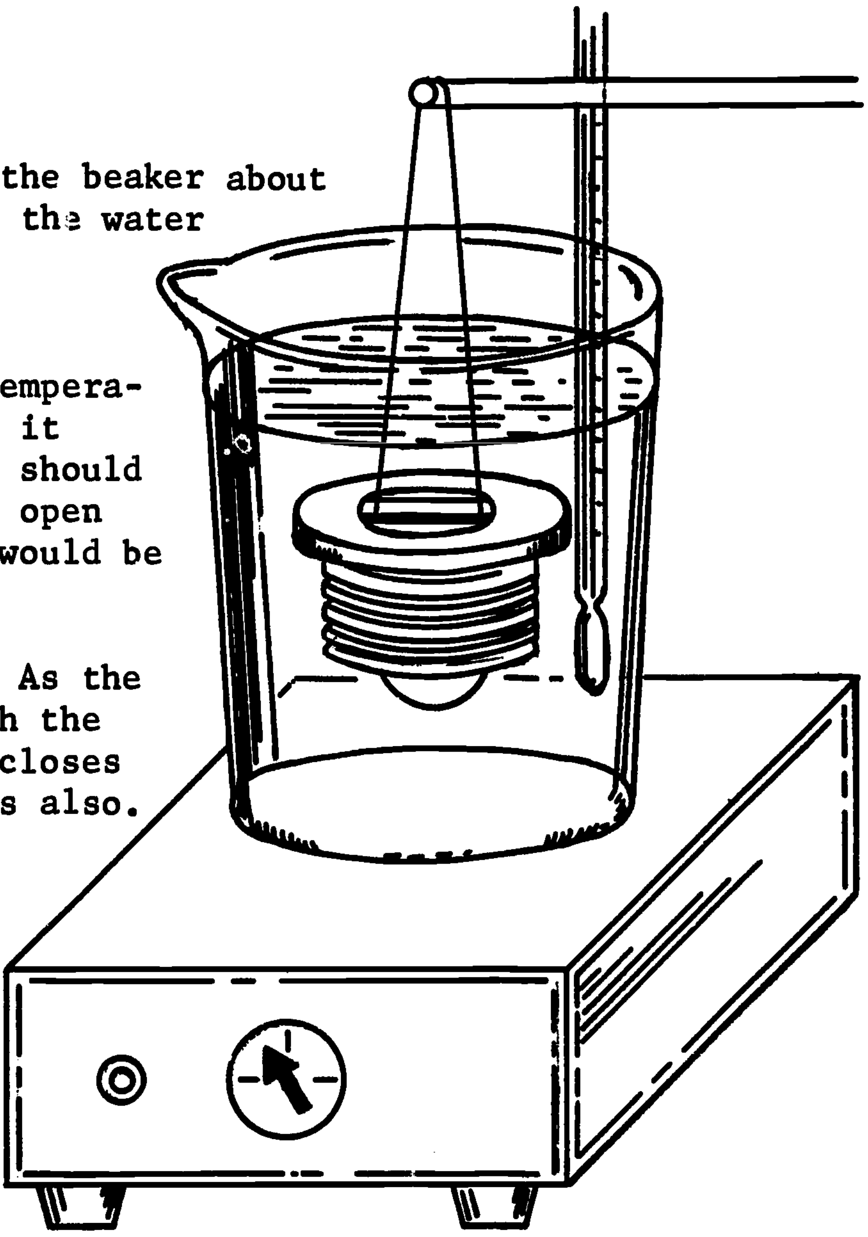
MATERIALS: Beaker, 400 ml. or 600 ml., thermometer (230°F.) water, hot plate, ring stand, clamps, wire.

PROCEDURE:

1. Set up the apparatus as shown. Fill the beaker about $\frac{3}{4}$ full of water. Hang the thermostat in the water with a piece of wire.

2. Heat the water gradually. Swish the thermostat up and down. Note the first temperature at which it begins to open and where it stops opening further. Both temperatures should be recorded. For example, if it began to open at 168^{o} and was fully open at 175^{o}, this would be written down as 168^{o}-175^{o}.

3. Turn off the hot plate or remove it. As the water cools, note the temperature at which the thermostat begins to close, and where it closes completely. Record these two temperatures also.



CONCLUSIONS:

1. Compare your results with the number stamped on the thermostat.

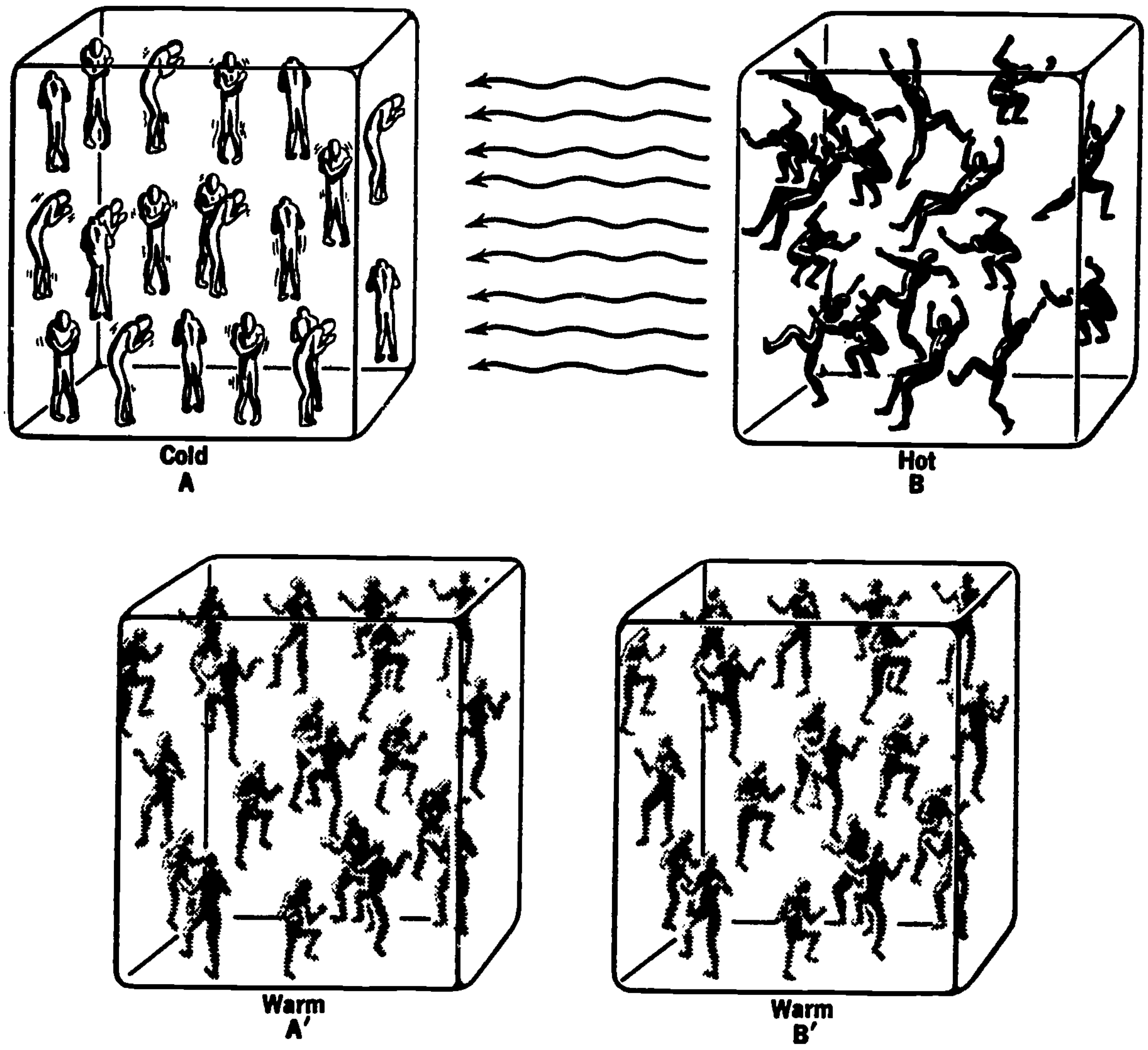
2. Is thermostatic control extremely accurate? Should it be?

3. If the liquid in the thermostat leaks out, what will happen?

4. Why is a thermostat necessary?

3. TRANSFER OF HEAT

Heat never stays in one place for very long. It tends to move to the surrounding air and objects until they are all at the same temperature (Fig. 4-12).

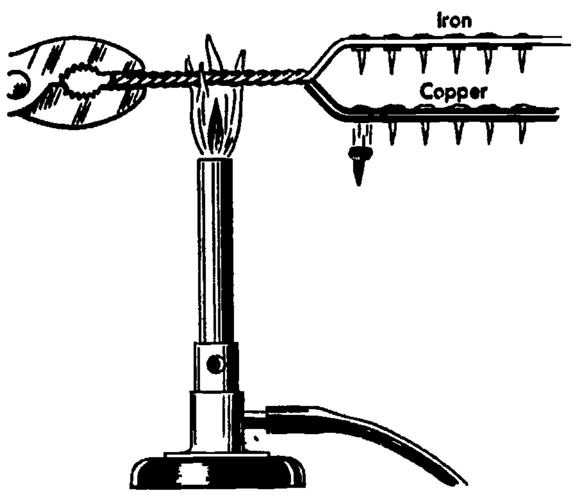


The molecules of block *A*, represented by the shivering figures, possess little thermal energy. Block *A* therefore has a low temperature—it is cold. The molecules of block *B*, represented by the jumping figures, possess a great amount of thermal energy. Block *B* therefore has a high temperature—it is hot. Since block *B* is at the higher temperature, it can transfer some of its thermal energy in the form of heat to block *A* until the molecules of both blocks have an equal amount of thermal energy—their temperatures are the same. See blocks *A′* and *B′*.

Fig. 4-12

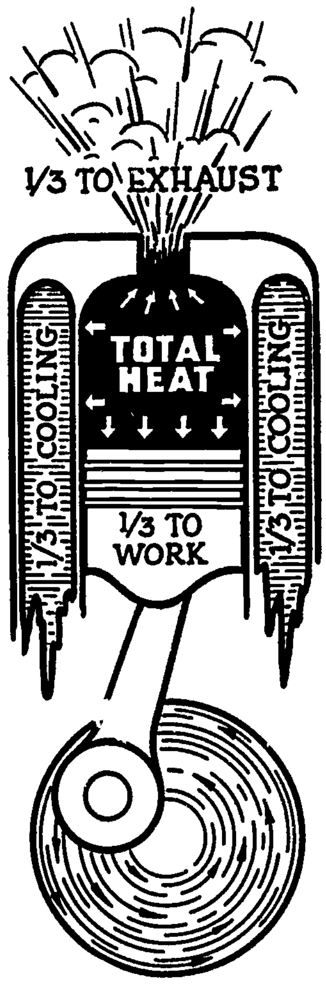
In an engine, heat from burning gas is needed to get pressure on the piston. But valves, pistons, cylinders, gasoline, and lubricants cannot stand too-high temperatures. They have to be cooled by carrying away large amounts of heat (Fig. 4-13). Heat also has to be carried away from brakes and tires.

All transfer of heat is in one (or more) of three ways--conduction, convection, and radiation. The first two are of most importance in the auto field.



Conduction • Why does the wax on the copper wire melt before that on the iron wire?

Fig. 4-14



When fuel is burned in the combustion space of an internal combustion engine, approximately ⅓ of the total heat energy does the work, ⅓ is used up in the cooling system, and ⅓ goes into the exhaust system.

Fig. 4-13

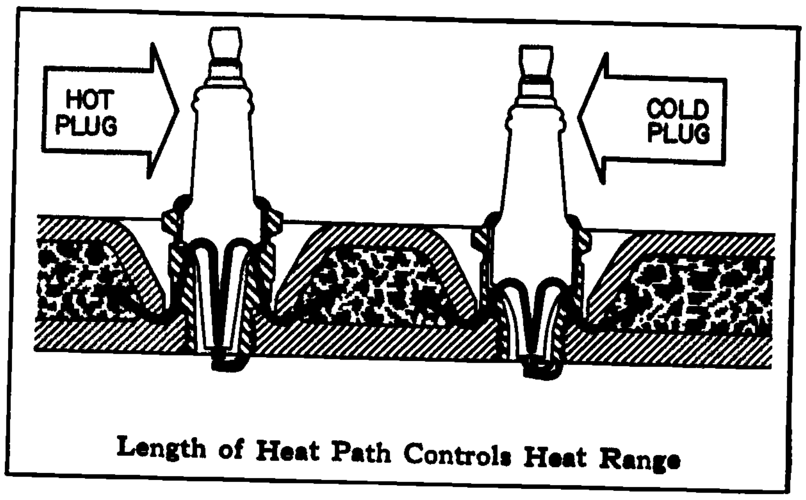
Conduction takes place in solids. Suppose a substance is heated at one end. The atoms or molecules at the hot place vibrate and, if the substance is a metal, their electrons move faster also. As these particles hit the ones near by, these move faster too. If a copper and an iron wire are twisted together, and tacks stuck to them with wax, as in Fig. 4-14, heating one end shows that copper conducts heat better than iron.

The heat conduction of common materials covers a wide range. Silver, the best conductor of all, is given a value of 100.

Silver	100
Copper	92
Aluminum	50
Iron	11
Glass	0.2
Wood	.03
Asbestos	.02
Air	.006
Water	.1

Remember how we pictured a metal as having electrons that move freely between the atoms? Metals conduct heat much better than other materials. Movement of electrons probably is the main way that heat is carried in metals.

Spark plugs have to be cooled to keep the electrodes from burning and the insulators from cracking. They are cooled by conduction of heat to the cylinder head (Fig. 4-15). If they run too cold, deposits of carbon will foul them. By having plugs with different distances for the heat to travel, they can be made "hot" or "cold".



Length of Heat Path Controls Heat Range

Fig. 4-15

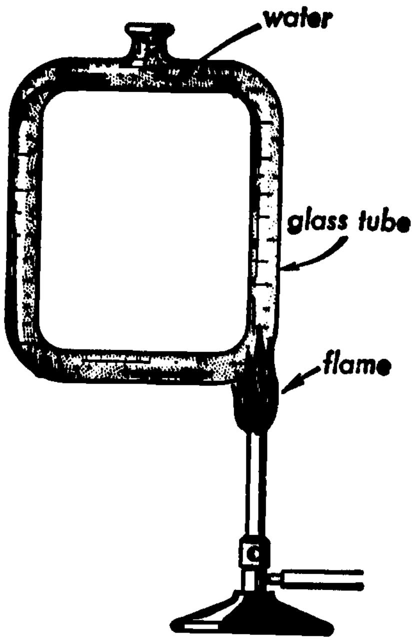
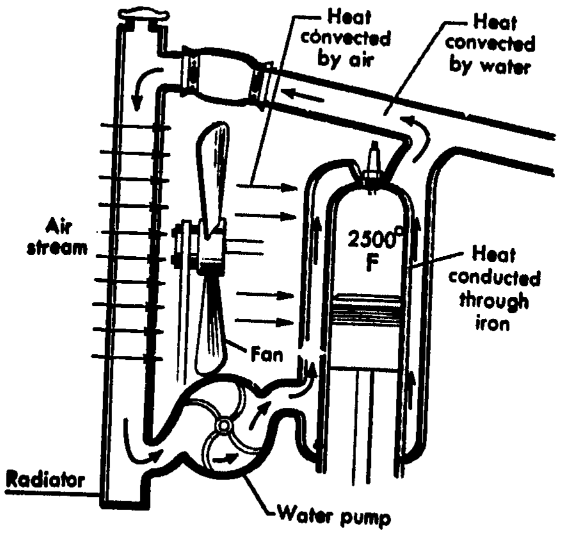


Fig. 4-16

Convection is the second way that heat moves from one place to another. Only fluids (gases and liquids) transfer heat by convection. Natural convection comes from warming a fluid at one place. It becomes lighter and rises (Fig. 4-16), and cooler fluid flows in to take its place. Thus a circulation is set up.

In the cooling system of a car, the water is heated by the engine. If we let it circulate naturally, this would be too slow to do much cooling, so a pump is used to force the water around (Fig. 4-17) to where it can be cooled rapidly by the cool air coming through the radiator.



The Cooling System of a Car • The pump forces water to circulate, and the water carries heat away from the engine to the radiator. Then what becomes of the heat?

Fig. 4-17

Heat transfer in the engine. There are some key places in the cooling system where heat has to be carried well:

1. Cylinder head. Aluminum is used for its good conduction.

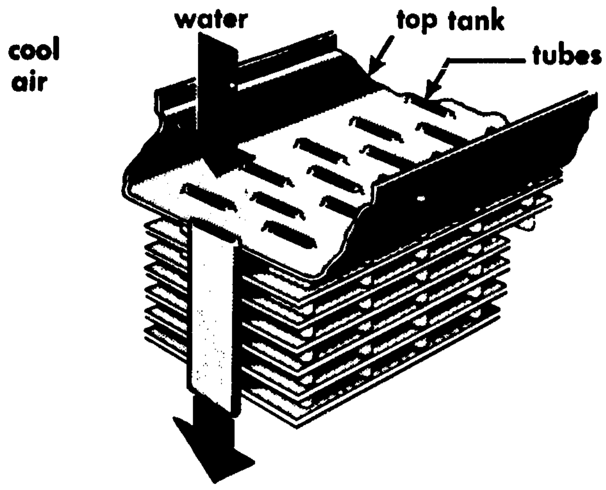


Fig. 4-19

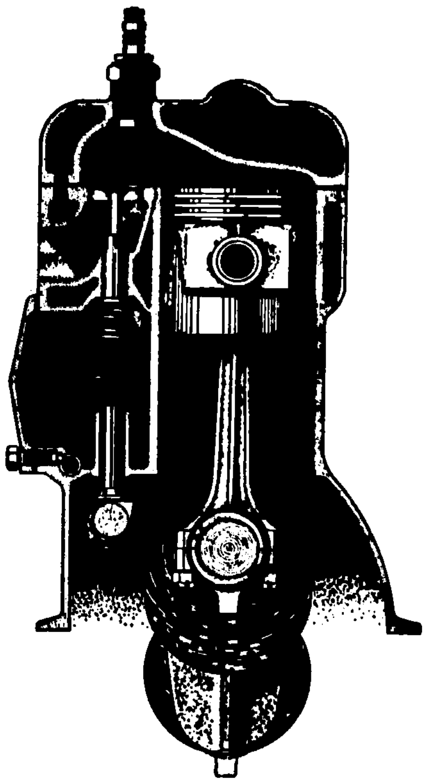


Fig. 4-18

2. Radiator. Copper alloys are used, and the tubes are made very narrow so that a small amount of water is surrounded by a large amount of cool air. The little passages tend to clog up with grease and rust from the engine, though, and the air side may become blocked by dead insects, etc.

3. Engine water jacket. Rusty scale, due to air and acid in the water, can coat the block.

4. Valves. Exhaust valves run very hot. Unless they make good contact with valve seats, valves will burn.

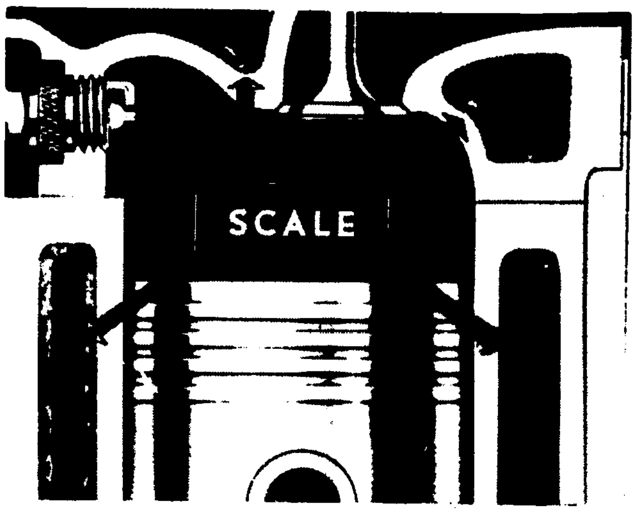
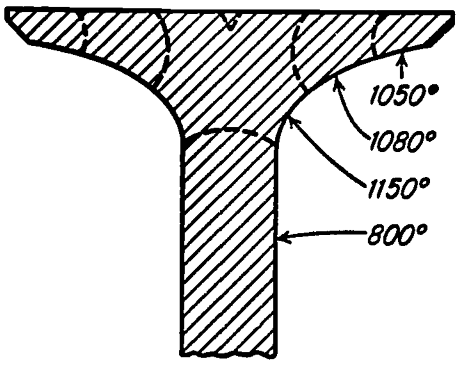
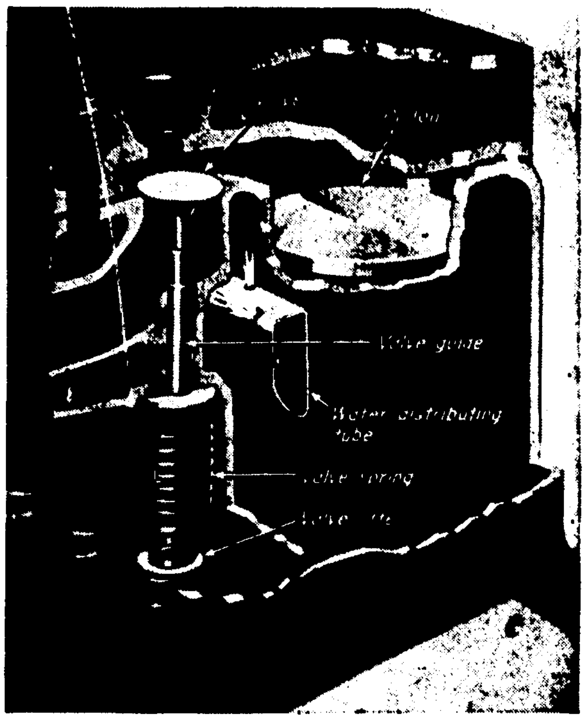


Fig. 4-20



Temperatures in an exhaust valve. Valve is shown in sectional view.

Fig. 4-21



Use of water-distributing tube to cool valve.

Fig. 4-22

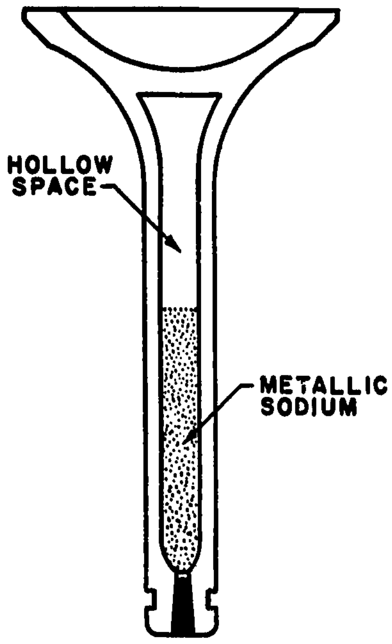
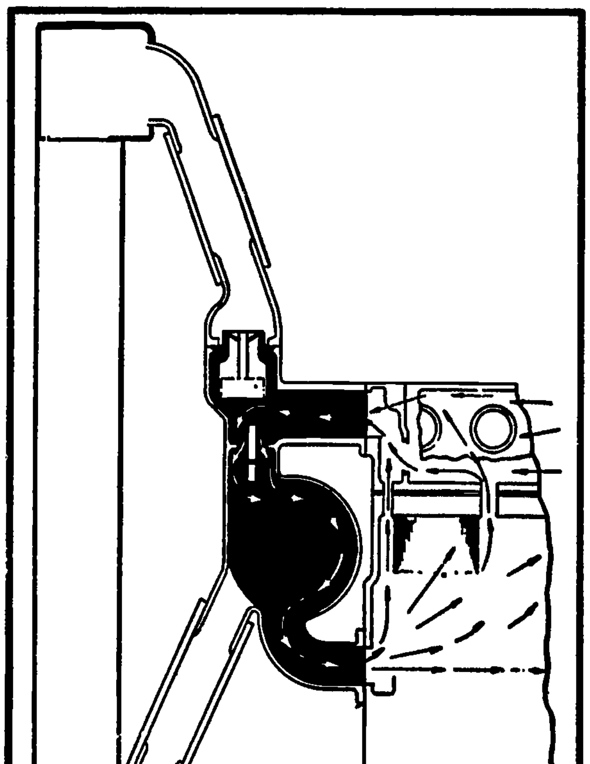


Fig. 4-23

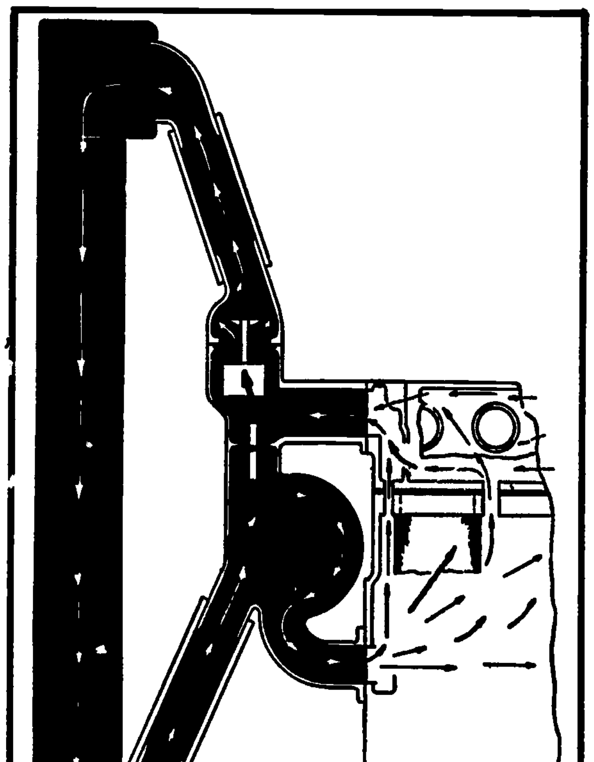
Special tubes or nozzles are used in some engines to cool valve seats (Fig. 4-22).

Some valves are made hollow and partly filled with sodium. Sodium is a metal that melts at 208°F. It splashes up and down as the engine runs, carrying heat from the valve head to the stem.



Location of thermostat in water passage between cylinder head and radiator. Engine is cold, thermostat closed, and bypass valve open. Water circulates as shown by arrows.

Fig. 4-24



Circulation of water with thermostat open. Some systems incorporate a bypass valve as shown here

Fig. 4-25

5. Thermostat. When the engine is cold, the thermostat is closed (Fig. 4-24). When the engine heats up, the thermostat opens to let water into the radiator (Fig. 4-25).

6. Combustion chamber. Carbon or lead deposits can coat the cylinder head. They are poor conductors, so they get very hot and pre-ignite the fuel.

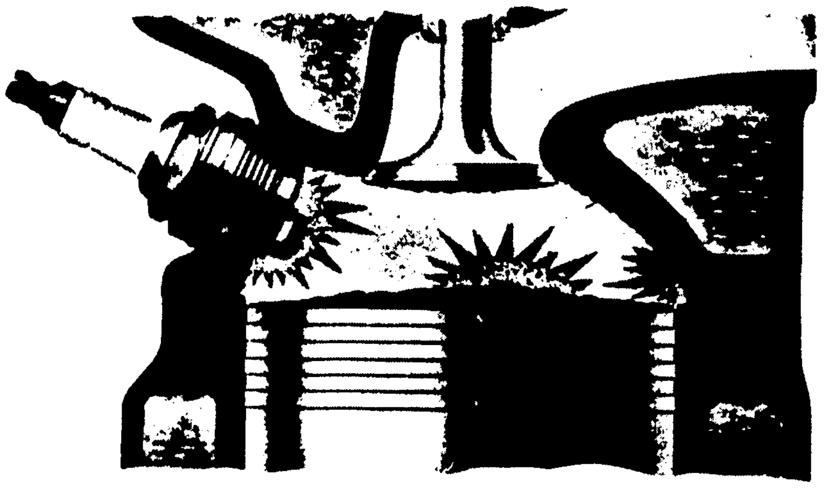
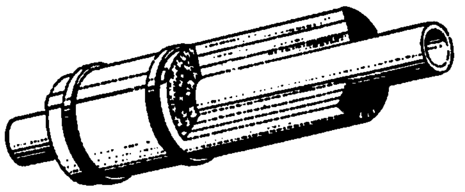


Fig. 4-26

Heat transfer to air. Automobile engines are cooled by passing their heat to water and from the water to the air around the cooling system. Heat is carried off by the air in proportion to the amount of surface exposed and how fast the air passes over the hot surface. Even when an engine idles, the fan (Fig. 4-17) pulls air over the large surface of the radiator.

Air-cooled engines (Fig. 4-27) have fins on the cylinder block to increase the surface area, and they often have a fan as well.



Steam-Pipe Insulation • How does it prevent convection and conduction?

Fig. 4-28

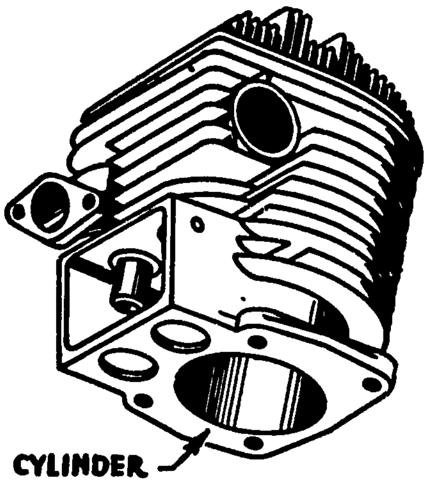


Fig. 4-27

Air compressors also have fins to help remove the heat that you get in compressing a gas.

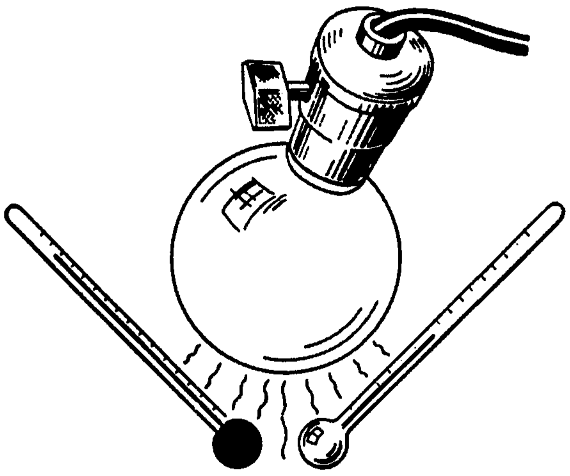
Heat insulation. To keep heat from being carried away when we don't want it to be, insulators are used. These are materials that are poor conductors, such as paper, cloth, or asbestos.

Air is one of the best insulators, if it is blocked so it cannot move by convection, as in fluffy rock wool or cloth. Rust in the water jackets of an engine, as shown in Fig. 4-20, acts as an insulator; it holds a layer of water in place, like a blanket.

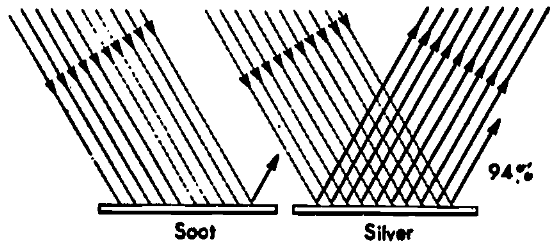
Radiation. This the third way that heat is transferred from one place to another.

All warm objects give off radiation--an invisible form of light rays called infra-red light. White or reflective surfaces bounce most of it away, but when this infra-red light hits dark surfaces, it is absorbed and turns into heat.

Absorption of radiant energy from the sun is what makes dark cars quite hot in the summer. It is this same principle that makes the snow in winter melt much faster from a (dark) asphalt road or driveway than from a (light) concrete one.



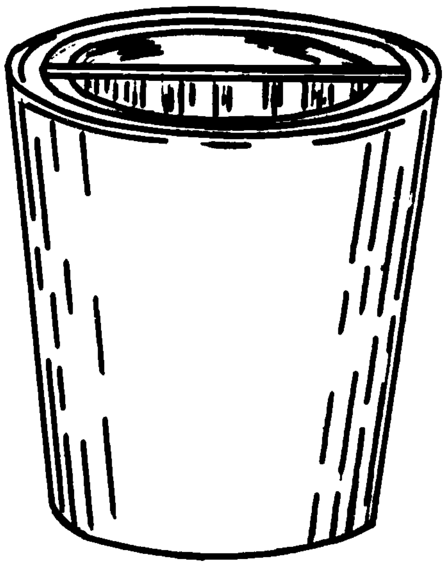
Absorption • The blackened thermometer bulb absorbs heat rays, but the silvered bulb reflects them. Black bodies are good absorbers



Good and Poor Absorbers • Soot absorbs about 97 per cent of the sun's rays. Polished silver absorbs about 6 per cent

Fig. 4-29

EXPERIMENT 22. HEAT TRANSFER



It might be said that without the transfer of heat from hot places to cold, an automobile engine would last only a minute or two. Do you agree?

Certainly in our engines today, good heat transfer is vital. In this experiment you will study some of the factors that control how fast heat is transferred.

Your main piece of equipment will be a Styrofoam cup with a partition across the middle of it. The partition, which will be available in different materials, is held in place by two halves of another, identical cup. You will pour hot water in one side and cold water in the other, and see how fast heat passes through various kinds of walls.

MATERIALS: Styrofoam cups, partitions as described in the table below; stopclock; thermometer (230°F.); ringstand and thermometer clamp; containers of water, boiling and cold.

PROCEDURE:

1. Gather the apparatus required, checking especially that the partitions form a fairly water tight joint with the wall of the cup.

2. Prepare a page in your notebook for the experiment, with a table like the one below.

3. Put your thermometer in the container of cold water until the reading stays the same.

4. Set the cup on the table with the thermometer in one side. Fill the two sections about $\frac{2}{3}$ full of water at the same time and to the same height--the empty one with boiling water and the other (with the thermometer) cold with water. Start the stopclock at once. Read the thermometer and read it again every minute for five minutes.

Partition Material	Thickness (inches)	Temperature, °F.							Change, °F.	Change/Min.
		min.	0	1	2	3	4	5		
Aluminum										
same, stirred cold side										
same, stirred hot side										
Copper										
Steel										
Steel										
Alum., cloth taped to side										
same, stirred cloth side										
same, stirred bare side										

5. Find the temperature change over the whole five minutes. Divide it by five to find the rate of change per minute.

6. In the same way test the other partitions listed in the table, or such ones as your instructor may suggest. Start with the thermometer in the container of cold water, as in (3).

7. (Optional) Make a graph of the temperature during the various tests. Do them all on the same graph paper, using different symbols for each test.

CONCLUSIONS:

1. Compare the metals as heat conductors.

2. How important is the thickness of the metal?

3. What conditions in an engine are like a layer of cloth on the partition?

4. Why is the rate of heat transfer not the same each minute?

5. Explain why stirring changes the rate of heat transfer.

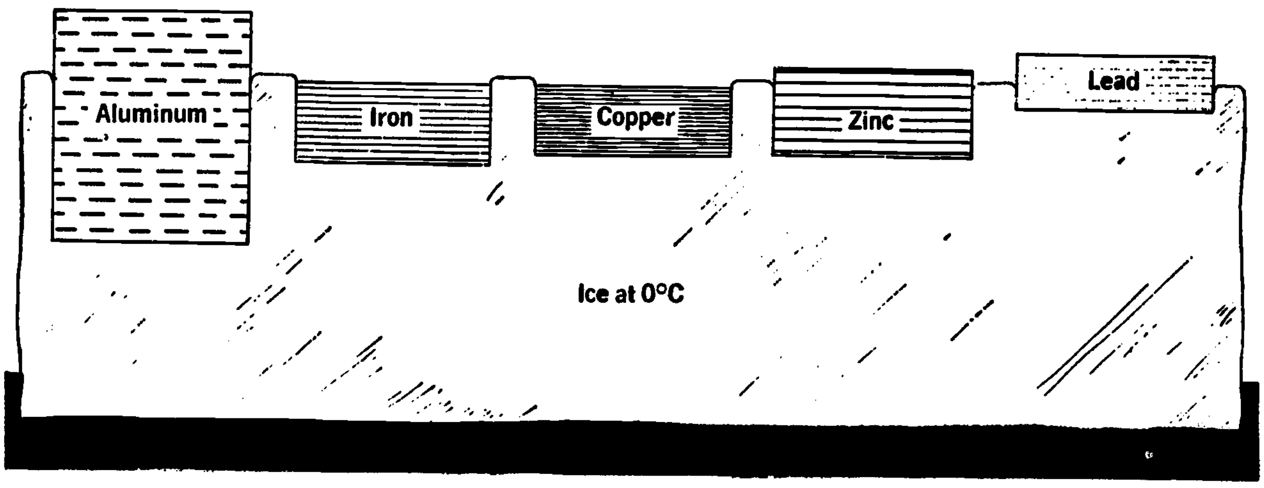
4. CHANGE OF STATE.

Heat quantities. The amount of heat that it takes to do things is measured in BTU's (British Thermal Units). One BTU will heat a pound of water one degree Fahrenheit. In the metric system, heat is measured in calories. A calorie will raise a gram of water one degree centigrade.

Other materials are easier to heat than water. For example, a pound of iron takes only about $\frac{1}{10}$ BTU to heat it up a degree.

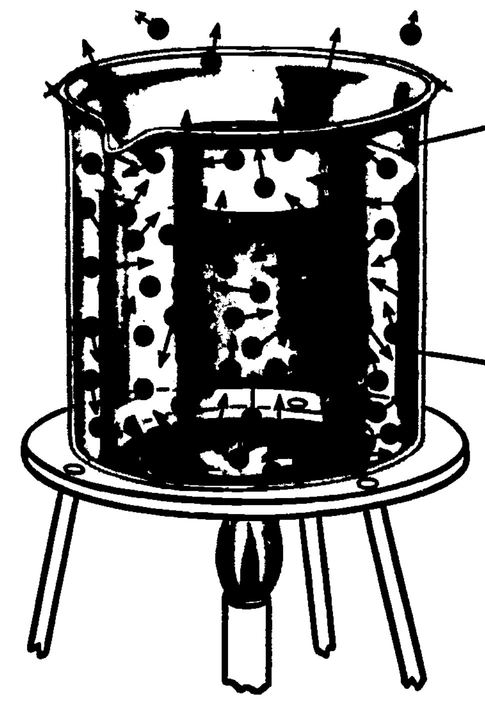
The same weight of different metals, heated to the same temperature in boiling water, will melt different amounts of ice (Fig. 4-30). This shows that they have absorbed different amounts of heat.

Water can absorb more heat than most substances. For this reason water is very valuable in cooling other substances (absorbing heat from them.)



Because metals have different heat capacities, these blocks, all of equal mass and heated to the same temperature, melt the ice to different depths.

Fig. 4-30



As a Beaker of Water is Heated the Heat is Absorbed Causing (1) the Molecules to Move Faster (Raising the Temperature) and (2) Causing the Molecules to Break Away from Each Other into the Gaseous State (Evaporation) · At the boiling point all of the energy absorbed is used for vaporization of the liquid and hence the temperature remains constant at the boiling point

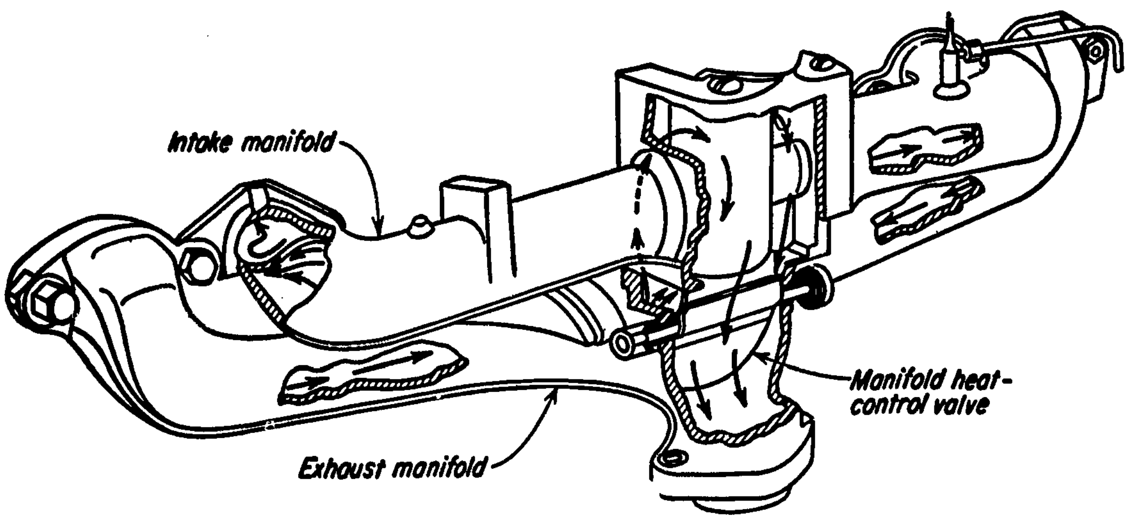
Fig. 4-31

The quantity of heat needed to melt a pound of ice is 144 BTU. The same number of BTU's is given off when a pound of water freezes.

The amount of heat that a pound of water takes in while evaporating or boiling is 967 BTU. Compare this with the 180 BTU that it takes to raise the pound of water from the freezing point to the boiling point. As you can see, the amount of heat that water takes up in evaporating is very large. As a result, water cools hot things very fast.

If an engine has run dry, parts will get too hot and expand. Then if water is put in, it will boil where it hits the hot metal. The part that is cooled fastest will shrink the most. As one end of a head, for example, contracts while the other stays large, it can warp permanently or even crack.

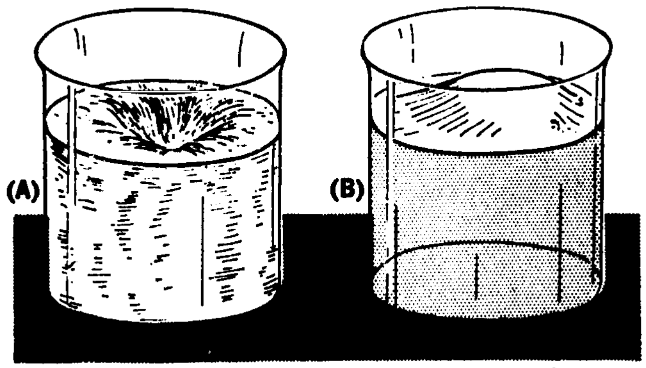
Other liquids, such as gasoline, absorb heat in vaporizing, too. We have seen that this can cool the intake air enough to turn water vapor into ice (Fig. 2-53). If heat were not furnished to the gasoline, it would not vaporize completely. Parts of it would stay liquid, washing oil from the cylinder walls, diluting the oil in the crankcase and turning to sludge there. To vaporize the fuel, modern engines have a heater in the intake manifold (Fig. 4-32).



Relationship between intake and exhaust manifolds, showing the thermostatically controlled manifold heat-control valve and directions of intake and exhaust gases with valve in cold-engine position.

Fig. 4-32

Ice. One of the odd things about water is that it expands when it freezes. When water in an engine freezes, it has to have more space. It can break a block, head, or radiator as it expands. Antifreeze in the water lowers its freezing point and prevents this. Even small amounts of antifreeze protects an engine from cracking; a soft, mushy ice forms which is too weak to do harm. This mush is no good for cooling, though, because it cannot circulate. It can cause the engine to overheat and may do damage that way.



Paraffin contracts when it solidifies

Water expands when it freezes

(*A*) Most substances are like paraffin and contract when they solidify. (*B*) Water is one of a few substances which expand on solidification.

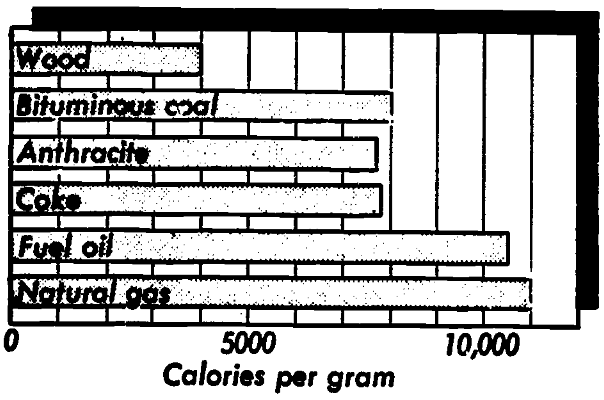
Fig. 4-33

Heat-energy equivalents. The automobile is built to change energy from one form (chemical energy "stored" in gasoline) into another (energy of motion). Its efficiency,

$$\frac{\text{useful work output}}{\text{total work input}}$$

shows up as miles per gallon when you drive a car.

How much energy does gasoline contain? It is possible to measure this by burning gasoline carefully in a bomb calorimeter and seeing how much warmer the water gets. Many tests of this kind have been done (Fig. 4-35); gasoline gives about 11,000 calories per gram, or 20,000 BTU per pound.



The amount of heat in equal weights of different fuels shows considerable variation.

Fig. 4-35

How much work can this heat do? The amount of work that heat is equal to, can be found, as in Fig. 4-36. Say that a weight of one pound is allowed to fall a distance of one foot, stirring the water with the paddles. This is one foot-pound of work. This would have to be done 778 times to heat a pound of water a degree Fahrenheit, so

778 foot-pounds = 1 BTU

(Using electricity to heat the water instead of fuel or motion, we can also find the electrical equivalent of heat.)

The bomb calorimeter is used by chemists to measure the amount of heat in a given weight of a sample of fuel.

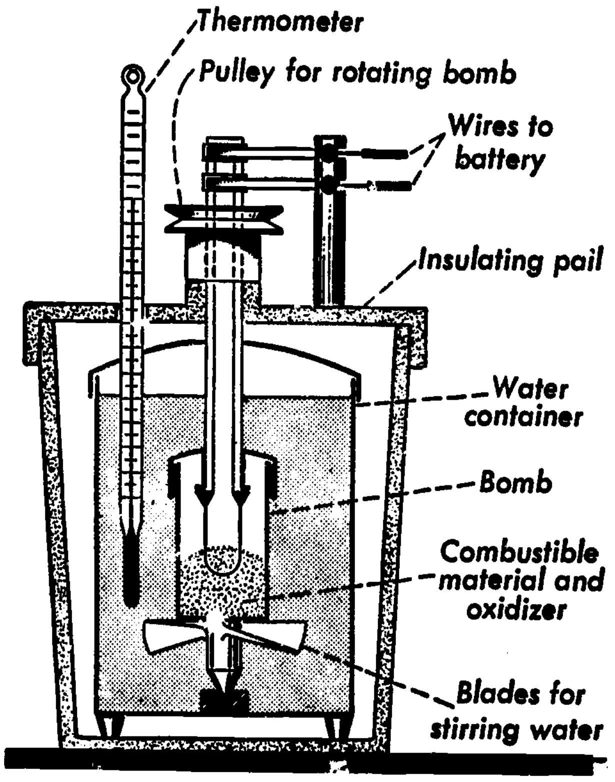
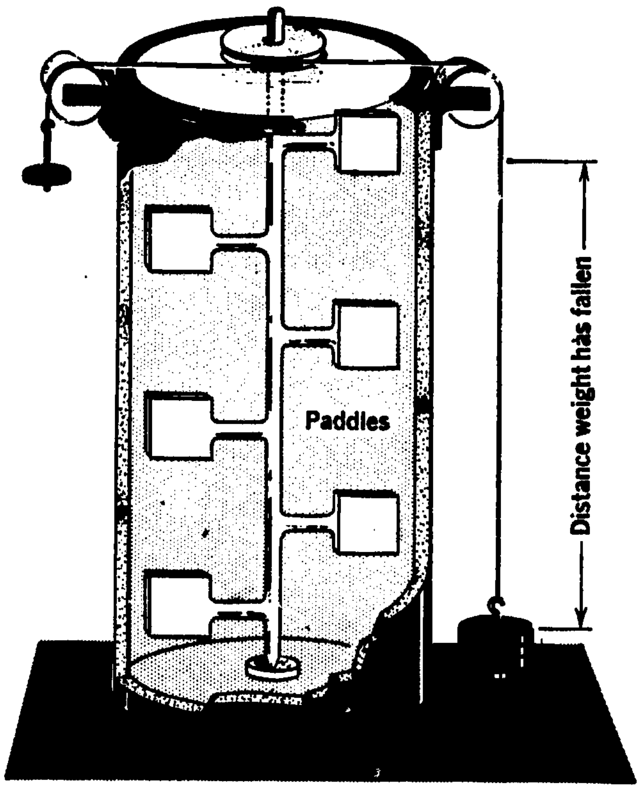


Fig. 4-34

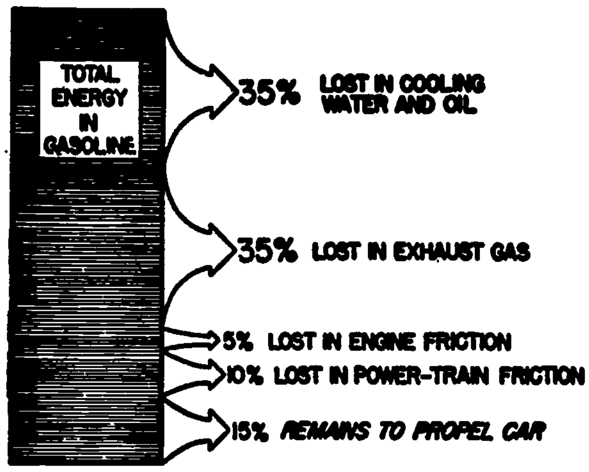


A simplified form of the apparatus Joule used to determine the mechanical equivalent of heat.

Fig. 4-36

From the facts given, you can see that a gallon of gasoline (about 7 lbs.) will give about 7 x 20,000 x 788 foot-pounds of work when burned. The actual figure is 108,920,000 foot-pounds. Fig. 4-37 shows that only about 15% of this energy is spent rolling over the road, pushing air out of the way, and speeding up the weight of the car.

The actual power output of a car is measured on a dynamometer (Fig. 4-38) and with other instruments. Such tests are explained in books like Crouse, Automotive Mechanics (Chapter 4).



Energy loss from cylinders to wheels.

Fig. 4-37

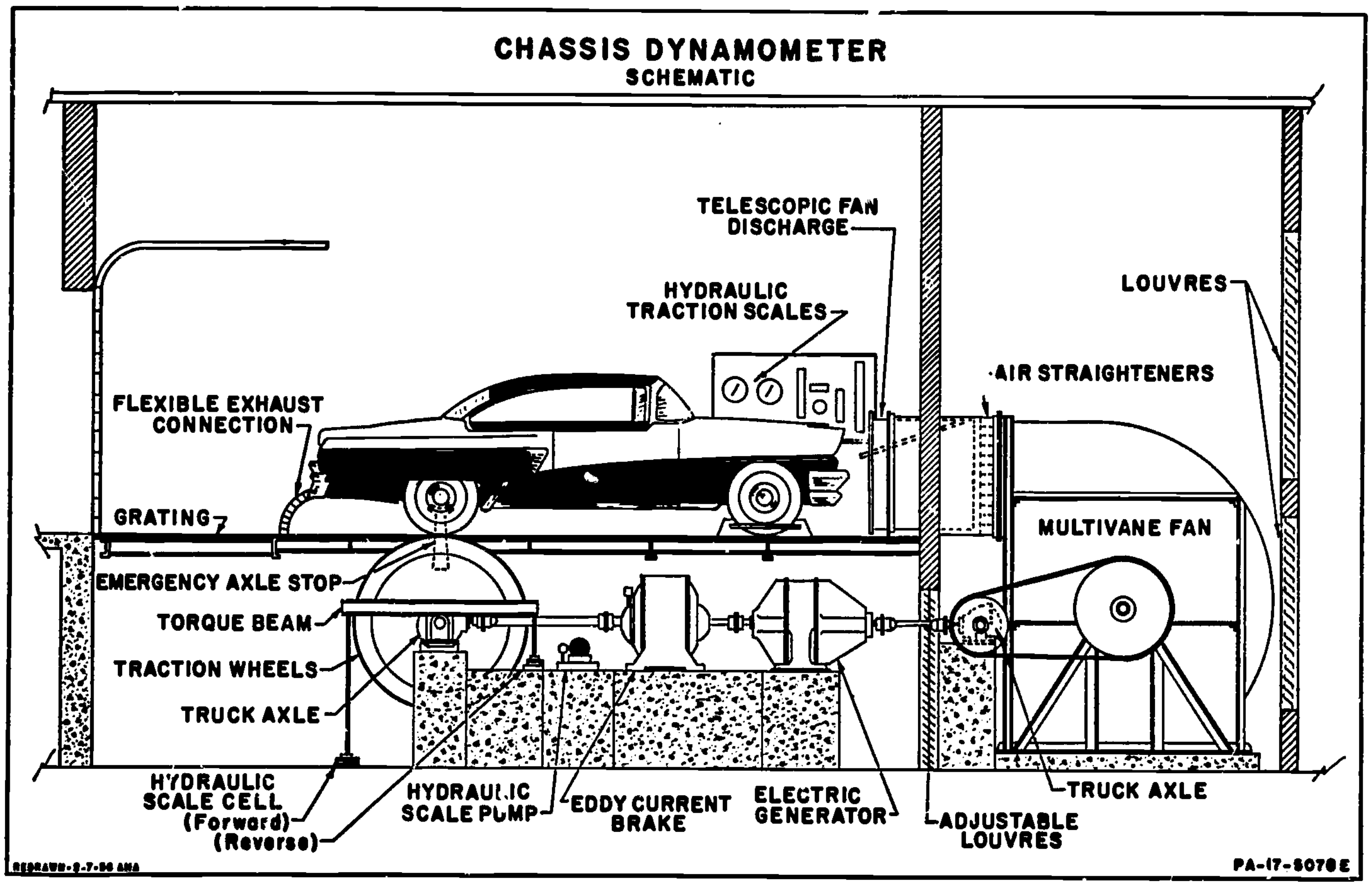
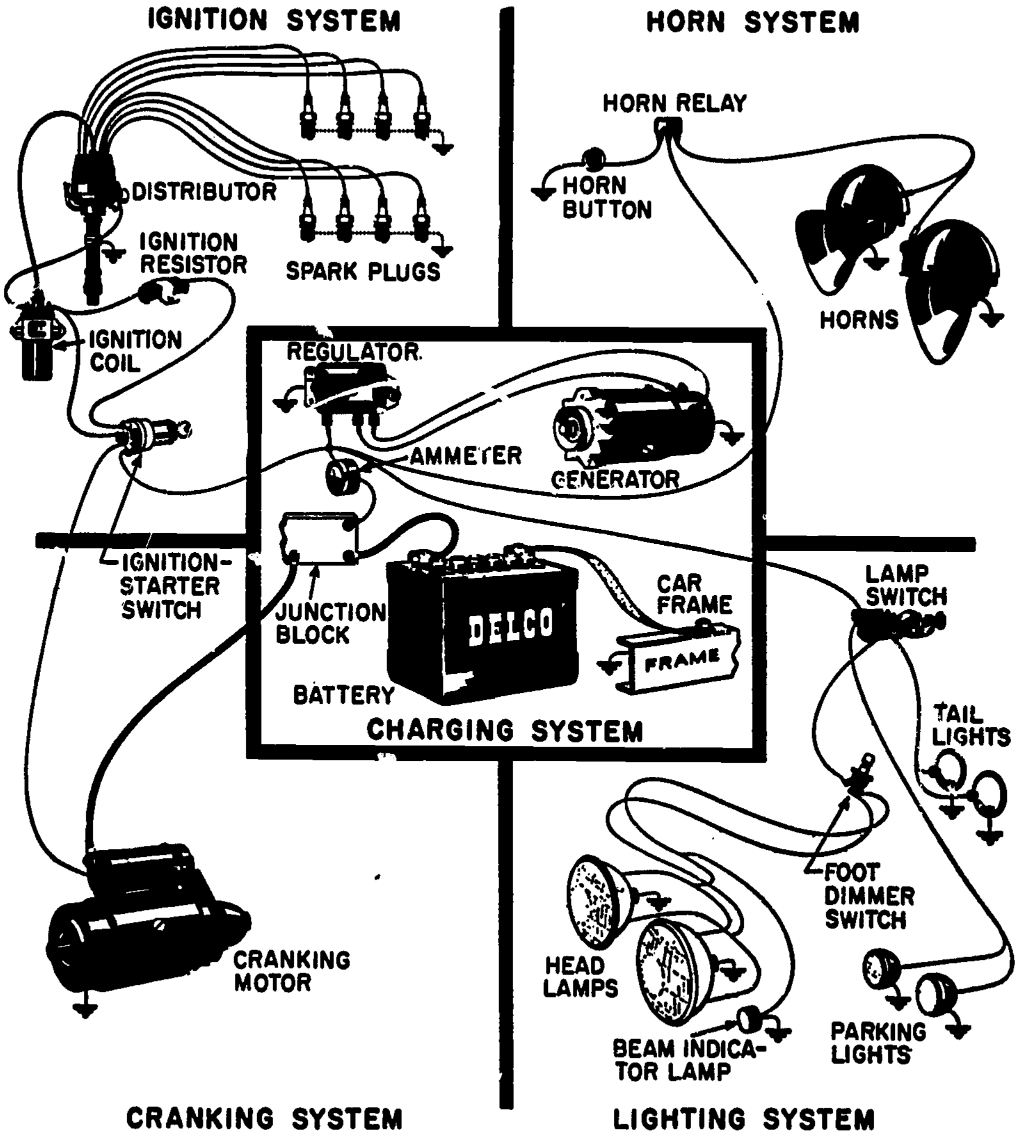


Fig. 4-38

UNIT 5. ELECTRICITY

You know how many electric devices there are in a car (Fig. 5-1). This unit will deal with the principles on which they are based.



A typical car electric system, illustrating the electric units and the connections between them. The symbol ⏚ means ground, or the car frame. By using the car frame as the return circuit, only half as much wiring is required. (*Delco-Remy Division of General Motors Corporation*)

Fig. 5-1

1. STATIC ELECTRICITY

In Unit 1 you learned that all matter is made of atoms, which have a nucleus surrounded by electrons.

In metals, the electrons fill spaces between the atoms as if they were fluid, like water in a bed of sand (Fig. 5-3). They can move around easily among the atoms.

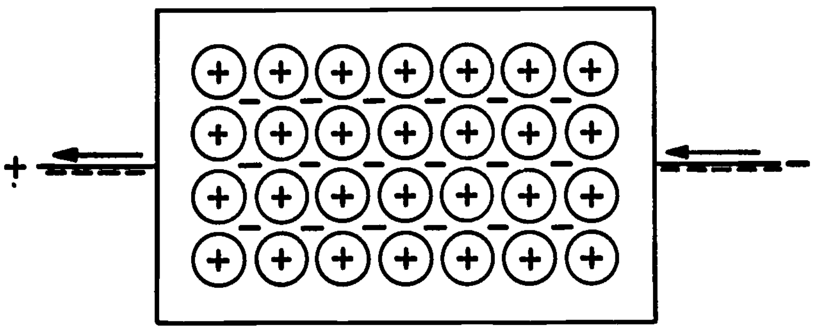


Fig. 5-3

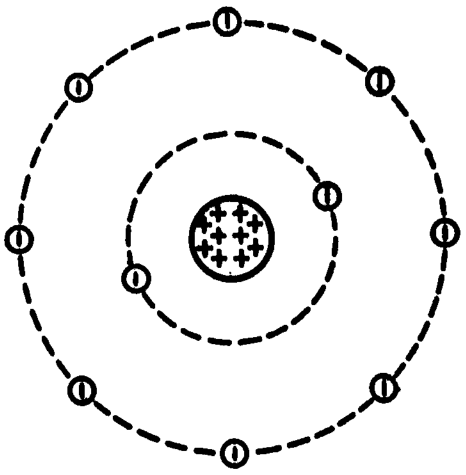


Fig. 5-2

Electricity is the science of electrons and their effects. When something has the same number of electrons as it has protons, it is electrically neutral. This is how most things are.

When you slide across the plastic seat covers of a car, electrons rub off your clothes onto the plastic fibers, building up a charge on your clothing and on you, which can cause a spark or a shock when you touch something that is grounded.

The same sort of thing happens when you rub a hard rubber rod with fur, or a glass rod with silk. With these rods (Fig. 5-4) we can learn an important rule of electricity:

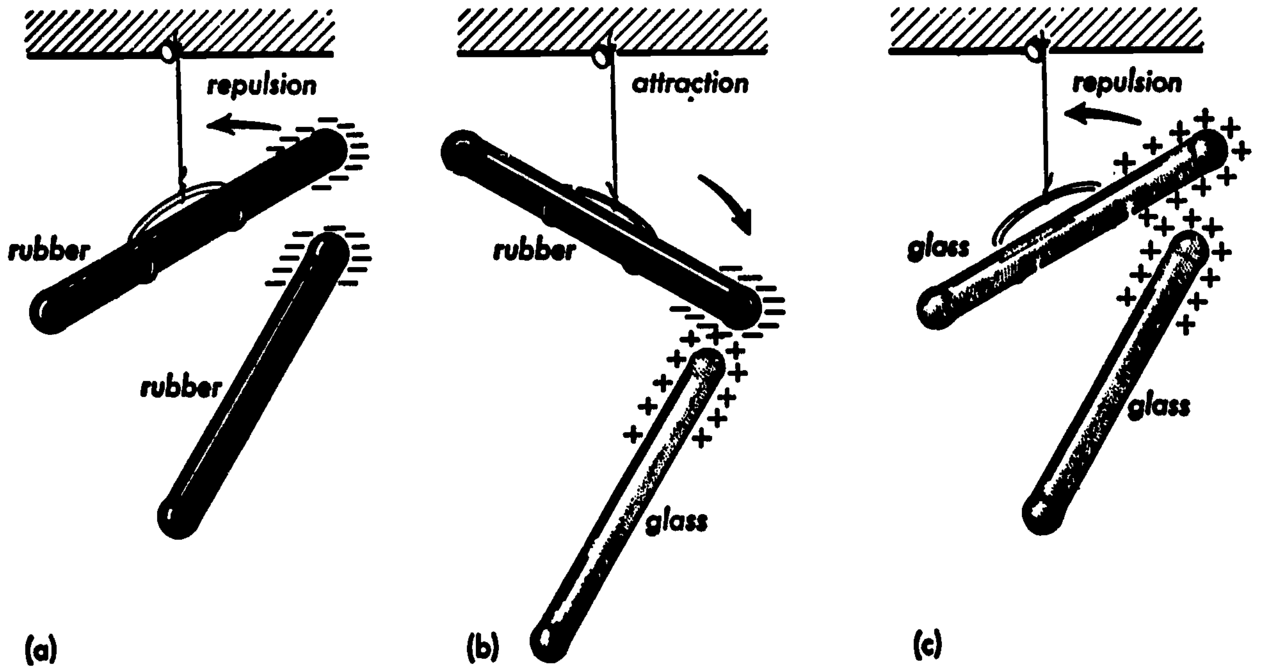
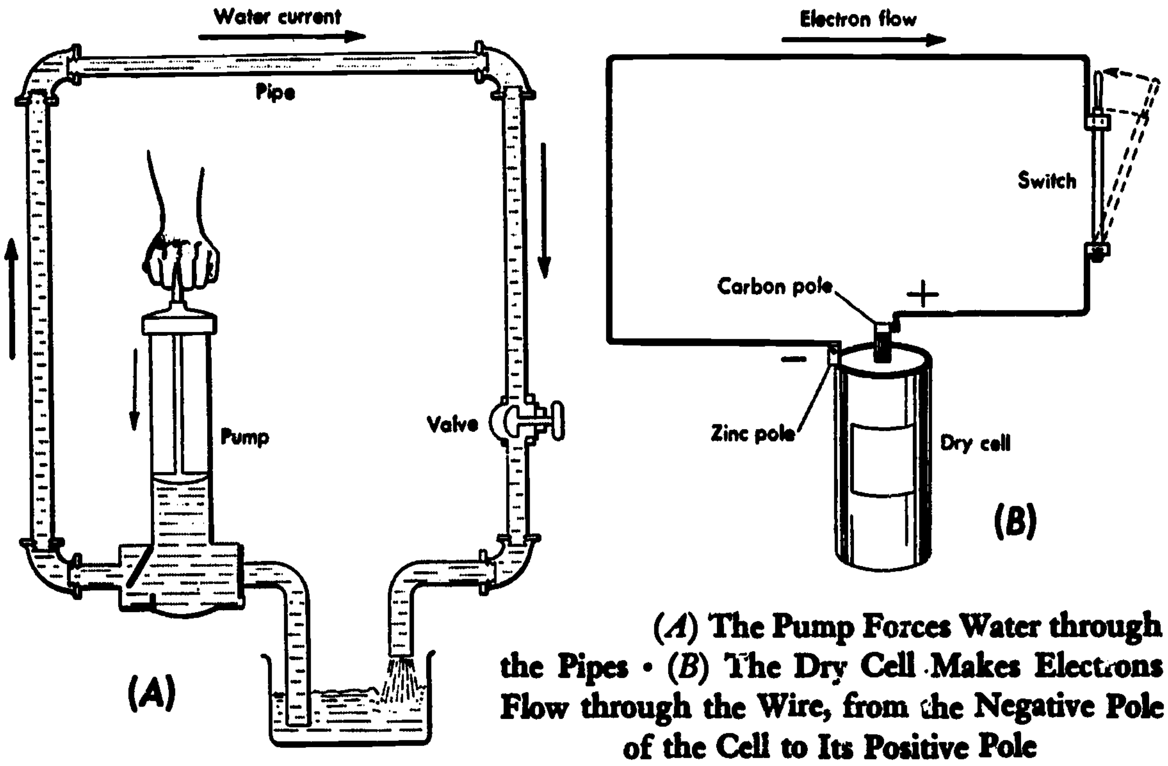


Fig. 5-4

Like charges repel each other and unlike charges attract. Charges which are "standing still" in one place (static electricity) are not very useful. How to put charges into motion and use them is the main point of studying electricity. From now on our main interest will be in electricity in motion.

2. CIRCUITS

Most uses of electricity call for electrons to move steadily in currents. They are like water flowing in pipes. As a pump can be used to push water through the pipes, a dry cell is used to push electrons through a wire. The circuit must be complete so they can go all the way around and end up at the cell again. The circuit is made of a conductor, a material such as copper or other metal which has low resistance to electron flow. If the switch in the circuit is opened, current cannot flow through the air space, because air has a very high resistance.

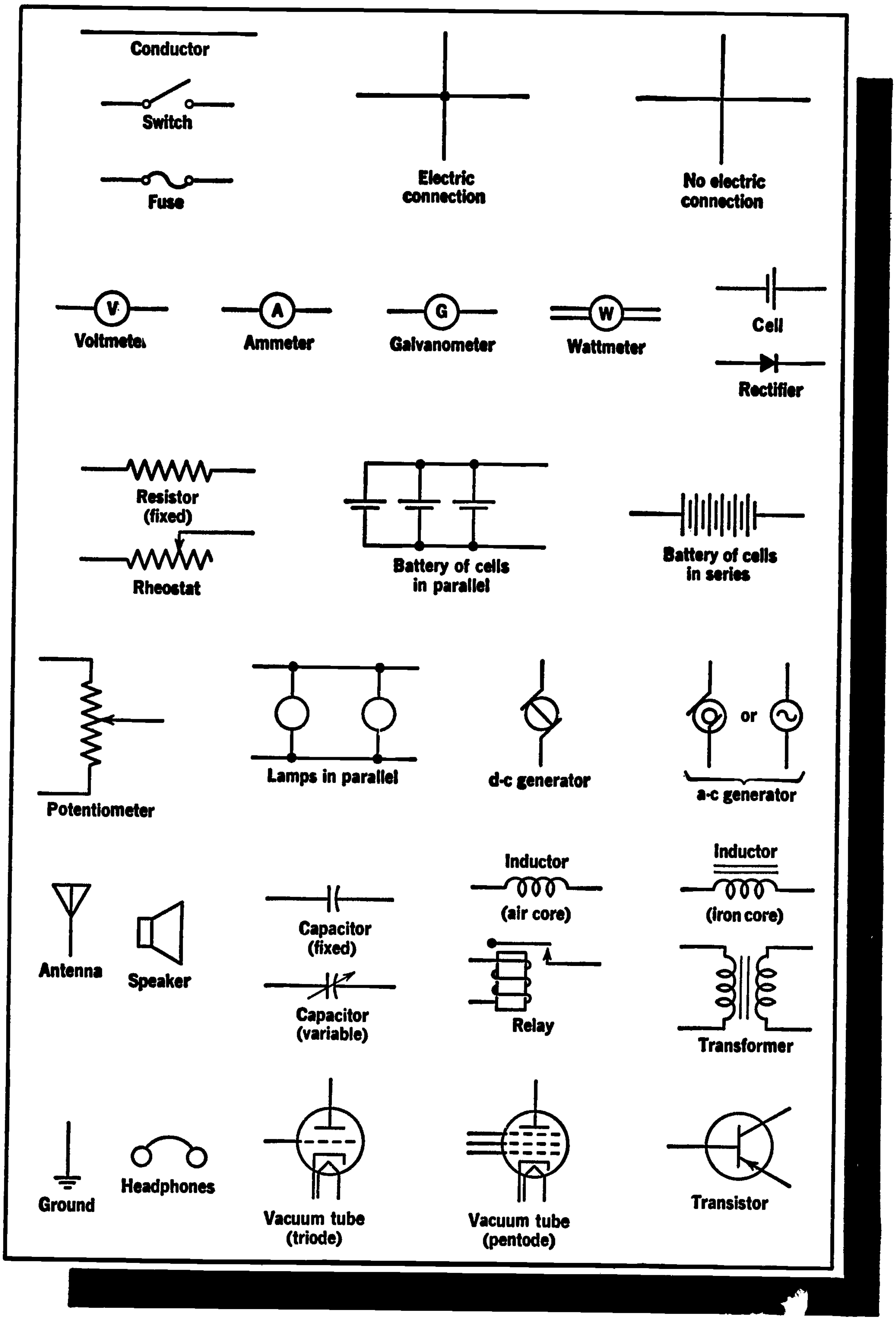


(*A*) The Pump Forces Water through the Pipes • (*B*) The Dry Cell Makes Electrons Flow through the Wire, from the Negative Pole of the Cell to Its Positive Pole

Fig. 5-5

The push mentioned above is called voltage. A dry cell gives a voltage of 1.5 volts, and the storage battery in most modern cars gives a 12-volt "push." The actual strength of the current is measured in amperes. The resistance of the circuit, or of any part of it, to the flow of electrons is measured in ohms.

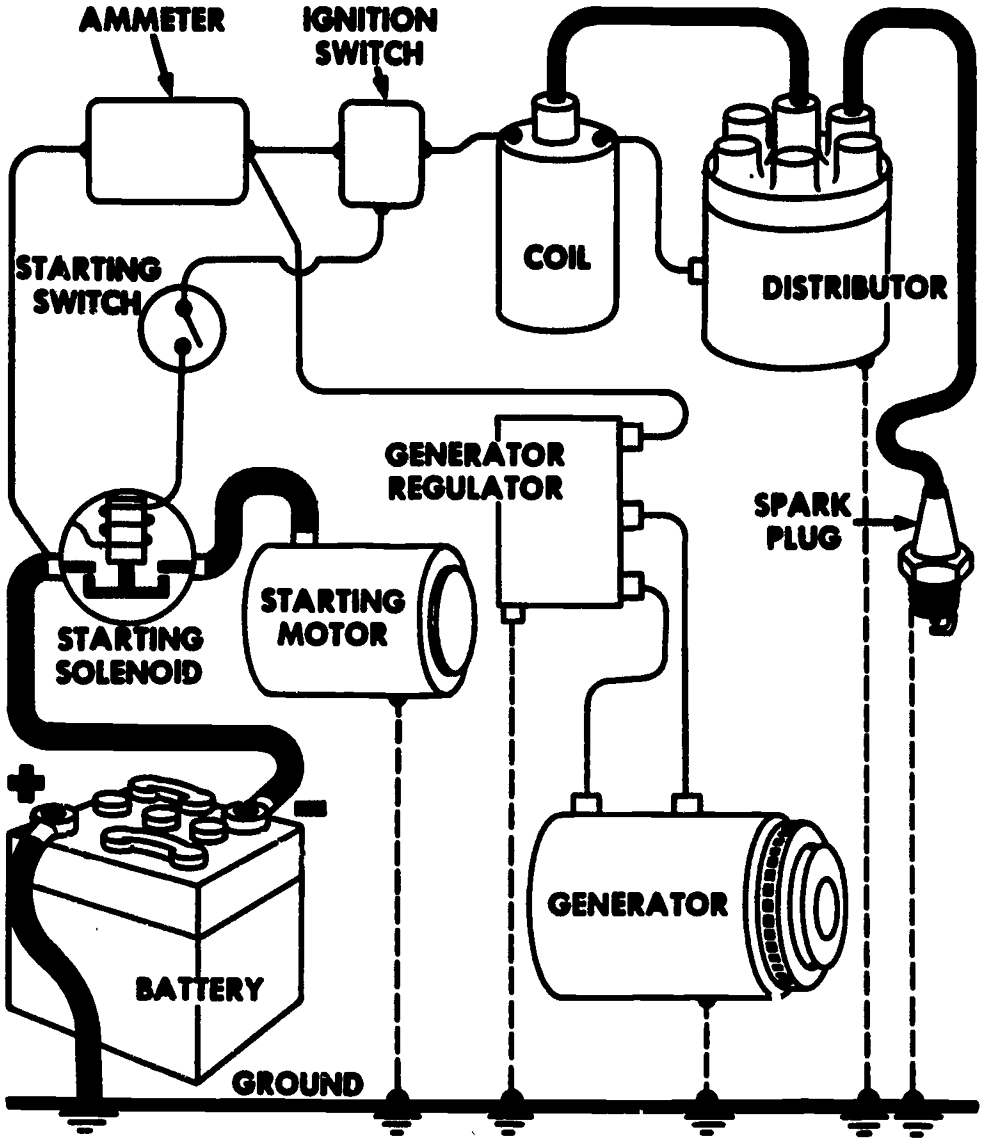
Circuits can be drawn with pictures but most of the time diagrams are made. Symbols standing for lamps, generators, batteries, and so forth are used. Fig. 5-6 shows some of the symbols that are used.



Conventional symbols used in schematic diagrams of electric circuits.

Fig. 5-6

Ground. In house circuits, you have seen that two wires are used to connect toasters, lamps, and irons. One leads the current in, one takes it back. In an automobile, one wire is used to bring current to most devices. It is carried back through the steel of the car itself. For electrical purposes the steel through which this return current flows is called a ground. It has a special symbol ⏚ Whenever you see this on a wiring diagram it means a connection is made to the metal of the car chassis, engine, or body.



Single-Wire
or
Ground-Return System

Fig. 5-7

Ohm's Law. The amount of current in a circuit is measured in amperes. In simple circuits like that in Fig. 5-7 it depends on the voltage and resistance, as shown by Ohm's Law:

$$\text{Current (Amperes)} = \frac{\text{Voltage}}{\text{Resistance (Ohms)}}$$

Fig. 5-8 shows that a lamp having three ohms' resistance will carry 0.5 amperes when connected to a 1.5 volt cell.

$$\frac{1.5}{3} = 0.5$$

A dry cell connected to a small light bulb.

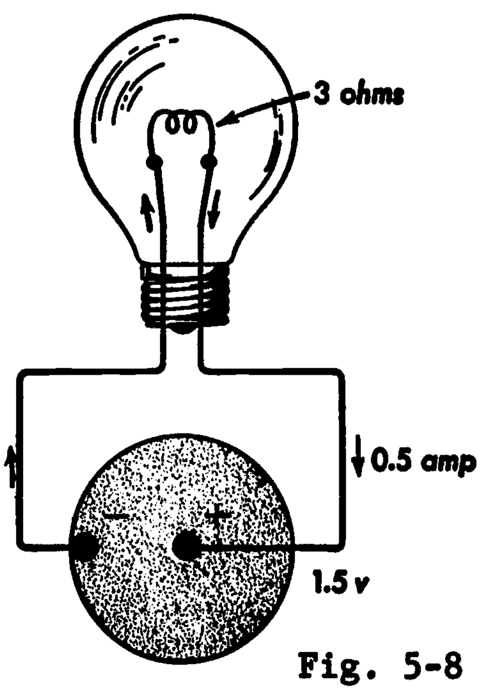
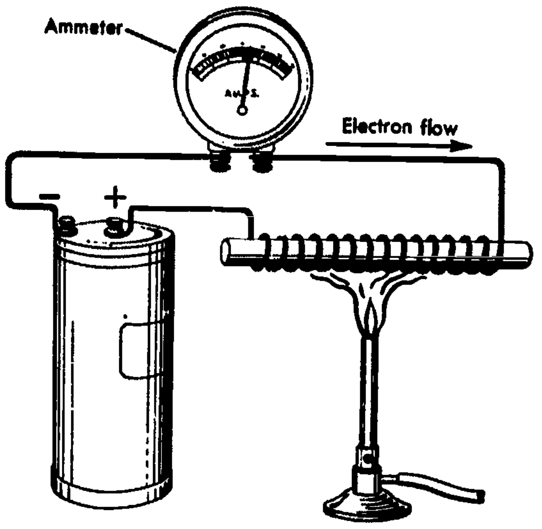


Fig. 5-8

The resistance of materials covers a wide range. Copper has the lowest resistance of common materials. Iron of the same size has six times as much.



Measuring the Current through a Hot Wire • The resistance of the wire increases when you heat it

Showing How the Resistance of a Wire Depends on Its (*A*) Length, (*B*) Area, (*C*) Temperature, and (*D*) Material

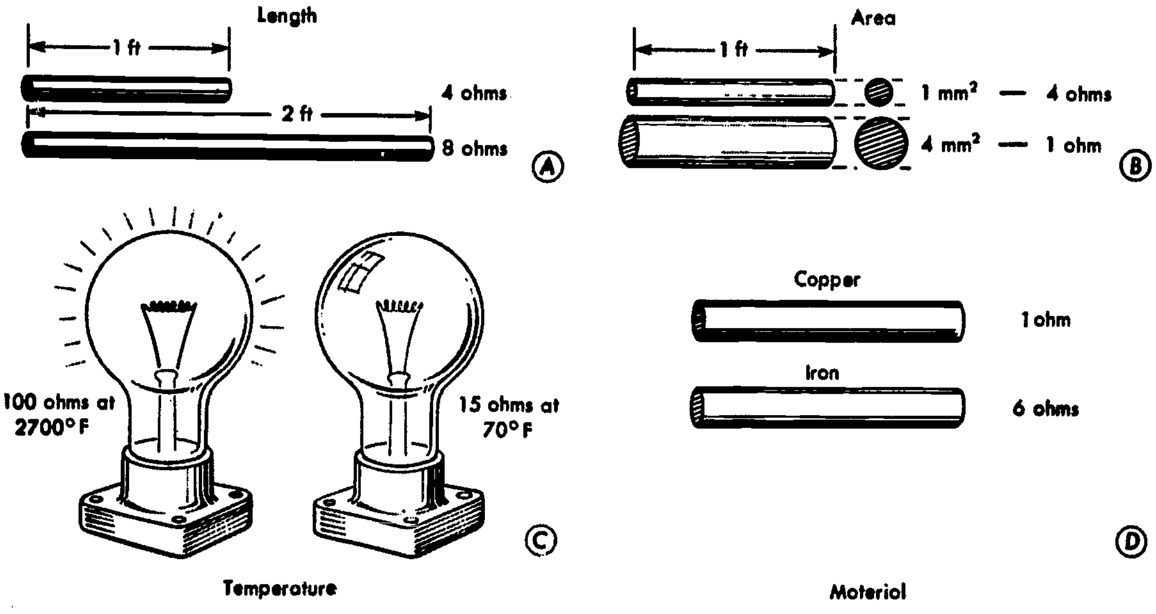


Fig. 5-9

Fig. 5-9 shows how resistance also depends on length, temperature, and wire size (diameter).

Rubber, plastics, paper, cloth, grease, dirt, or paint have such high resistance that they are called nonconductors or insulators. Where you do not want current to flow, an insulator should prevent contact between conductors. But if you want current flow, there must not be an insulator. That is why rust, dirt, and grease must be cleaned off battery terminals and other places where connections are to be made.

In order to be sure that connections stay good over a long time, special terminals are used at the end of every wire. Some of these are shown in Fig. 5-10.

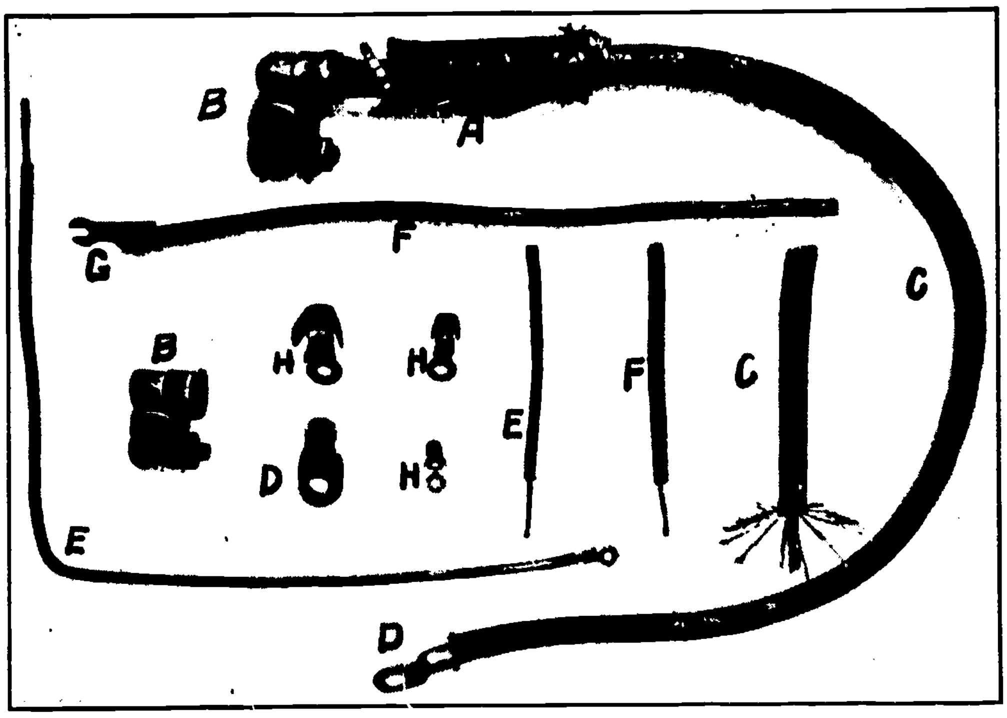
Voltage Drop. From Ohm's Law we find that, to push a certain current through a resistance, a certain amount of voltage is needed:

Voltage = Current x Resistance

The amount of voltage used to send current through a line is called the voltage drop in the line. The amount of voltage that can be used at any point is the total put out by the battery or generator minus the line drop. If all circuits had the same size wire, in many cases the line drop would be too great to get full use of all the units on the line. The following table shows how the voltage would drop in the case of different lamps, for example:

	Small dash lamp	Headlamp
Circuit voltage	12 volts	12 volts
Current drawn	1 amp.	5 amps.
Line resistance	1 ohm	1 ohm
Voltage drop	1 volt	5 volts
Usable voltage	11 volts	7 volts

To have enough voltage at all points, heavy lines are used where heavy currents flow--at the battery, generator, and starter. These heavy lines greatly reduce the resistance of the circuit and keep the line drop low.



Samples of wires and terminals. A, loom; B, battery-post and starting-lead terminals; C, battery-to-starting-motor cables (note size and number of strands of wire); D, heavy copper terminals for starting-motor cables; E, primary or lighting cable, single conductor; F, secondary or spark-plug cable; G, spark-plug terminal; H, primary- or secondary-lead terminals.

Fig. 5-10

A short circuit results when a wire carrying voltage touches a grounded metal part. The current seeking the path with the lowest resistance, drains through the ground rather than lighting the lamp or doing whatever it was to do. This cuts down the power to the device. Due to the low resistance of the ground circuit, it also draws heavy currents which tend to drain the battery and overheat wires.

To prevent short circuits, wires are insulated with rubber or plastic. Where-ever rubbing might take place, they are covered with a strong woven sleeve of loom to protect the insulation. (Fig. 5-10) Wires are also held in place by clips so the insulation will not be rubbed through.

Spark plugs have a porcelain insulator that can stand great heat, but deposits that collect on them can carry a little current. They carry it better at high temperatures, which may short out the plug at high speeds or during acceleration, causing a miss.

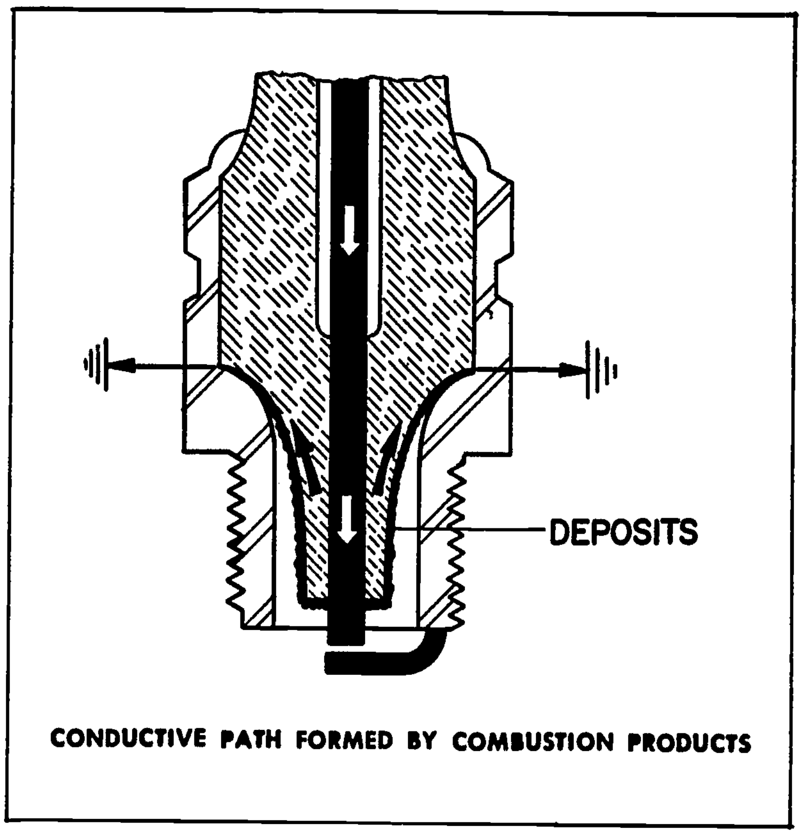
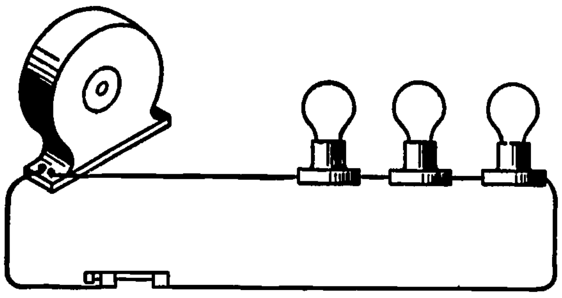


Fig. 5-11



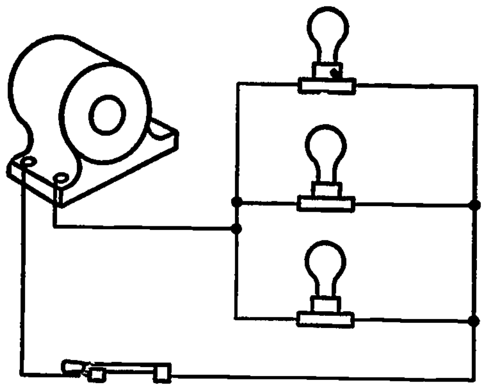
Light bulbs connected in series. Same current flows through all.

Fig. 5-12

Series and Parallel Circuits. The circuits in an automobile (Fig. 5-1) have more items in them than the simple ones we saw earlier, but they are not really hard to figure out. There are two main ways to wire circuits.

In series circuits, the same current goes through one device after another. A switch is always wired in series with the thing it controls, so that opening the switch keeps any current from flowing to the device. If any of the bulbs in a series circuit should go bad, so that the current could not get through it, the effect would be the same as if the switch were opened-- all the bulbs would go out.

Parallel circuits divide the current. The current that goes through one lamp does not go through another. Lamps are usually wired in parallel; so are the spark plugs in a car. If one of the bulbs in Fig. 5-13 should burn out, the current would continue to flow through the others, which would remain lit.

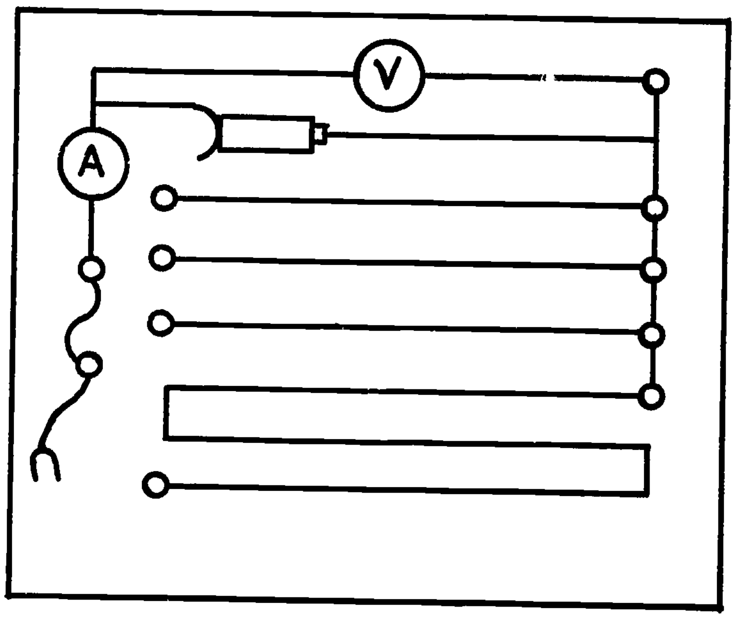


Light bulbs connected in parallel to current source. Current divides, part flowing through each light bulb.

Fig. 5-13

Turn back to Fig. 5-7. It shows a simplified wiring circuit. You can see that some parts form parallel circuits, some are in series with each other.

EXPERIMENT 23. RESISTANCE



In electric circuits, current flows--that is, current is pushed--by electromotive force (EMF). The amount of current is controlled by two factors: (1) the EMF and (2) the circuit materials. The nature and arrangement of these can be rated as a number called resistance. The relationship of this number to current and EMF is given by Ohm's Law:

$$\text{Current in amperes} = \frac{\text{EMF in volts}}{\text{Resistance in Ohms}}$$

In this experiment you will study the effect of type of material, length, and thickness on the resistance of wires.

MATERIALS: Test board as shown with 500 m.a. and 3.0 volt meters; 1.5 volt flashlight cell; fuse wire; micrometer.

PROCEDURE:

1. Prepare a page in your notebook with a data table.

2. Check the test board to see that all connections are tight and that the proper fuse wire is in place.

Metal	Gauge	Length (inches)	Diameter (inches)	EMF (volts)	Current (amperes)	Resistance (ohms)
Copper	22	12				
Copper	20	12				
Copper	18	12				
Copper	18	36				
Steel	18	12				

3. Measure the diameter of each wire with the micrometer. Connect the loose lead from the fuse to the open binding post on the first wire, read the ammeter carefully and disconnect the lead at once. Record the current and calculate the resistance of the wire.

4. In the same way test each of the wires. Do not leave the dry cell connected for more than the time you need it, or it will run down.

5. Remove the dry cell from the board. Write up the conclusions. Return the cell to your instructor and show him the results of the experiment.

CONCLUSIONS:

1. What conditions must be met for current to flow in this experiment?

2. In what different ways is it possible to compare various conductors?

3. What three factors did you find determined the resistance of the various wires?

4. How did the diameter of a wire affect the current flow?

5. How did the length of a wire affect the current flow?

EXPERIMENT 24. CIRCUITS

In the main circuits of an automobile, any two parts are connected either in series (where the same current flows through both) or in parallel (where the current divides, part going through one and part through the other).

In this job you will learn to connect up a simple auto lighting circuit. You will see that switches are always in series with the lamps they control: if no current goes through the switch, none can go through the lamp. Separate lamps are in parallel: one can burn whether the others do or not.

In circuits like these, dirt, corrosion or looseness at connections and switches raises resistance. To push current through this resistance, voltage is used; this leaves less voltage at the lamp or other device, making it weaker. You will learn how to measure this voltage drop.

In auto circuits most devices have only one wire going to them. The current returns to the battery through the metal of the car itself. The ground connection at this point must be clean and tight, like all other connections.

MATERIALS: Metal circuit board, unwired but with devices mounted: ammeter, circuit breaker, light switches (head, stop, 2 dome, and dimmer), lamps (2 high beam, 2 double filament head-, 2 parking, 2 tail-, license, instrument, and dome), 2 terminal blocks, wires, voltmeter, battery or charger.

PROCEDURE:

1. Obtain the board, wires, and other materials.

2. Following the circuit diagram, Fig. 1, wire up the battery (or charger used in its place) and the next two devices in series.

Fig. 1. Circuit Diagram.

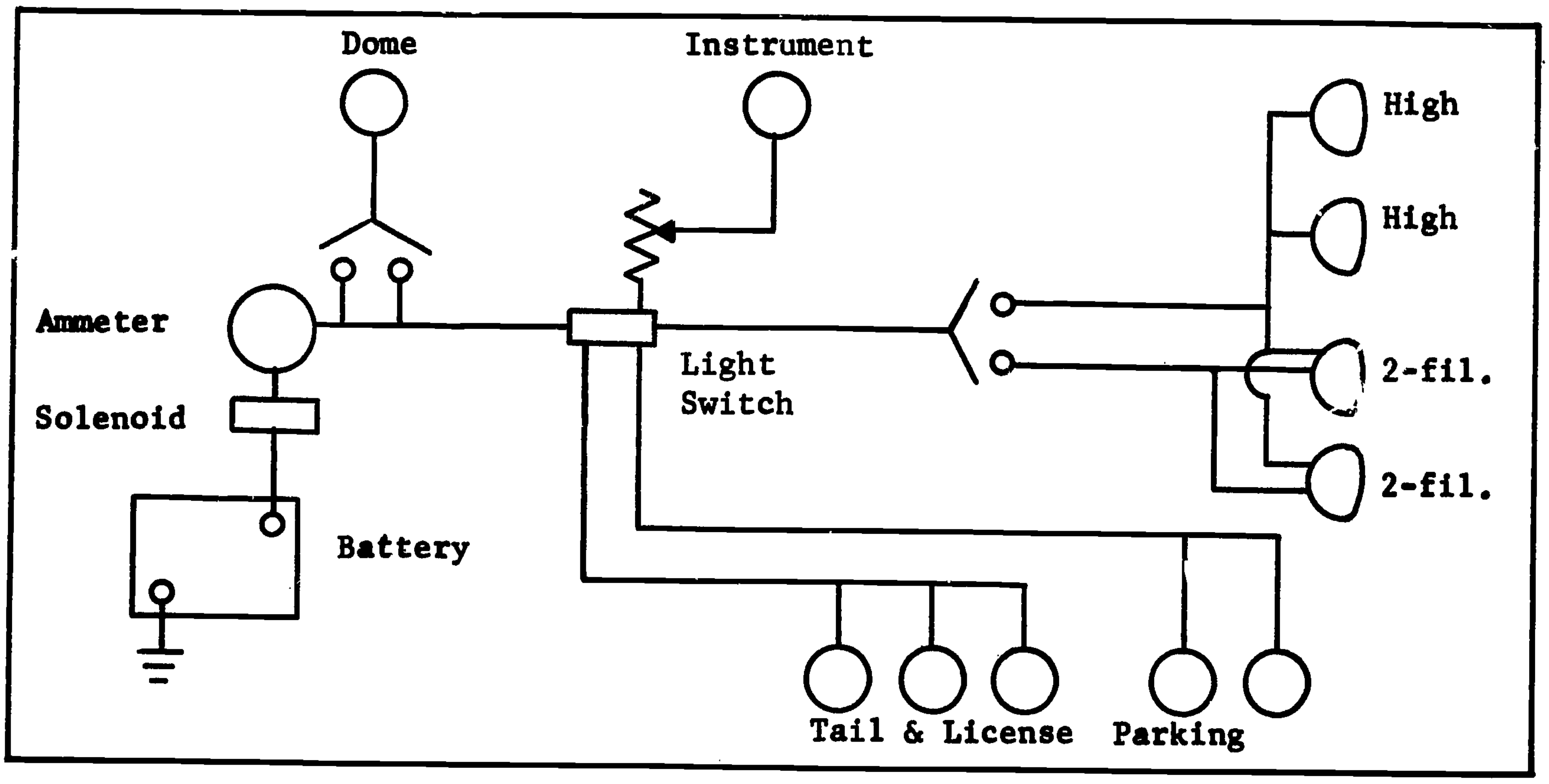
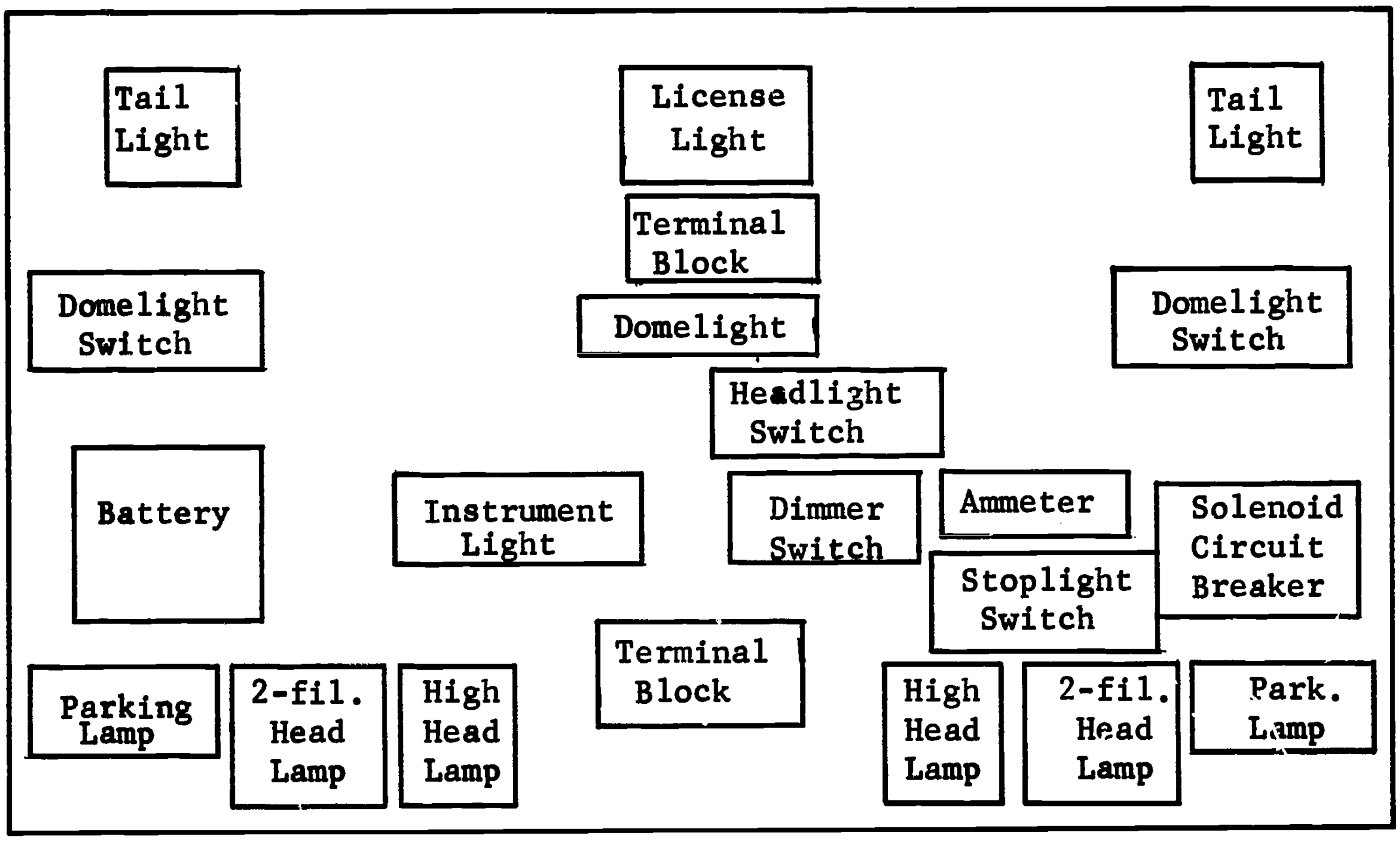


Fig. 2. Circuit Board Layout



3. Wire up the first lamp with its switch.

4. Study the headlight switch. With two wires--one from the ammeter, the other from one of the small lamps--test out the various positions. Find the <u>common post</u>. (When the switch is in one of the "on" positions, the common post is always connected to at least one of the other posts; when the switch is "off", the common post is not connected to anything else.) Connect the line from the ammeter to the common post firmly.

5. Pull the light switch to the first position. Again using the line to the small lamp, find which post is "hot" in this position but not in the second one. Which lamp should it light? Using a terminal block to branch the circuit, connect these lamps.

6. In the same way, find the post that is "on" in both the first and second switch positions. Connect it up to the proper lamps.

7. Find which terminal changes when the knob is turned. What should it control? Make this connection.

8. The remaining post is "on" in the second position only. What is it for? Where should this line go first? Think about this circuit carefully. Then connect it up.

9. Connect a voltmeter with its (+) to the (+) of the supply. Check the voltage drop to the near side of each lamp while it is burning. Are any of the drops over 0.2 volts? If so, try to find which point in the circuit is causing the drop.

10. Ask your instructor to check the board. When he approves it, make a table in your book listing each type of lamp. Measure the amperage in each circuit. If several lamps are in parallel, calculate the current each draws. Calculate the resistance of each type of lamp.

3. MAGNETISM

One of the things that electricity does is produce magnetism. Electricity also can be made by magnetism. So you see that magnetism and electricity are so tied together that many electric devices depend on magnetism. Before we go into this, let us look at magnetism a little more.

A magnet is a thing that can attract pieces of iron or steel. Magnetic rocks called lodestones have been known for thousands of years. Sailors used them to make compasses, for a lodestone free to turn will always line up pointing north and south.

A lodestone and a bar magnet point north and south.

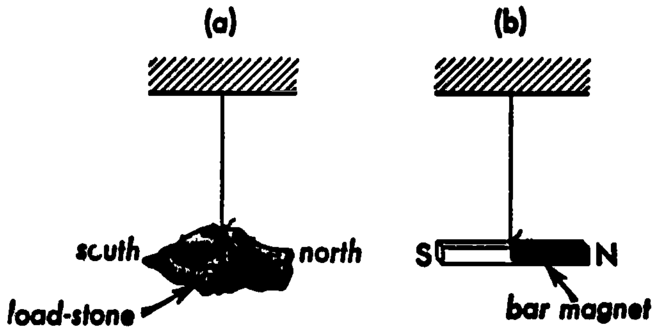
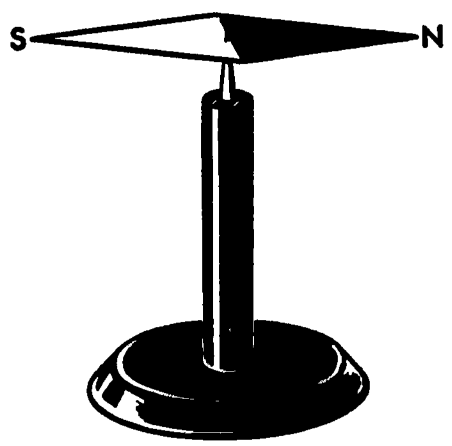


Fig. 5-14



A compass needle points toward the north.

Fig. 5-15

Steel bars can be magnetized by rubbing on a lodestone. Then they also point north and south. A compass is a small magnet set on a pivot so it can turn easily.

Attraction. Magnets attract iron. They attract right through things--air, water, glass, paper, etc.

If you file a piece of iron you get little pieces. These little filings show you several things about magnets.

Magnetic poles. If iron filings are sprinkled on a bar magnet, most of them collect at the two ends of the magnet. These are called poles. Magnets normally have two poles. The end that points north when we hang the magnet as in Fig. 5-15 is called the north magnetic pole; the one that points south is called the south magnetic pole. For convenience, these terms are usually shortened to north pole and south pole.

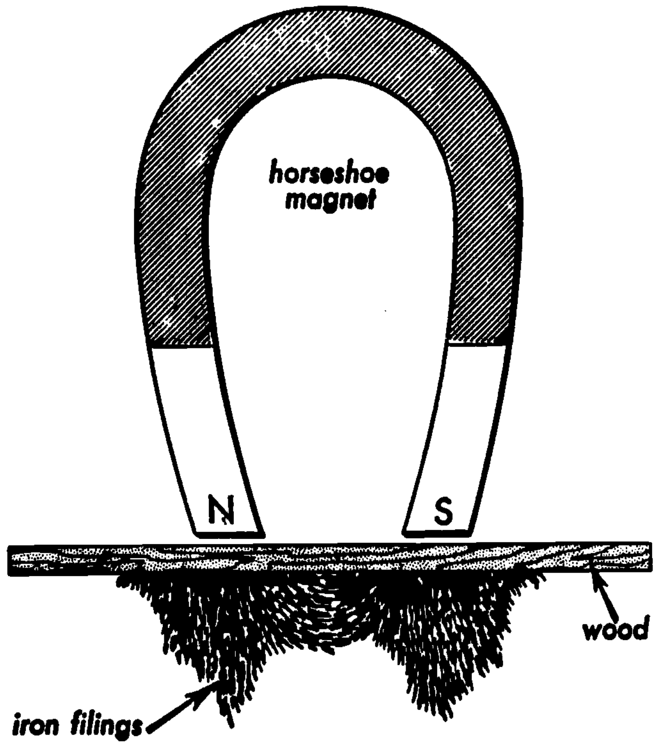


Fig. 5-16

The attraction of iron filings by a straight bar magnet shows greater attraction near the ends. These regions of greatest attraction are called *magnetic poles.*

Fig. 5-17

When two magnets are brought close to each other, we find that

Like magnetic poles repel each other, and unlike poles attract each other.

Magnetic fields. A small compass held near a magnet, as in Fig. 5-19, will point in a certain direction. By moving it around, we can make a "map."

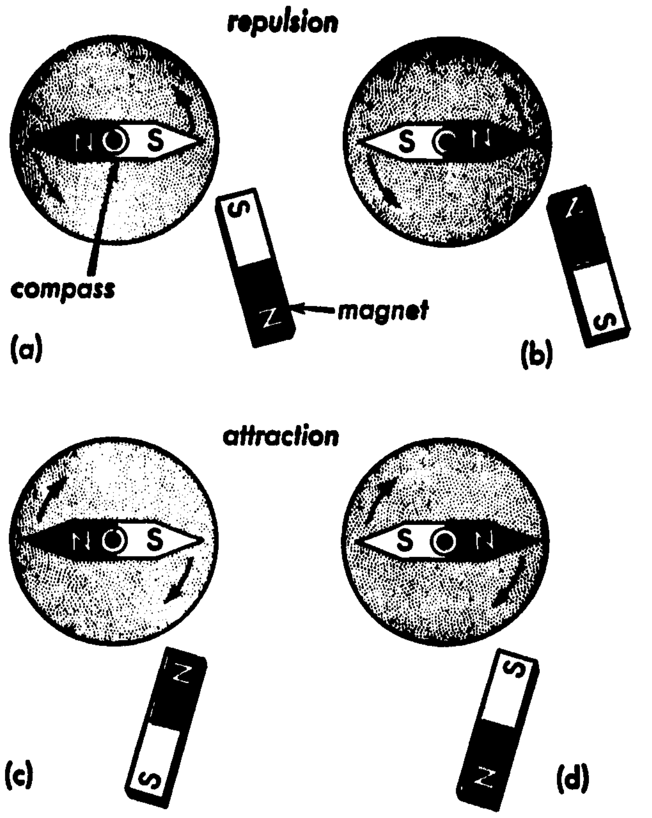
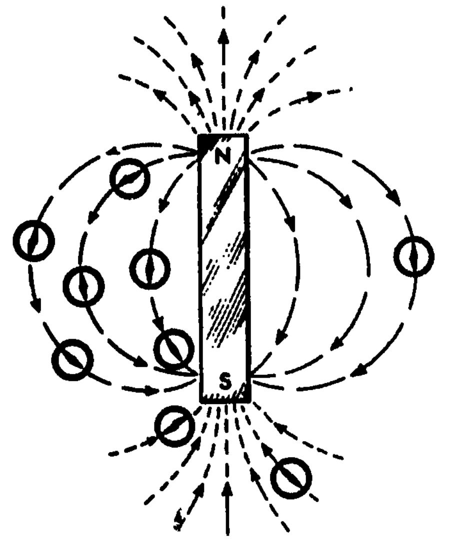


Fig. 5-18



Little Compasses Show the Direction of the Magnetic Field • Why do its magnetic lines of force go from north pole to south pole?

Fig. 5-19

Photograph of the iron filings lined up by the magnetic field of a permanent straight bar magnet.

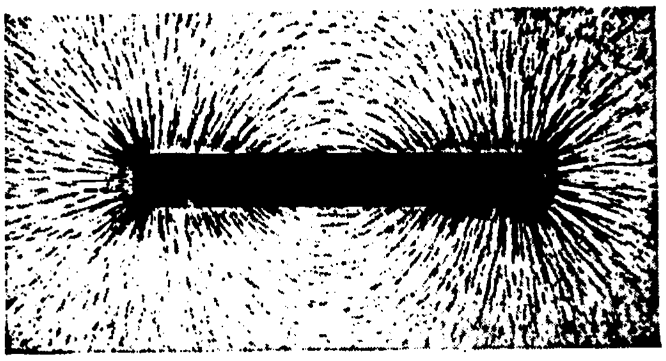
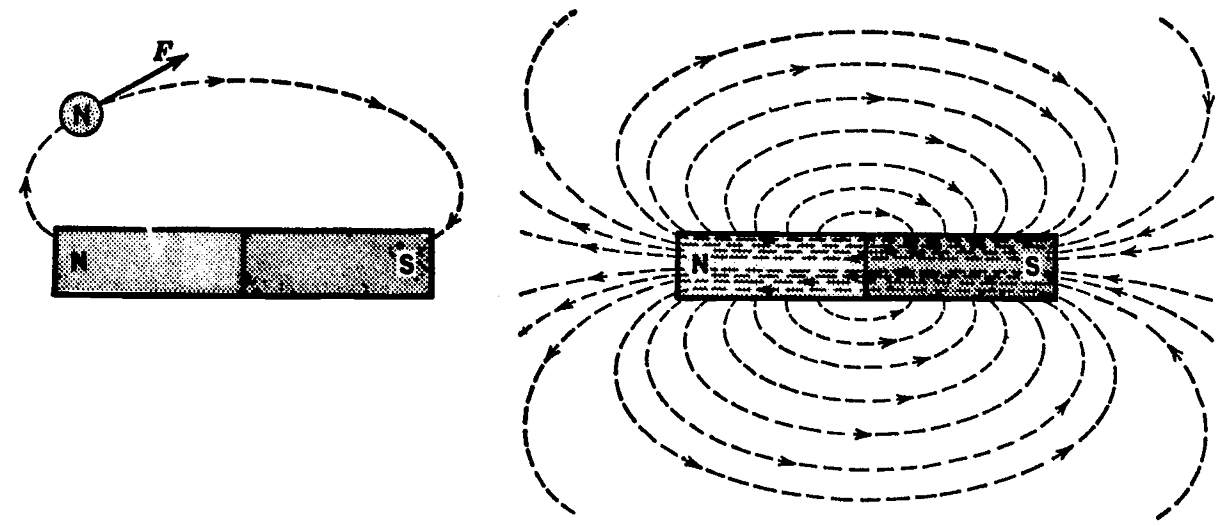


Fig. 5-20

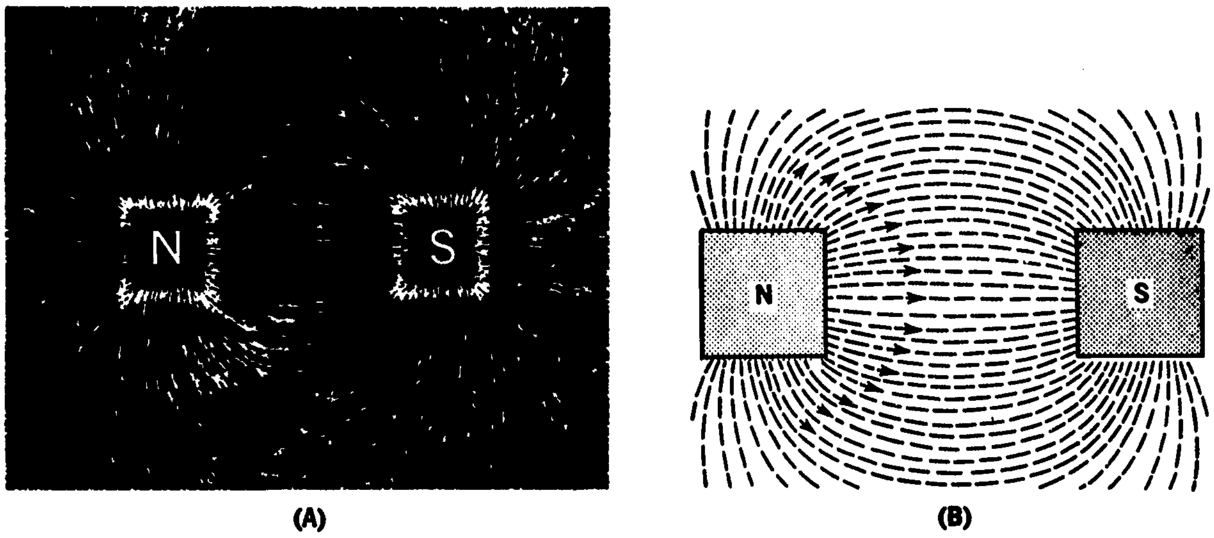


(A) (B)

(*A*) The path taken by an independent N pole in a magnetic field is called a line of flux. (*B*) Magnetic flux about a bar magnet.

Fig. 5-21

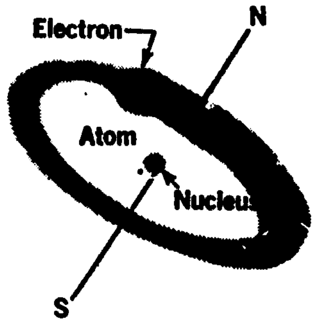
Iron filings sprinkled over a magnet will line up in the same way. A magnetic zone having strength and direction of force is called a magnetic field. The path a compass follows through a magnetic field is called a line of flux. A magnet bent into the shape of a horseshoe, with its two poles close together, has a strong field between them.



(*A*) **Iron filings near the poles of a horseshoe magnet, end on.** (*B*) **An idealized drawing of** (*A*) **showing lines of flux.**

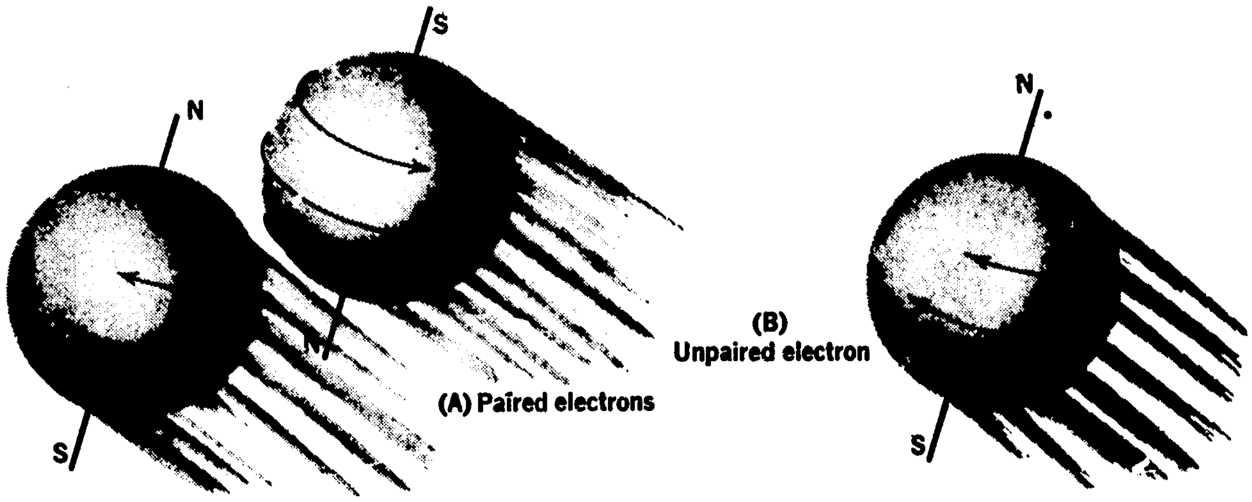
Fig. 5-22

Theory of magnetism. It has been known for a long time that electricity passing through a wire, as in Fig. 5-29, will make a magnetic field. The moving of a single electron around a nucleus (Fig. 5-23) makes a magnetic field. In most atoms the spin of electrons is paired, as in Fig. 5-24 (A), so that most of them cancel each other out. Unpaired electrons, as in Fig. 5-24 (B), make a material magnetic.



Revolving electrons impart a magnetic property to the atom.

Fig. 5-23

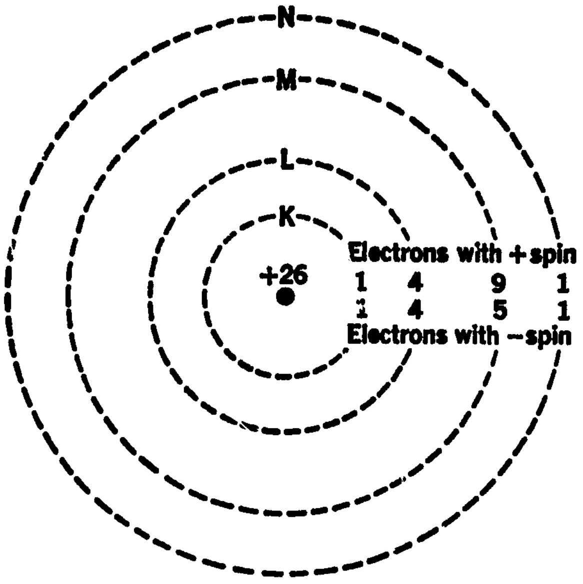


Magnetism in matter stems basically from the spin of electrons.

Fig. 5-24

Each atom of iron has four unpaired electrons in its M shell, so you see why it is so magnetic.

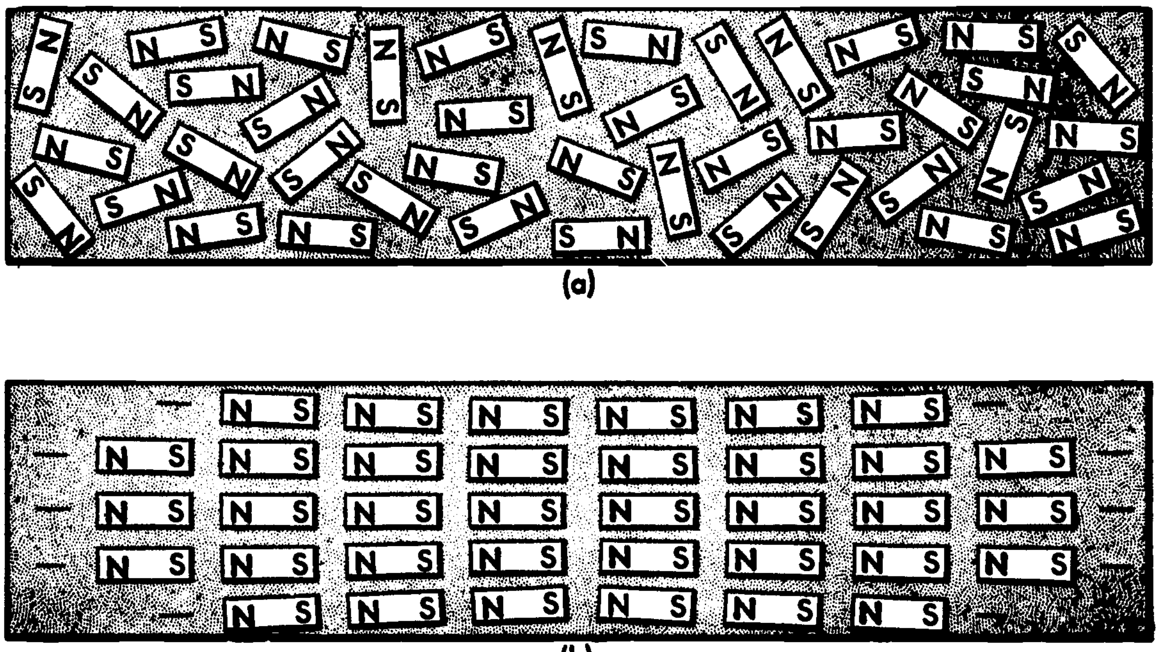
A bar of ordinary iron or steel is made of billions and billions of tiny magnets headed in all different directions. When this bar is placed in a magnetic field, they line up as if they were little compasses. When this happens to an object made of iron, it turns into a magnet.



The iron atom has strong ferromagnetic properties.

Fig. 5-25

Schematic diagrams of the elementary magnets within a piece of iron, (a) unmagnetized and (b) magnetized.



(a)

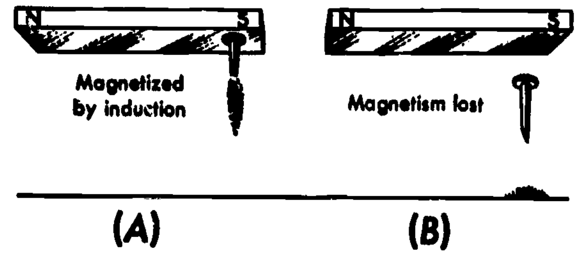
(b)

Fig. 5-26

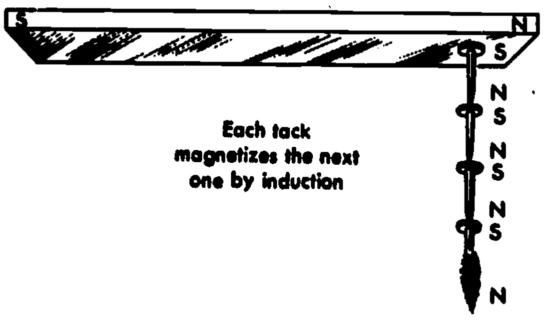
Normally, if the object, like the tack in Fig. 5-27B, is taken away from the magnet, it loses this induced magnetism. If it is made of high-carbon steel, however, like a screwdriver or a file, it may become permanently magnetized.

Permeability. In Fig. 5-16 we saw that magnetic fields act through wood and air, as well as other materials. Some materials carry magnetic fields better than others. Fig. 5-28 shows that magnetic lines go through iron rather than air.

Next we will see how electricity and magnetism are related.

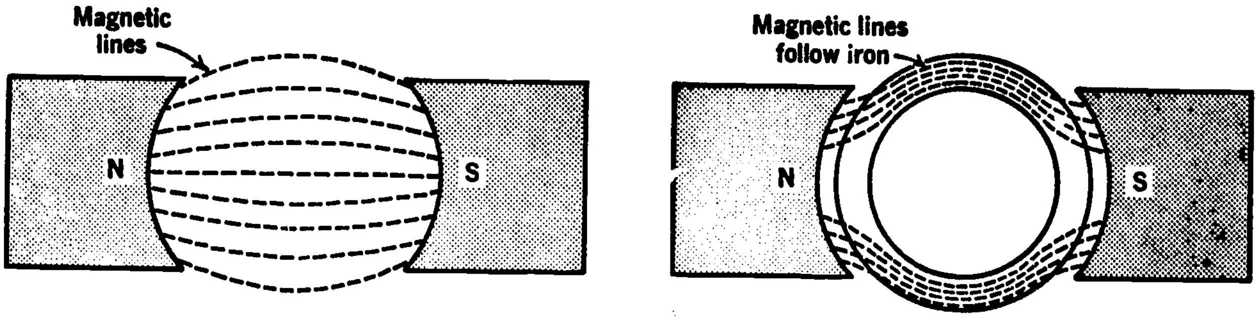


(*A*) The Bar Magnet Magnetizes the Tack by *Induction.* (*B*) The Nail Loses Its Magnetism



The Bar Magnet Magnetizes Several Tacks by Induction

Fig. 5-27



At left, magnetic flux crosses the air gap between the poles of a magnet. At right, magnetic flux follows the soft iron ring, which is more permeable than air.

Fig. 5-28

EXPERIMENT 25. MAGNETISM

You probably know that iron and a few other materials can be magnetized--that is, given poles that attract and repel, in a zone known as a magnetic field. In this experiment you will study magnetic fields to see how they act on iron to form poles, how they are shaped, and how they interact with each other.

MATERIALS: Compass, 2 bar magnets, horseshoe magnet, iron filings, needle, cork disk, dish of water, small nails, cardboard, glass, thin board.

PROCEDURE:

In your notebook write up the experiment as you go along, in the form of sentences answering the questions.

1. Put the dish of water on the table with the cork disk floating on it and the needle on the cork. Does the needle point in any one direction?

2. Bring the bar magnet near the side of the dish. What does the needle do? Are both ends of it affected the same way? Try the other end of the magnet.

3. Stroke the needle with the magnet. Now put it back on the cork. Does it point in any one direction?

4. Bring the N end of the bar magnet near the dish. Which end of the needle does it attract?

5. Repeat the needle experiments (Nos. 1-4) with a nail. What differences do you see?

6. In place of the needle, put a magnetic compass on the table. Observe it by itself and with the bar magnet 3-4 inches away. Try both ends of the magnet. What rule describes the action between them?

7. Put the magnet on the table and a glass plate over it. With the compass explore the top of the glass and see if the magnetic effects are changed because it is in the way. Do the same with cardboard and wood. Does magnetism pass through them? Does it pass through air?

8. Put the cardboard over the bar magnet. Sprinkle iron filings over it. Tap it a little. In your notebook sketch the lines of direction of the magnetic field as shown by the filings. When you have done this, take the magnet away without getting filings on it. Dump the filings on a paper and slide them back into their container.

9. Put two bar magnets in a line, with the N end of one about an inch from the N end of the other. Using the cardboard and filings again, study the magnetic field as you did in (8) and sketch it in your book.

10. Line up the two bar magnets N to S, again an inch apart, and in the same manner sketch the field in your notebook.

11. Put a bar magnet on a clean page in your notebook. Set a small compass near it, note carefully the direction of the needle, lift it up and, where it was, make a small arrow showing the direction. Do this same thing in 20 to 30 places around the magnet. Try with light lines to fill in the diagram of the field which the compass arrows show in part.

12. By the iron-filing method sketch the field of a horseshoe magnet in your notebook.

13. Lay a nail across the end of the horseshoe magnet. Set a small compass several inches from the magnet. Does the nail affect the strength of the field? Take it away; bring it back; move the compass about until you are sure of your answer.

14. Pick up a string of nails with the magnet. What holds up the ones that are not actually touching it? Take away the one that is touching the magnet. What happens to the others?

CONCLUSIONS:

1. What happens to a piece of high-carbon steel like a needle when a magnet touches it?

2. What happens to a piece of low-carbon steel like a nail when a magnet affects it?

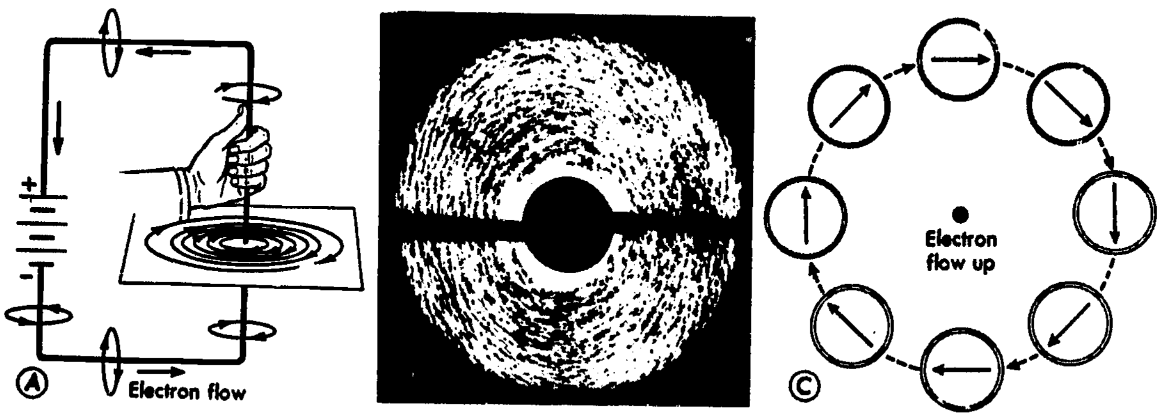
3. Name some materials that magnetic fields can pass through without effect.

4. Name a material that magnetism cannot pass through.

5. What two ways can be used to trace lines of magnetic force?

4. ELECTROMAGNETISM.

You know that an electric current is the flow of electrons. If you hold a compass near a wire through which a current is flowing, it will show by the way it points that a magnetic field is set up by the current. The field goes around the wire in circles.

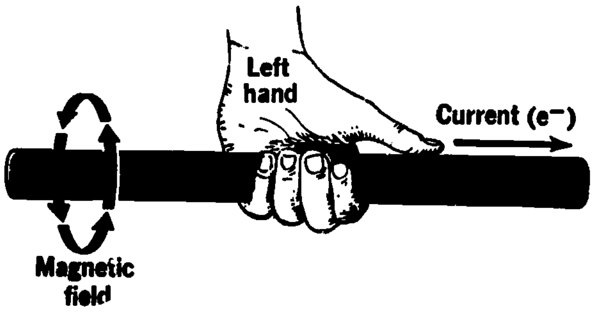


(*A*) **The Current Makes the Iron Filings Line Up in Circles.** (*B*) **This Photograph Shows the Magnetic Field near a Wire.** (*C*) **Compasses Indicate the Direction of the Field**

Fig. 5-29

The direction of the field is shown by Ampere's "left-hand rule":

> If the current-carrying wire is held by the left hand so that the thumb points in the direction of electron flow (- to +), the fingers will show the direction of the magnetic lines, pointing north.



Ampère's rule for a straight conductor.

Fig. 5-30

A loop of wire will have little fields all around it which add up to a magnetic field as shown in Fig. 5-31.

A series of loops in a wire make up a coil. If current flows through the coil, it will produce a magnetic field like that of a bar magnet (Fig. 5-32). A coil of this kind is called a solenoid.

Diagram of the magnetic field through and around a single loop of wire carrying an electric current.

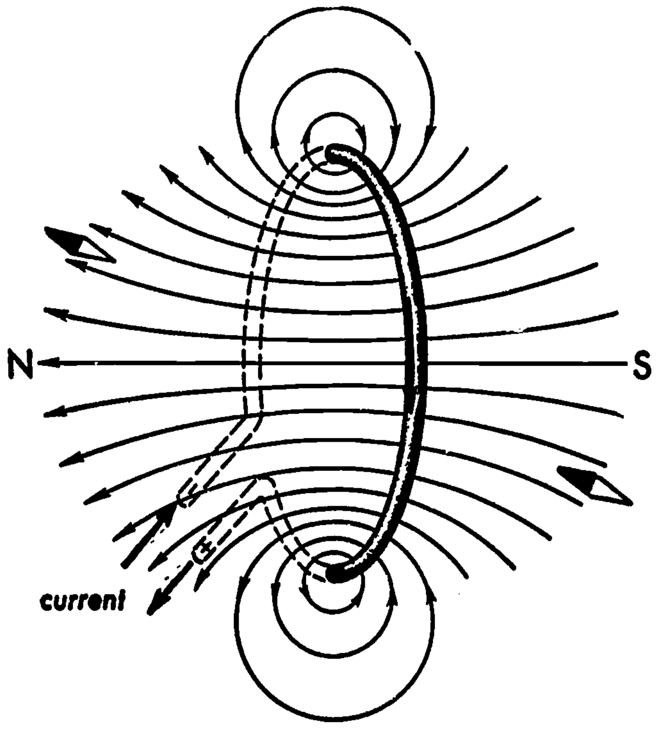
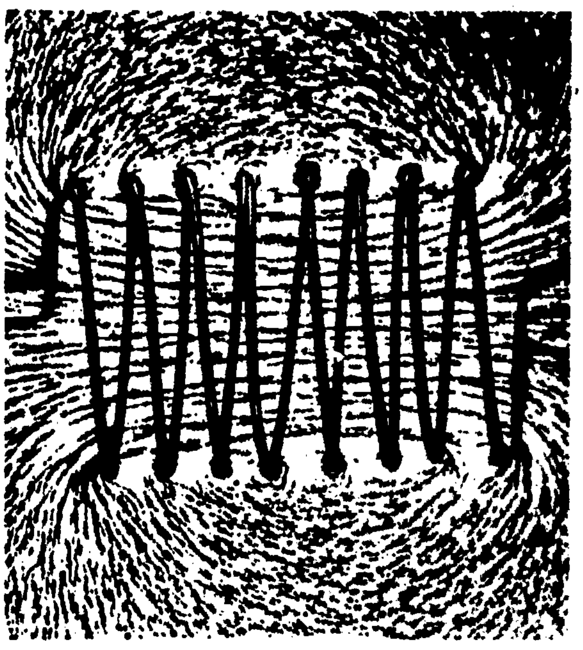


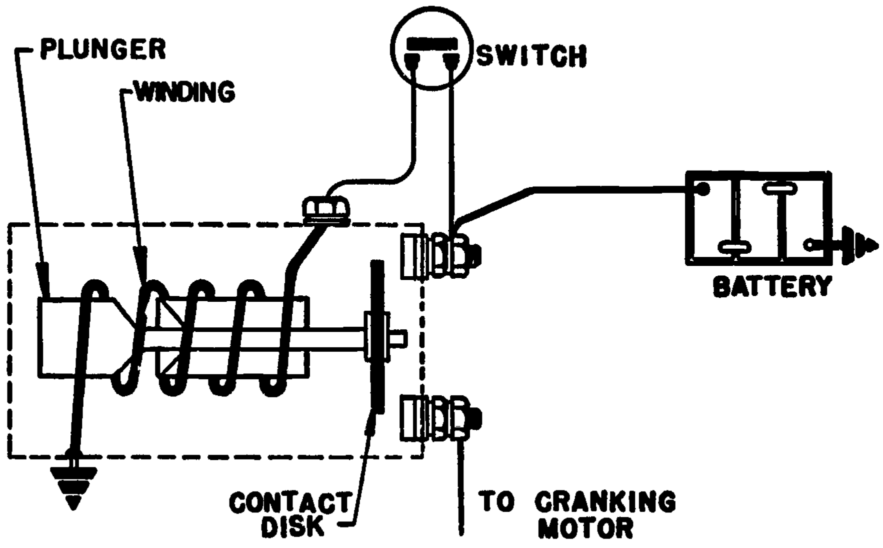
Fig. 5-31



Iron Filings Reveal the Magnetic Field Due to the Current in a Coil

Fig. 5-32

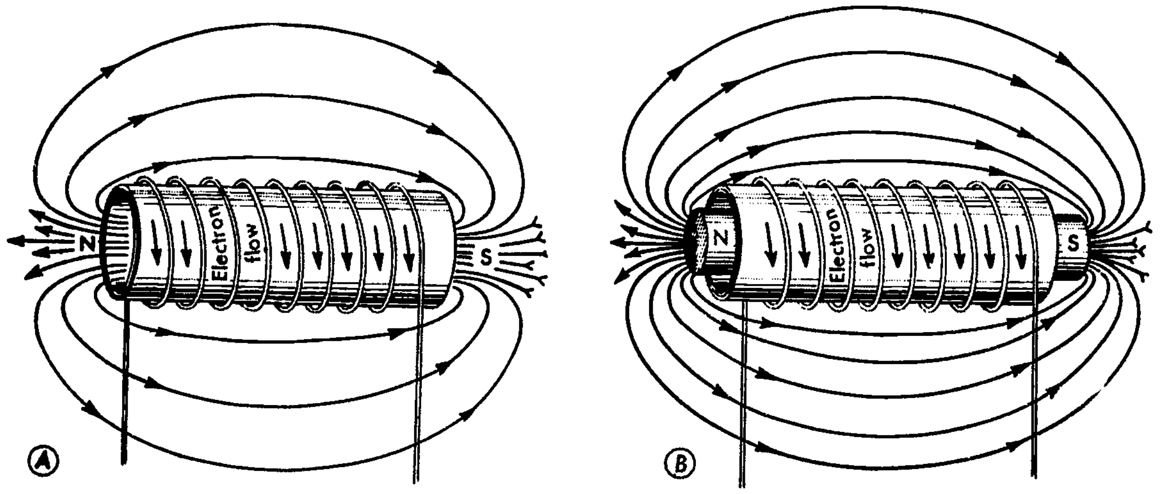
A coil of this kind with a movable core is used in the solenoid or magnetic switch of some starters. When the driver closes a small switch, current flows through the solenoid. The magnetic field pulls in the plunger, forcing the contact disk against the two terminals to send a heavy current to the cranking (starter) motor.



Magnetic-switch schematic wiring circuit.

Fig. 5-33

When an iron core is put in the center of a coil (Fig. 5-34), the magnetism of the coil is strengthened. The coil and core together make up an <u>electromagnet</u>.

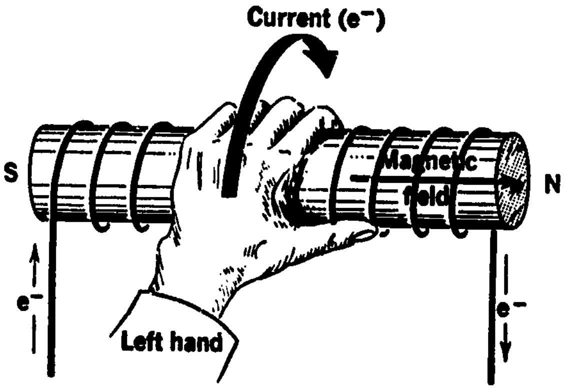


(*A*) The Field Due to a Current in a Long Coil Resembles That Due to a Bar Magnet. (*B*) Inserting an Iron Core Increases the Strength of the Field

Fig. 5-34

The polarity of an electromagnet follows another left-hand rule:

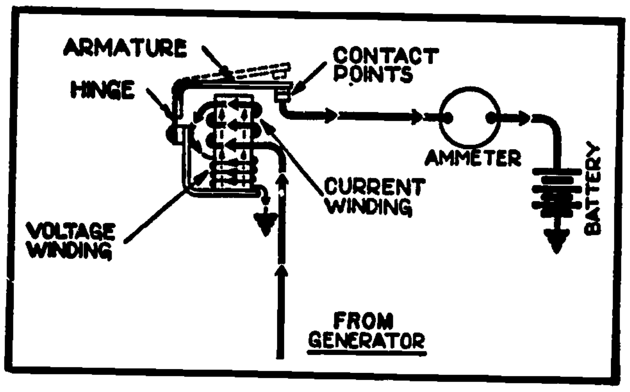
> If the coil is held by the left hand so that the fingers point the direction of electron flow (- to +) the thumb will point to the north magnetic pole of the field.



Ampère's rule for a solenoid.

Fig. 5-35

The cutout relay of an automobile which allows the battery to be charged by the generator but keeps it from discharging through the generator (Fig. 5-36) depends on this rule. The generator (which we will study a little later) makes a voltage that may be more or less than that of the battery.



Schematic wiring circuit of cutout relay.

Fig. 5-36

A small current flows from the generator through the "voltage winding" to ground whenever the engine runs. When the current is great enough, magnetism pulls the armature down, closing the contacts. Current can now flow through the battery and charge it. But if the voltage of the battery is more than the generator puts out, the battery will drain through the generator. Current flowing the wrong way will make a field in the current winding that bucks that of the voltage winding, and the spring hinge will open the contacts. So when the generator voltage is too low, the cutout opens and keeps the battery from discharging through the generator.

The strength of an electromagnet depends on the type of core, the number of turns of wire, and the amount of current passing through it.

Electric meters are able to measure the strength of a current or a voltage. A meter has a movable coil mounted on a fine spring, set in the field of a permanent horseshoe magnet. Current passing through the coil makes a magnetic field of its own that opposes the field of the permanent magnet. Since like poles repel each other, the movable coil will turn. In order to turn, it has to bend the spring; the more current in the coil, the stronger the field, the greater the force of repulsion, and the more the coil turns.

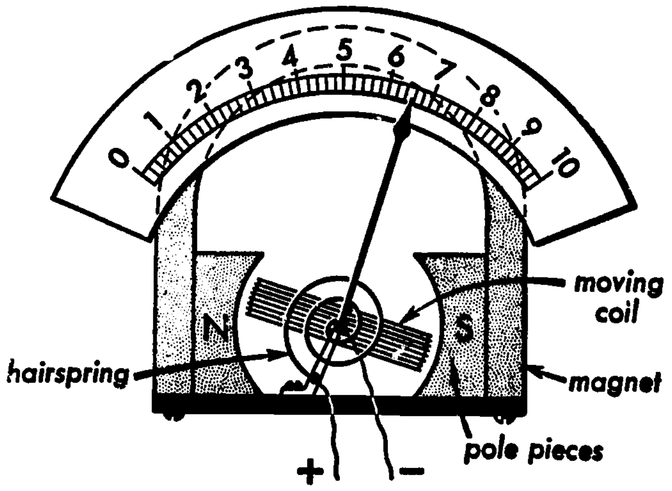
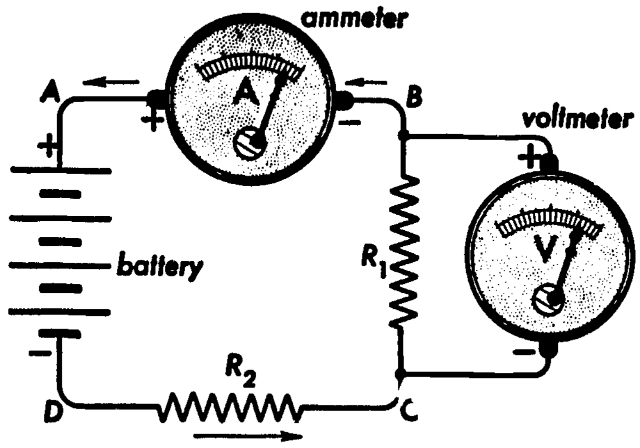


Diagram of the essential parts of an ammeter or voltmeter.

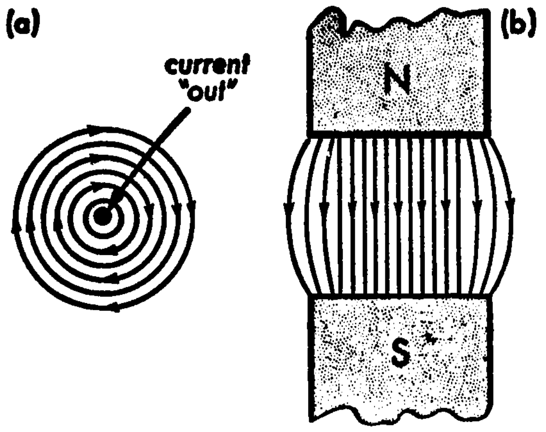
Fig. 5-37

In use, an ammeter is always put in series in the circuit, or it may be burned out. A voltmeter is put in parallel; or the circuit will not operate. These connections are shown in Fig. 5-38.



Circuit diagram showing the connections for an ammeter and voltmeter.

Fig. 5-38



Magnetic fields (a) due to an electron current and (b) due to magnetic poles.

Fig. 5-39

Electric motors. The flow of electrons in the meters we just studied makes a magnetic field which, pushing against another magnetic field, causes motion. This motor effect may be understood if we look at Fig. 5-39. It shows at (a) the head-on view of a wire with current coming up from the page, producing a circular magnetic field, and at (b) a second, permanent, magnetic field.

Diagrams of two interacting magnetic fields.

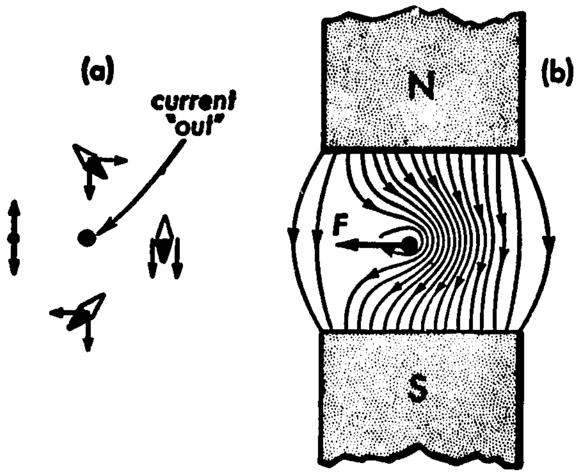
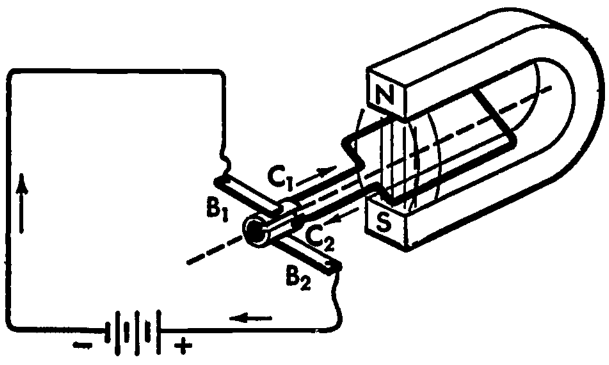


Fig. 5-40



A simple d-c motor.

Fig. 5-41

If the wire is placed within the second field, as in Fig. 5-40, the compressed fields on the right of the wire will push it to the left, as shown.

A simple motor can be made by mounting a loop of wire so that it can spin in a magnetic field. Its two ends should receive a supply of current through a split-ring commutator on which brushes slide (Fig. 5-41).

As the loop turns through a half circle, contact is made for the current to flow in one way. Then the brushes slide onto the opposite ring, and the current flow enters the other side of the loop. In this way, the current is always flowing into the loop at the same point in the magnetic field.

A study of Fig. 5-42,using the left-hand rule to get the direction of the lines of force around the wire, will show you how the coil will turn.

Better motors have iron armatures within the coil to strengthen the magnetic fields. Two-pole motors (Fig. 5-43) have dead spots in their cycle. For smoother power, armatures are wound to have four or even more poles.

Diagram of the magnetic field around a current-carrying loop as found in the electric motor.

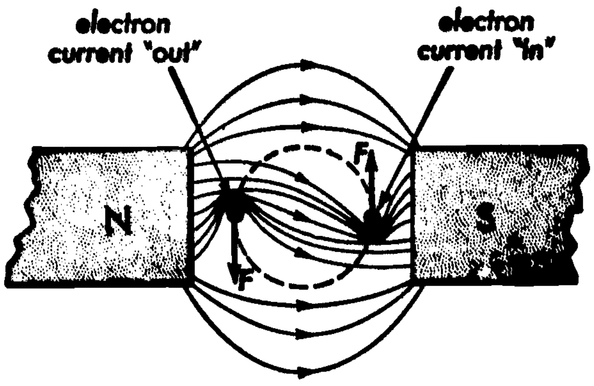
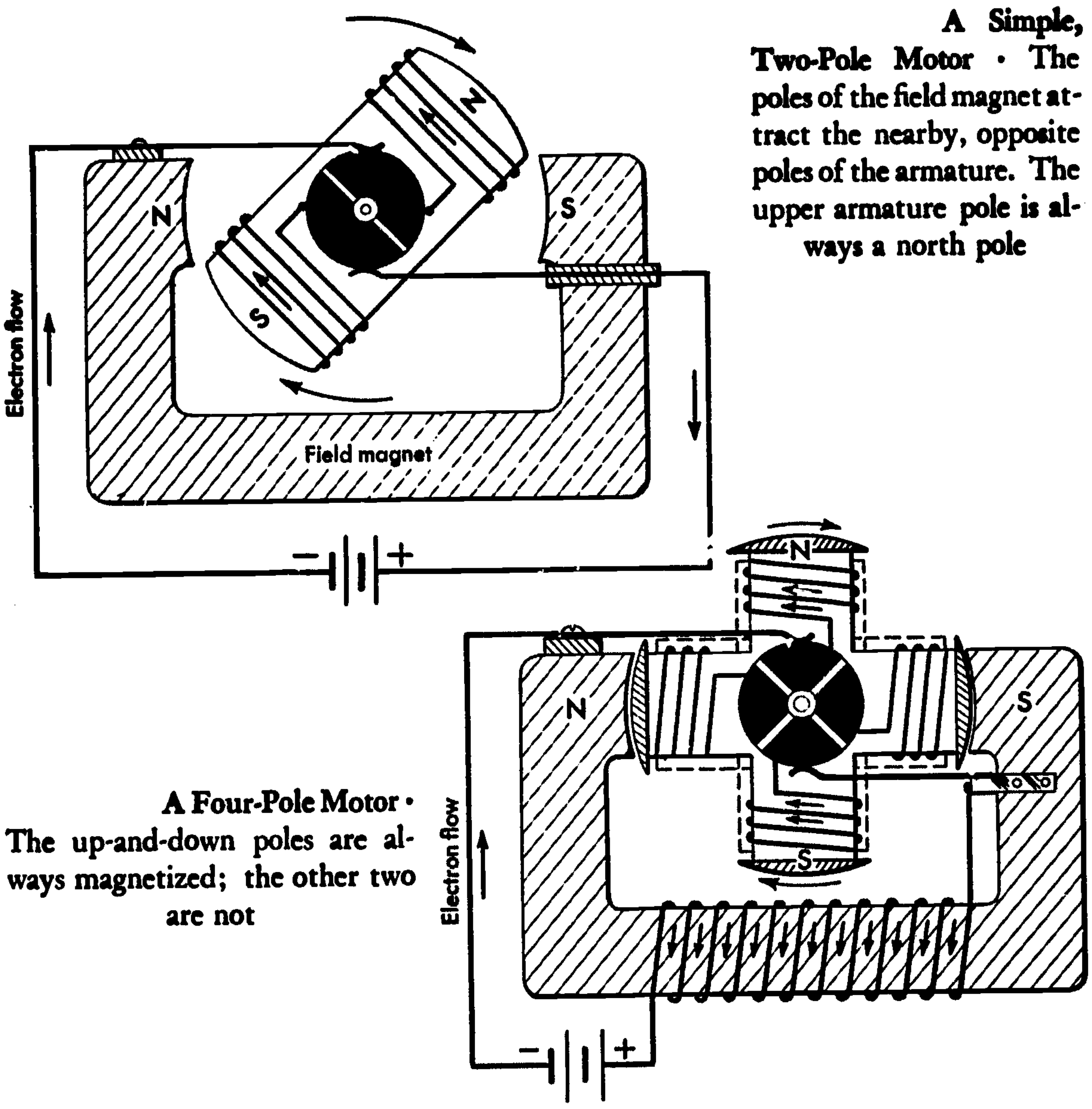
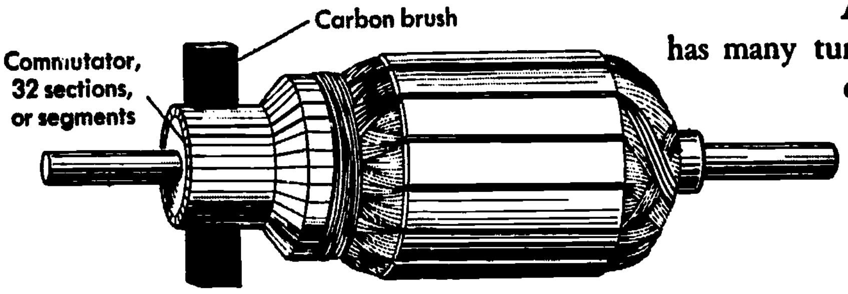


Fig. 5-42



A Simple, Two-Pole Motor • The poles of the field magnet attract the nearby, opposite poles of the armature. The upper armature pole is always a north pole

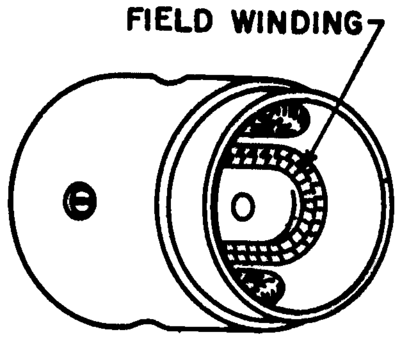
A Four-Pole Motor • The up-and-down poles are always magnetized; the other two are not



A Drum Armature • It has many turns, wound in the slots of the drum

Fig. 5-43

Large motors, like the starter of a car, do not depend on permanent magnets for their field, but have heavy windings to make a strong electromagnetic field, as the diagram of the four-pole motor is shown. Starting motors often have four field windings, as in Fig. 5-44.



FIELD FRAME ASSEMBLY

Fig. 5-44

EXPERIMENT 26. ELECTROMAGNETISM

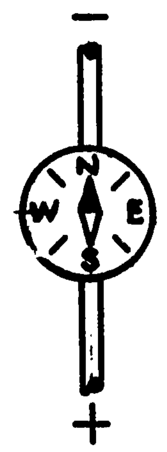
When current flows through a wire, a magnetic field is formed. In this experiment you will learn how the direction of the field can be known and what affects its strength.

MATERIALS: Compass, insulated copper wire about 24-28 gauge, large nail or bolt, small rheostat, 1½-volt dry cell.

PROCEDURE:

In your notebook record the results of each step by a sketch or statement.

1. Clean the insulation off the ends of a piece of wire about a foot or so in length. Connect one end to the dry cell. Lay the wire on the table in a north-and-south direction. Set the compass over the wire so that its needle is parallel to the wire. When the needle stays still, touch the other end of the wire to the free terminal of the cell. Note the effect on the compass and disconnect the wire at once, so as not to run the cell down. Make a sketch like the sample, showing the compass direction.



2. Put the wire over the compass and see what happens when current flows. Make a sketch of this test too.

3. Change the ends of the wire so that the current flows in the reverse direction and see what happens when current flows above and below the compass.

4. Check these results by Ampere's left-hand rule for electron flow, as given in your textbook.

5. Wind 5-10 turns of the insulated wire around a pencil to make a coil. Take the pencil away and test the magnetic polarity of the coil with a compass. What happens when no current flows? Check the magnetic field against the left-hand rule for coils.

6. Put a nail or bolt in the coil and compare the strength of the magnetic field to what it was without this core.

7. Make a coil with many turns and compare its strength to the one with few turns. Do this by leaving the core out and seeing how far away each one affects a compass. Always disconnect the cell except for the actual moment of testing.

8. Connect the cell in series to the rheostat and then to the coil. What happens to the strength of the field when the rheostat is changed? Why?

CONCLUSIONS:

1. How can the direction of the electromagnetic field around a wire be predicted?

2. How does the strength of field vary with the amount of current?

3. How can the field from a given wire, with a given current, be made stronger?

4. How can the field of a coil be made stronger without changing the coil or current?

5. How can the polarity of an electromagnet be reversed?

EXPERIMENT 27. ELECTROMOTOR DEVICES

When a current is sent through a coil that is near a piece of iron or a magnet, the iron is attracted. If either the coil or the iron can move, you have what might be called an electromotor device. Generally we think of motors as rotating machines, but this same principle of electromagnetism is used in many parts of an automobile to make something move back and forth also. In relays, for example, a small current in a coil is used to move a plate that closes a switch that carries a large current. In some kinds of gauges, there is a sensing element whose resistance varies with fuel level , temperature,or other condition to be measured. This sends a varying current to a coil that moves an indicator in proportion to the current. In this experiment you will study several devices of this kind.

MATERIALS: Battery charger; small 12-volt lamp with socket; horn relay; electromagnetic fuel gauge (2 units); electromagnetic temperature gauge (2 units); variety of lead wires; compass.

PROCEDURE:

In your notebook, as you come to each part make a simple sketch of the device and its circuit. Answer all questions as you go along.

1. Attach a lead to the (+) terminal of the battery charger.

2. Connect the same lead to the "B" (for battery) terminal of the relay.

3. Touch a second lead from the "S" (for switch) post of the relay for a moment to the (-) of the supply. What happens to the relay?

4. In place of a horn, connect a small lamp to the relay terminal marked "H" (for horn) and ground the body of the lamp to the supply (-). Close the circuit from the (+) to the "B" terminal again. What happens? Disconnect the devices.

5. Take the tank unit of the fuel gauge and connect it in series with the lamp and the supply. (Whenever a device has only one terminal, where do you make the second connection?) What happens when the float arm is moved up and down? Disconnect the circuit.

6. Now take the tank unit and the gauge unit. Connect the bodies of both to the supply (-). Connect the supply (+) to the gauge at the post common to both coils. Connect the other post to the terminal on the tank unit. Now move the float lever up and down. When you have the gauge working properly, hold a compass near the two coils and see if it shows how the gauge works.

7. Optional. The electromagnetic type of temperature indicator has a resistance which changes with heat. Try it in series with a lamp as in (5), heating the end with a match. Then connect it to its two-coil gauge as in (6) and heat it again.

CONCLUSIONS:

1. What is the purpose of a relay?

2. In what ways is an oil-pressure indicator light like a gauge, and in what ways is it different?

3. Could the gauges used in this experiment be used as ammeters? How would they work out as automobile ammeters?

4. What determines how much current goes through the coils in a fuel gauge?

EXPERIMENT 28. THE DC ELECTRIC MOTOR

An electric motor is a machine that turns because it has two magnetic fields that push against each other. One is held in place (the field winding); the other is on an armature and is rotated by the force between the two fields. In a DC motor, connections are made to the armature by a commutator.

Simple DC motors fall into three basic types: (1) Magneto wound, in which the field is a permanent magnet; this type is not powerful enough for practical use. (2) Series wound, in which the armature is in series with the field. (3) Shunt wound, with armature and field wired in parallel.

In this experiment you will study these three types of motors, taking note of the amount of current drawn and the direction of rotation.

MATERIALS: St. Louis motor with bar magnets and electric field; two dry cells; hook-up wires; ammeter.

PROCEDURE:

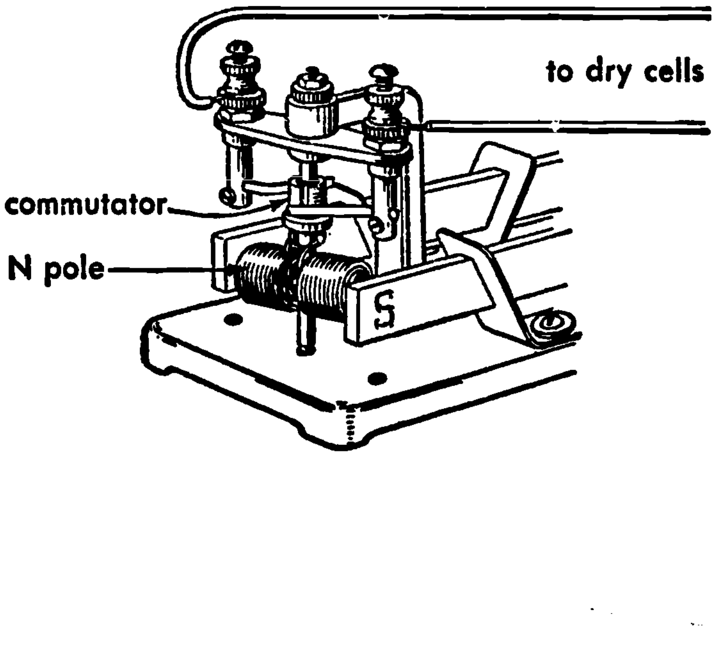
1. In your notebook prepare a table like this:

Situation	Current Flow
Magneto Winding	
Shunt Winding	
Series Winding	

Situation	Effect on Rotation
Reversal of current (magneto)	
Reversal of field (shunt)	
Reversal of current (series)	

Record the results of each test in the table.

2. Set up the motor with the two bar magnets in place as shown, and with the two dry cells and the ammeter in series. Adjust the com-



mutator brushes and field magnets until the motor runs. (If it will not run, disconnect the cells until the trouble is found.) Record the amount of current drawn.

3. Reverse the direction of current and see which way the motor turns. Record it.

4. Take off the bar magnets and put the field electromagnet in place. Connect the field in parallel with the armature (shunt winding). Record the current flow.

5. Reverse the connections to the shunt-wired field. Note the direction of rotation.

6. Wire the field in series with the commutator. Record the current flow.

7. Reverse the connections at the battery, still leaving the two cells in series + to -. Note the direction of rotation.

CONCLUSIONS:

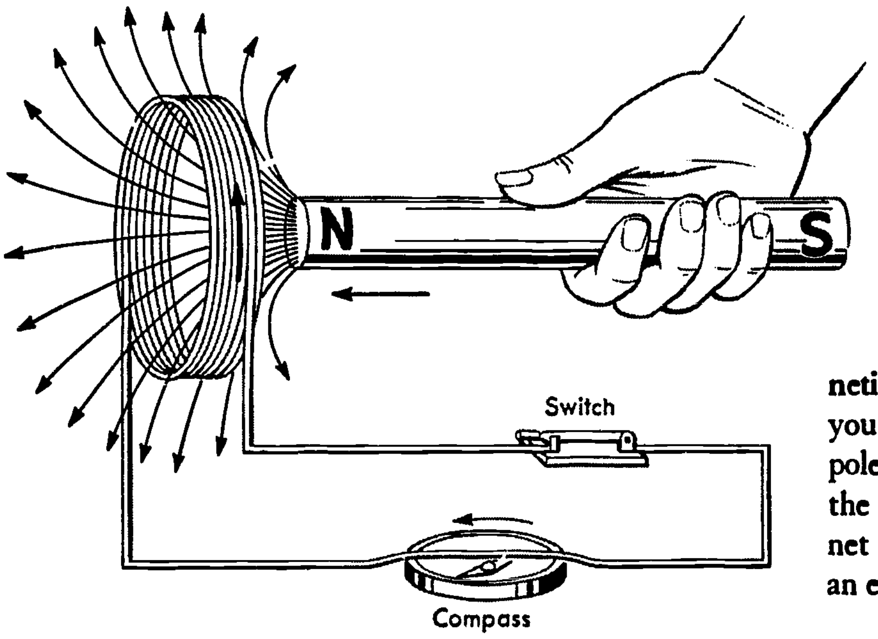
1. Which type of winding drew the most current?

2. If the connection to either the armature or the field of a series motor (but not both) is reversed, what should happen?

3. If the connections in a shunt-wound motor are reversed, what should be the result?

5. GENERATING ELECTRICITY

Electricity is common and cheap today because of Michael Faraday's discovery of electromagnetic induction over a century ago. This principle, which is illustrated in Fig. 5-45, says that:



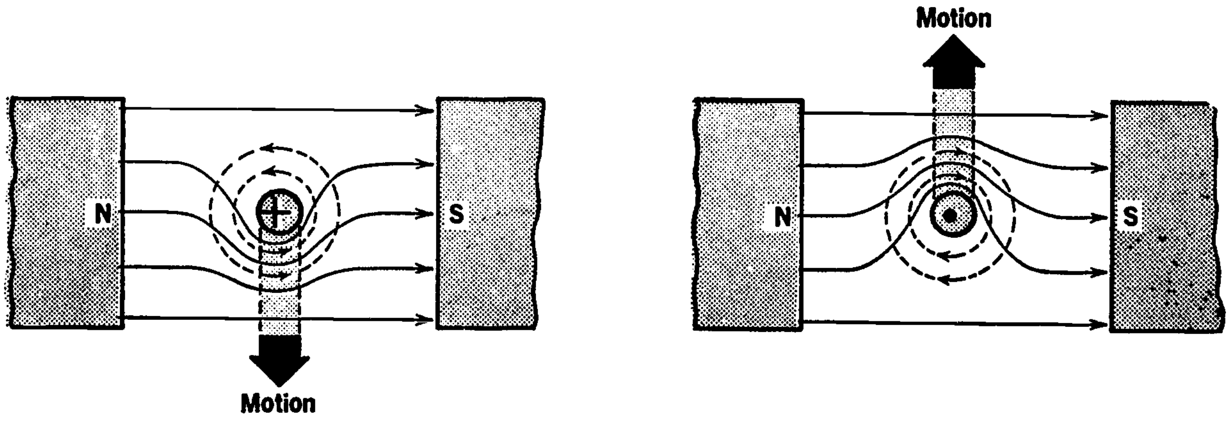
Electromagnetic Induction • When you move the magnet pole toward the coil or the coil toward the magnet pole, you will induce an electric current (if the circuit is closed)

Fig. 5-45

Whenever a magnetic field cuts an electrical conductor, a voltage is induced.

The voltage will be proportional to the strength of the magnetic field, the number of wires in the coil, and the speed of movement.

The direction of the current is such that it makes a magnetic field that opposes the field which induced it. This is Lenz's Law.



(A) Current in

(B) Current out

An induced current always produces a magnetic force which opposes the force causing the motion.

If you set up a coil magnet and compass as shown in Fig. 5-45, you will see the compass move (a sign of current flow) if either the coil or magnet moves relative to the other and the circuit is closed. (With the circuit open, as in Fig. 5-46, no current flows, of course.)

The current will flow so long as the motion continues, because it is the motion that makes the conductor <u>cut</u> <u>through</u> the lines of force. When the motion stops, the current stops.

Cutting Magnetic Lines Induces a Voltage • When you move the magnet toward the coil, the wires cut the magnetic lines. This cutting always induces a voltage. A current will flow if the circuit is closed. The cutting of the lines, while it induces a voltage, mav or may not induce a current

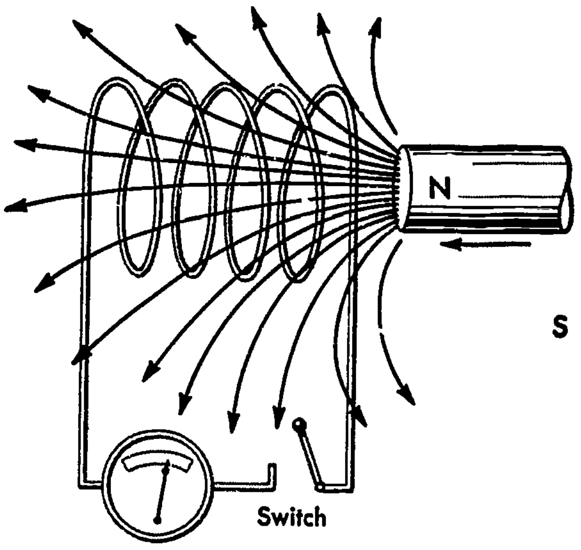
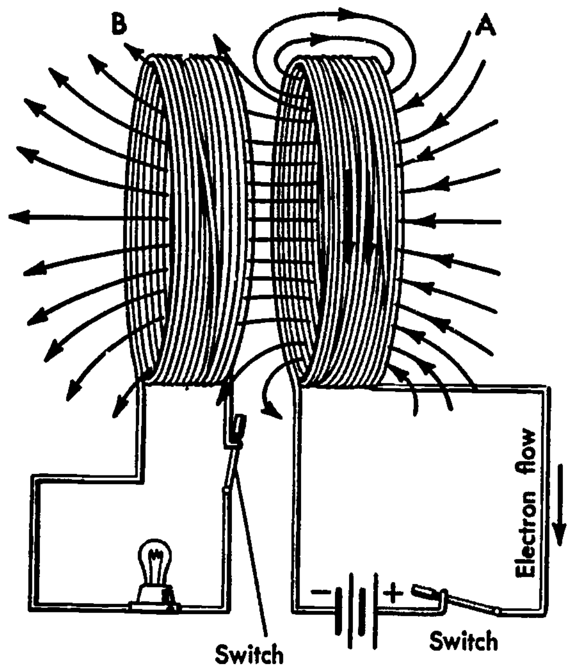


Fig. 5-46



Varying a Current Induces a Voltage • Opening the switch will stop the current in coil *A*. Then the magnetic field will disappear. The wires in coil *B* will cut the magnetic lines and thus induce a voltage in *B*. By stopping and starting the current in *A*, you can induce a voltage in *B*

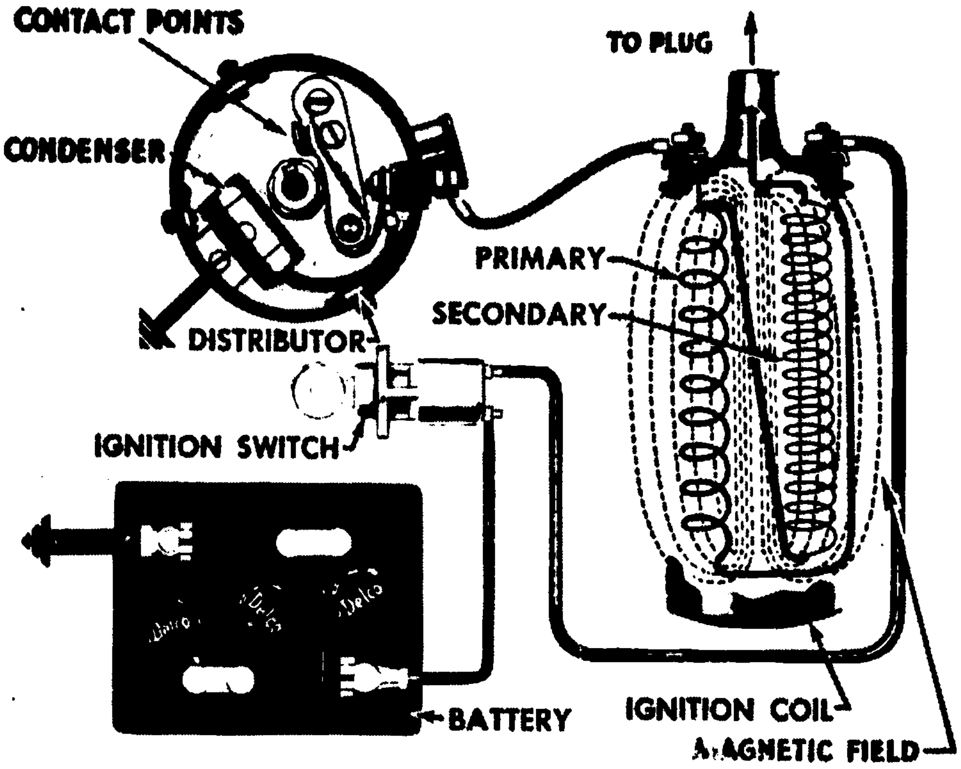
Fig. 5-47

<u>The</u> <u>induction</u> <u>coil</u>. So far you have seen that a voltage results when a magnet is moved into a coil, causing the coil to cut through lines of force. A second way to have a coil cut lines of force is to have the lines of force themselves move. We can do this by turning on the current in a solenoid.

Fig. 5-47 shows a <u>primary</u> coil A on the right connected to the battery. When the circuit is closed, current in this coil makes a magnetic field. As the field moves out, it is cut by the wires in the <u>secondary</u> coil B. This induces a voltage in B; current flows, lighting the bulb. The bulb will stay lit as long as the field is moving. Once the current in A becomes steady, the field stops moving and the light goes out.

If the primary circuit A is opened at the switch, the magnetic field will collapse; as it moves back it cuts the secondary coil B again, making another little surge of current, which again lights the bulb .

The ignition circuit of a car (Fig. 5-48) works in the same way. Current from the battery flows through some 200 turns of heavy wire in the primary circuit of the ignition coil. A magnetic field builds up. When the cam in the distributor turns and opens the contact or breaker points, the field collapses, cutting some 20,000 turns of wire in the secondary winding. A voltage, high enough to spark across the plugs, develops and is sent to the proper plug.

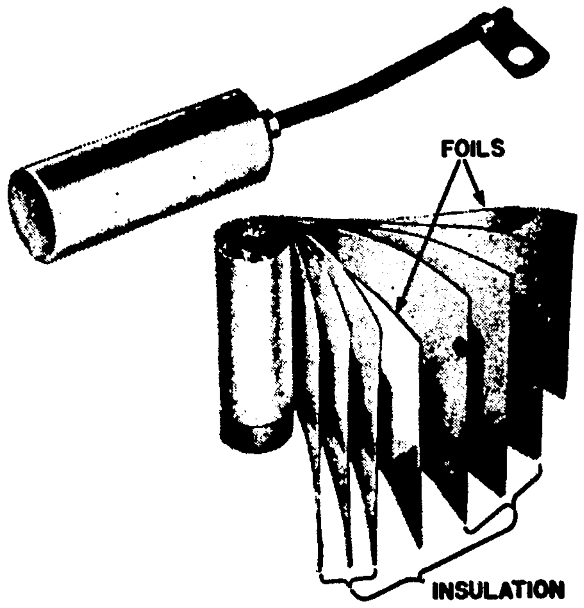


Schematic wiring diagram of the primary circuit of an ignition system. Primary circuit shown by heavy lines. Secondary winding of ignition coil shown by light lines, and magnetic field shown by dotted lines.

Fig. 5-48

The collapsing field also induces a voltage in the primary winding. To prevent a spark across the breaker points in the distributor, a condenser is put in parallel with them, to accept electrons long enough for the points to open. The condenser is made of two long strips of metal foil separated by insulating paper. Many electrons can flow onto the large surface of the foil, building up only a low voltage.

The generator. You have seen how electricity can be made by moving a magnet or a magnetic field past wires. How about moving wires through a field? This is actually our main way of making electricity.

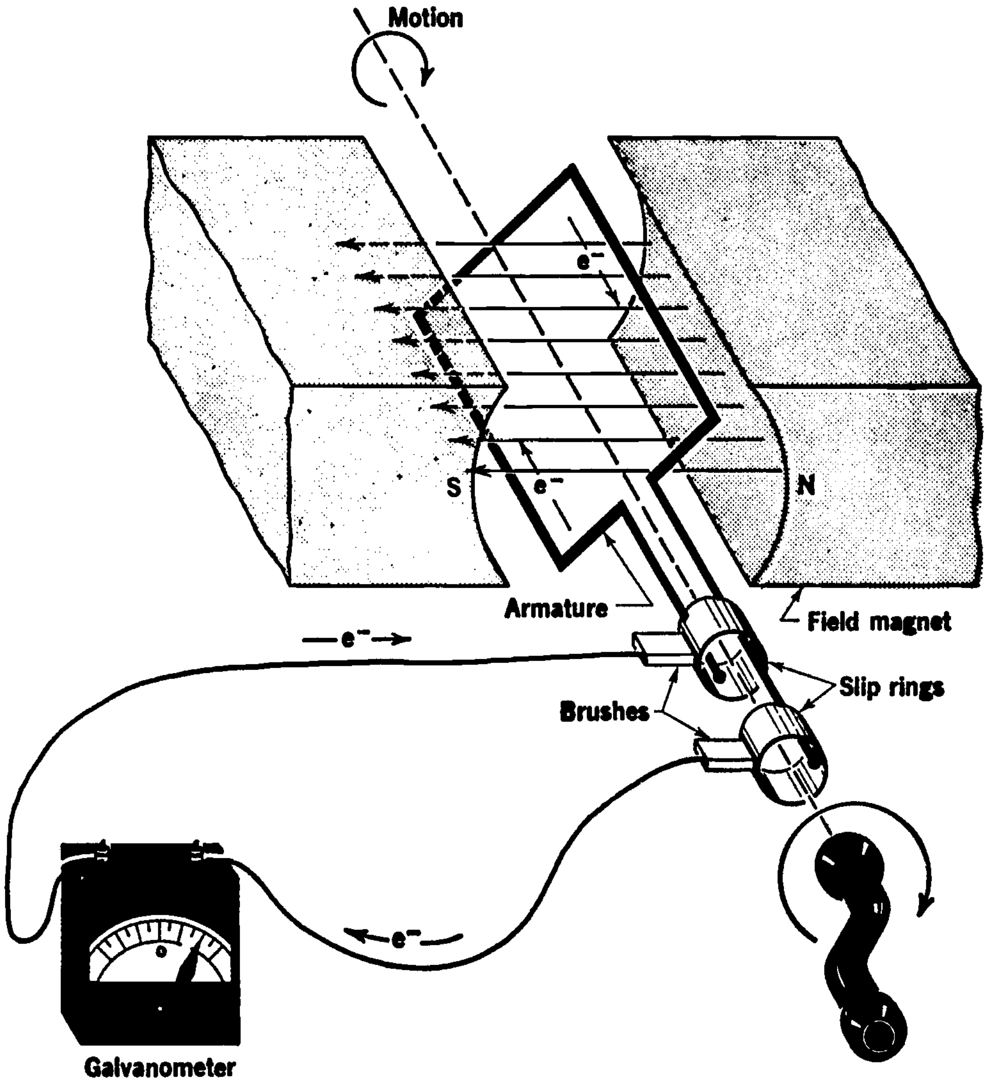


A condenser assembled and with the winding partly unwound.

Fig. 5-49

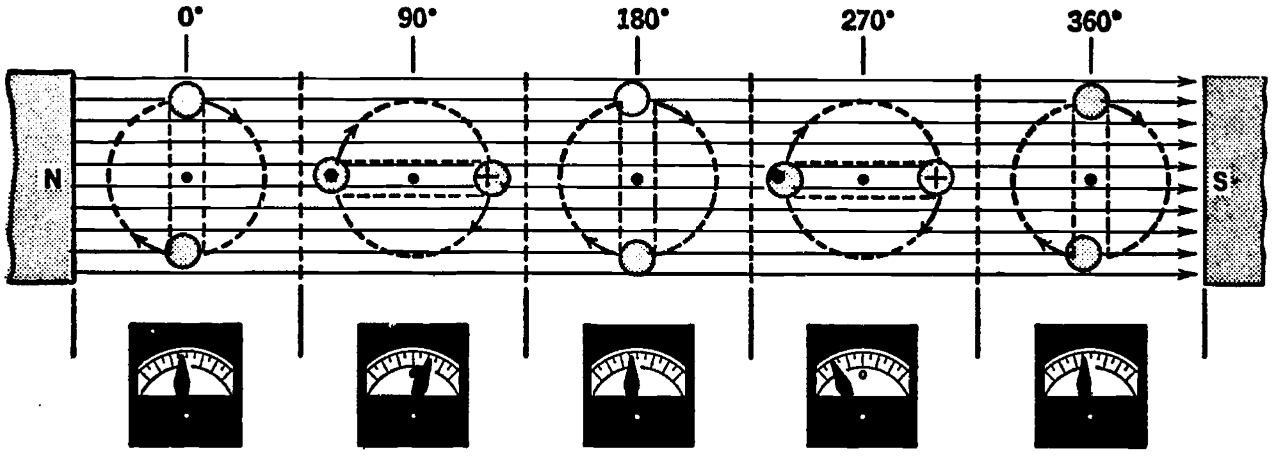
The machine for doing this is called a generator. A generator converts mechanical energy into electrical energy. In the manufacture of electricity, the mechanical energy is usually produced by either water power or, more often, steam.

A generator is built like an electric motor. Fig. 5-50 shows a simple generator. You may notice that it does not have a commutator, but uses slip rings to deliver the electricity it produces to graphite brushes. As the wire moves up through the field shown, a current will be induced in the wire. When it has gone half way around, and starts to move down, the current will also reverse direction. So within the armature of a generator the current changes its direction twice in every turn, as shown in Fig. 5-51. When the generator is connected through slip rings, its output also changes directions and is called alternating current (AC).



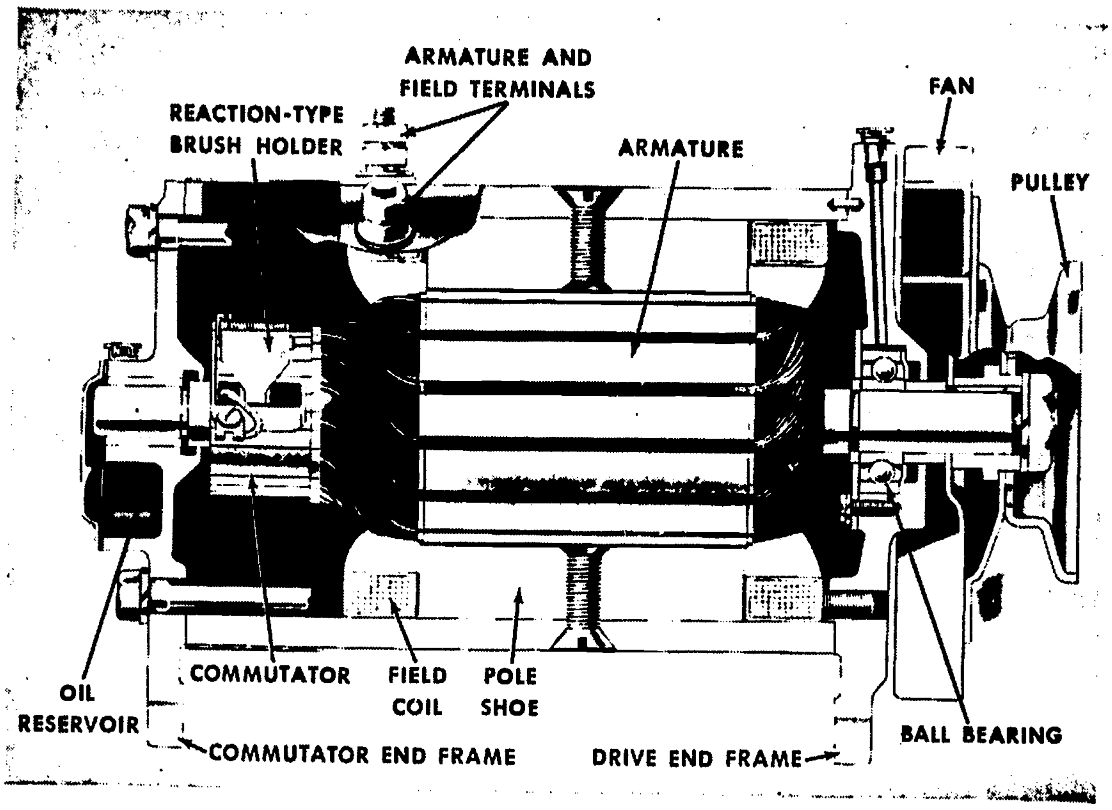
A simple electric generator.

Fig. 5-50



One cycle of operation of an a-c generator.

Fig. 5-51

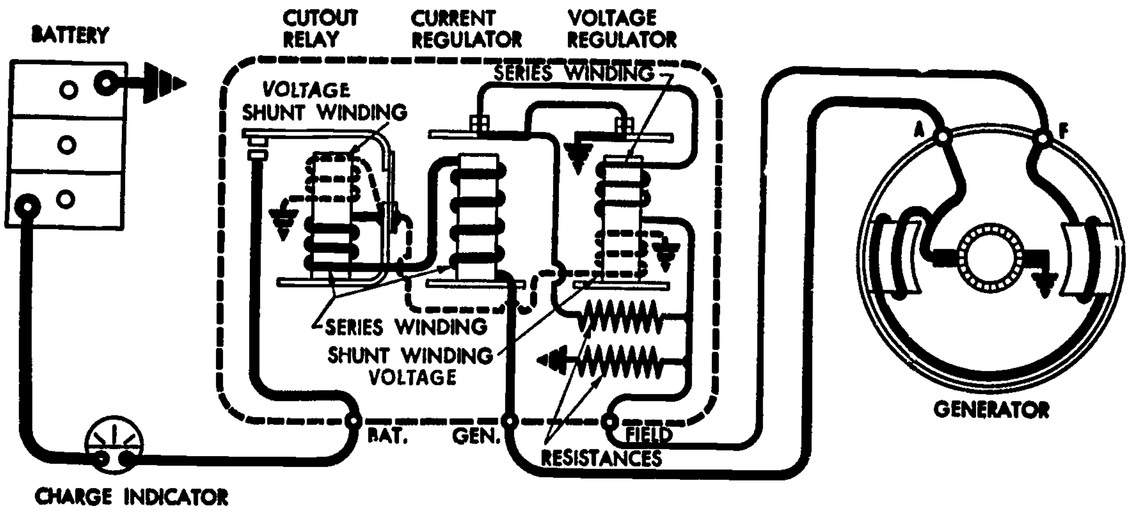


Sectional views of a passenger-car generator. *(Delco-Remy Division of General Motors Corporation)*

Fig. 5-52

Since storage batteries give direct current (DC), which flows in one direction, most cars have DC generators. Like the motors you studied earlier, these have commutators.

The field of an automobile generator is magnetized by electricity from the generator itself. In order to start making electricity, the iron pole shoes must have a little permanent or residual magnetism. This can be done by sending a little current from the battery through the field windings--polarizing them.



Typical Delco-Remy wiring diagram for shunt-wound voltage and current-control generator circuit. (Courtesy Buick.)

Fig. 5-53

Regulators. The output of a generator must be controlled so that it does not burn itself out by overheating, or damage the battery, lights, etc. with too much voltage. This is done by a regulator (Fig. 5-53) that controls the amount of current that flows through the field windings.

Two resistances limit the field current. The grounded one always allows some field current. The other draws current only when the contacts on the two regulators are closed. One will open when the current is too great. The other opens when the voltage is too high. When the generator is producing just enough voltage and little current is drawn, this regulator normally vibrates open and shut to control the voltage, no matter how fast the generator is turning.

Alternators. Several makes of cars now use an alternator (AC generator) which can give good voltage at lower speeds than DC generators do. The alternator has its field magnet on the rotor, powered by slip rings. The output is taken from the stator as AC. It is then rectified by passing it through silicon diodes. These contain crystals that pass current in one direction only. The diodes do not let current "back up," so no cut-out relay is needed. The alternator also needs no current regulator, but does have a simple voltage regulator and sometimes a fuse.

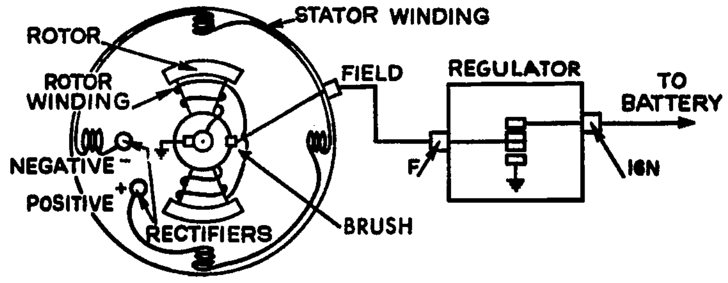


Fig.5-54

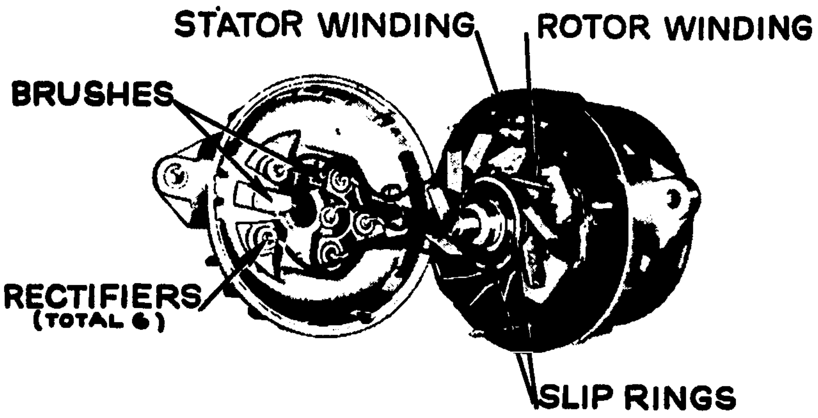


Fig. 5-55

EXPERIMENT 29. INDUCTION

An electromotive force (voltage) is induced whenever a wire or other conductor moves in a magnetic field so as to cut lines of force. It does not matter which of the two moves. If the conductor forms a closed circuit, electric current will flow. This is the principle of the generator, by which most of our electric power is made. It is also the principle of the auto ignition coil and transformer. In this experiment you will induce currents and learn the principles of these devices.

MATERIALS: Bar magnet, U magnet, 2 coils (50 or more turns each), contact key, iron core rod, galvanometer, wire, flat coil, St. Louis motor, dry cell.

PROCEDURE:

In your notebook record the experiment by sketches and sentence answers to the questions as you go along.

1. Find which way the galvanometer (a very sensitive voltmeter) points when the right terminal is (+) and the left one is (-) by passing a little current through your body, as in Fig. 1.

CAUTION: Do not connect the instrument directly to the cell, or it will be burned out.

2. Connect a coil to the galvanometer terminals. Push a magnet through the coil, N end first. What happens at the galvanometer?

3. Study the left-hand rule in your text, and decide which end of the coil should be N, due to the current flow in the coil. What is the relationship between the magnet in motion and the field it induces in the coil?

4. Pull the magnet back out, watching the galvanometer. Does the rule apply as before?

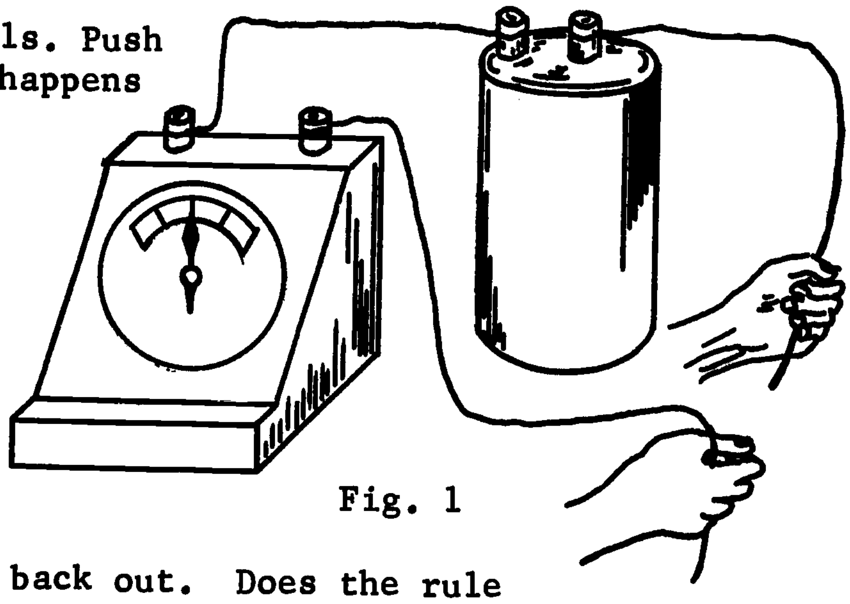


Fig. 1

5. Push the S end into the coil. Now pull it back out. Does the rule hold for this case?

6. Attach the flat coil to the galvanometer in place of the long coil. Put the flat coil between the poles of the U magnet with its plane cutting the lines of force, as shown in the upper part of Fig. 2.

7. Turn it 90° as shown. What happens to the galvanometer when the coil is moving? What happens when the coil stops moving?

8. Turn it another 90° and note the effect; then another 90°; and finally complete the full circle. When does the coil have the most EMF in it? What kind of current is produced?

9. Set up the St. Louis motor with the bar magnets. Wire the galvanometer to the slip rings. Turn the armature slowly and watch the galvanometer. What kind of current do you get?

10. Now wire the galvanometer to the commutator. Turn the armature again and study the current produced. How would you describe it? Disconnect the motor.

11. Wire a circuit with two coils and galvanometer as shown. Connect one lead to the cell but leave the second terminal on the cell open.

12. Close the cell connection by touching the end of the wire to the terminal. After 2 or 3 seconds take it away. What happens when contact is made? What happens when contact points remain closed? What happens when contact is broken?

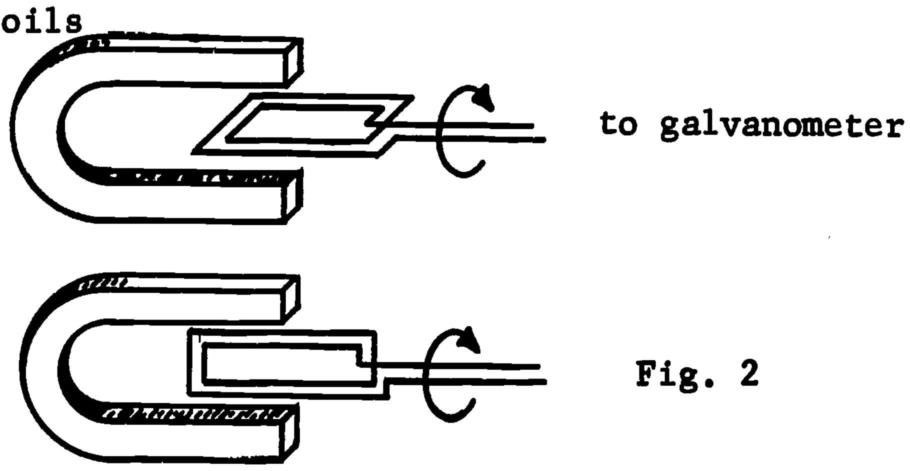


Fig. 2

CONCLUSIONS:

1. When a voltage is induced in a conductor, what is its direction?

2. How can we describe the EMF in the armature of a generator.

3. In order to get DC from a generator, through what must the output be taken?

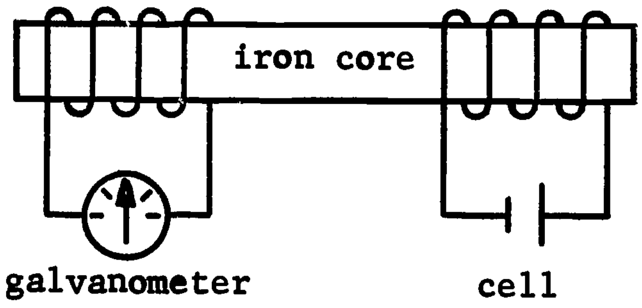


Fig. 3

4. When is there an EMF in the secondary winding of an induction coil?

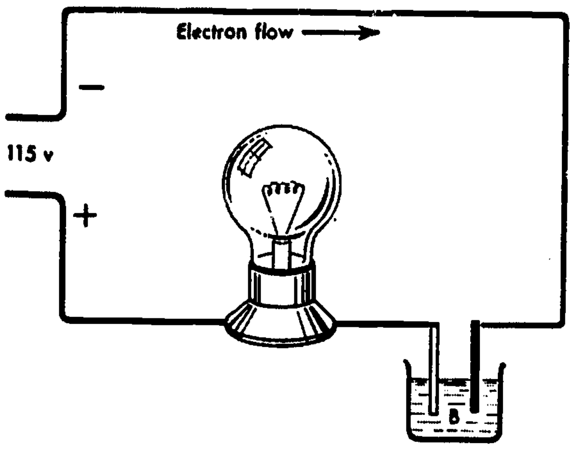
5. A transformer is built like an induction coil, but has an EMF in the secondary winding all the time. What kind of primary supply is needed?

6. ELECTROCHEMISTRY

You will recall that all atoms are made of electrical parts--protons and electrons--and that chemical reactions are shifts of electrons. Some of these reactions are tied in closely with the study of electricity. Making current by cells and batteries is one part of electrochemistry. Corrosion, such as rusting, is another. Plating of metal coatings is a third.

Most of these processes need a liquid that will carry electricity. Generally these are water solutions. A liquid that carries current is called an electrolyte.

You might be surprised to know that pure water carries very little electricity when tested, as in Fig. 5-56. But a little chemical added to the water makes it a good conductor.



Pure Water, in the Vessel *B*, Will Not Conduct Electricity; but a Solution of an Acid, Base, or Salt Conducts It Fairly Well

Fig. 5-56

When sodium chloride crystals are dissolved in water, the polar water molecules exert attracting forces which weaken the ionic bonds. The solution process occurs as sodium and chloride ions become hydrated.

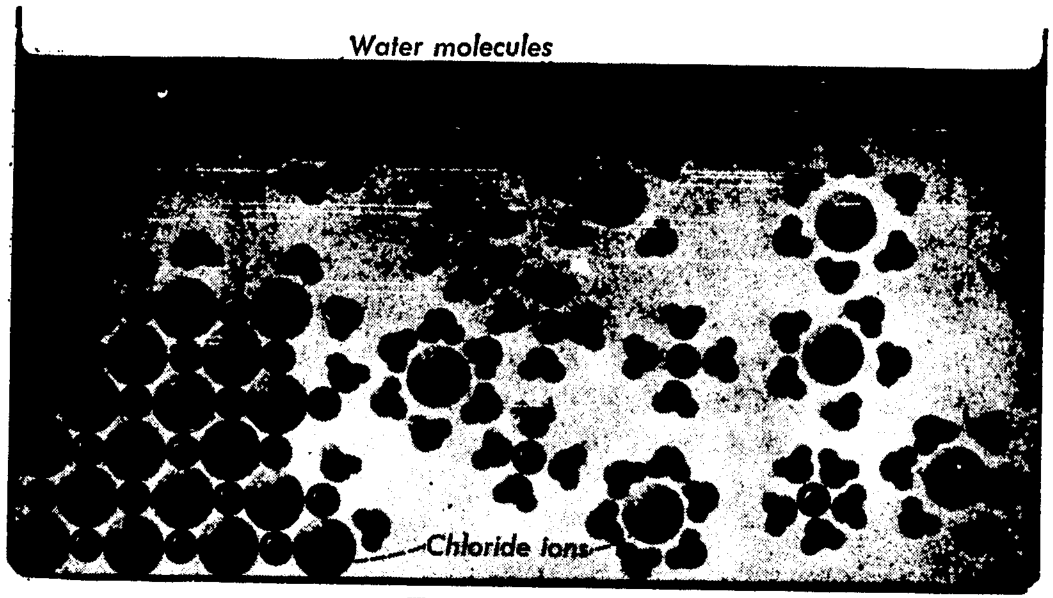
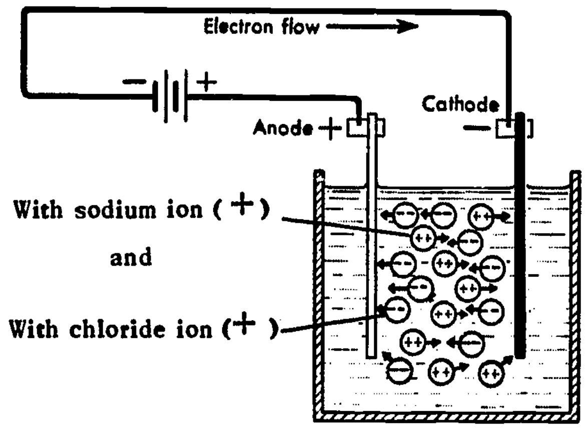


Fig. 5-57

What makes these solutions good conductors is the ions in them. You may remember that crystals of salt, for example, are made of sodium atoms that have loaned away electrons and chlorine atoms that have taken them. These atoms have become electrically charged ions. In a water solution, these ions separate, as in Fig. 5-57, and are free to move about, each surrounded by water molecules.

If electrically charged plates are put in the solution, negative ions will move toward the (+) plate and positive ones toward the (-). This movement of ions lets electricity flow in the circuit.

Electricity in common use is made either by chemical cells or by generators. From a cost point of view, generators give power more cheaply when a lot of it is needed. Cells are simpler in their principles, though. A battery is several electric cells hooked together.



The Current through the Liquid Is Two Oppositely Moving Streams of Ions • In the wire it is a stream of electrons

Fig. 5-58

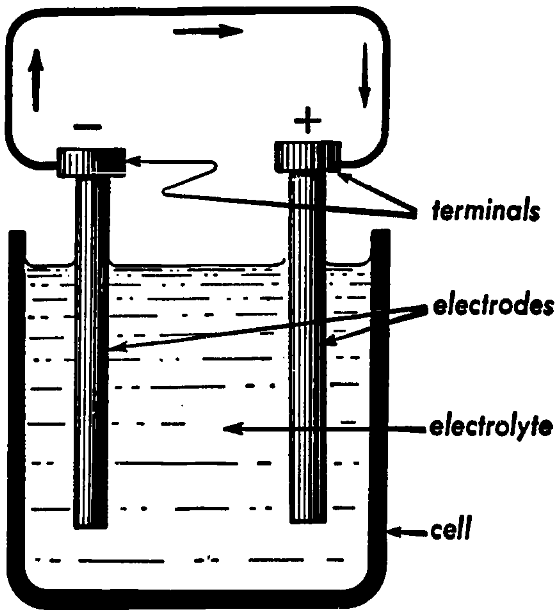


Diagram of a voltaic cell.

Fig. 5-59

The voltaic cell. Every wet cell has plates or electrodes, made of two different materials, and a solution called electrolyte. Many metals and some nonmetals can be used as electrodes. Generally cells having two different metals and an electrolyte are called voltaic cells, named after Alessandro Volta, the discoverer.

One common cell uses a zinc rod, a carbon rod, and sulfuric acid as the electrolyte. When the two rods are connected by a conductor, electrons flow from the negative (zinc) rod to the positive (carbon) one. Let us see why this happens.

When sulfuric acid (H_2SO_4) is dissolved in water, some of the molecules ionize or come apart. Hydrogen atoms leave the SO_4 part of the molecule. You will recall that an ordinary hydrogen atom has one electron. In ionization, the hydrogen atom leaves its electron with the SO_4, so each molecule can give two H^+ ions and an SO_4-- (sulfate) ion.

Some of the sulfuric acid molecules and water molecules in a dilute solution dissociate.

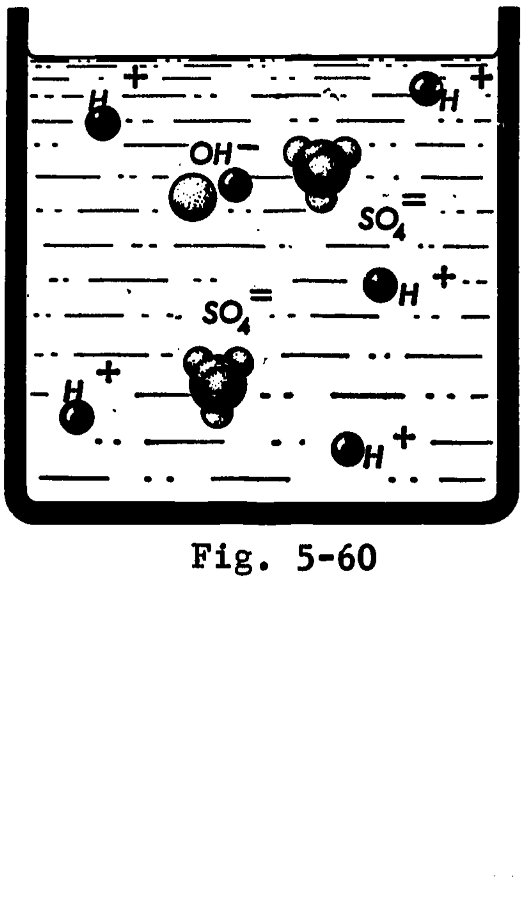
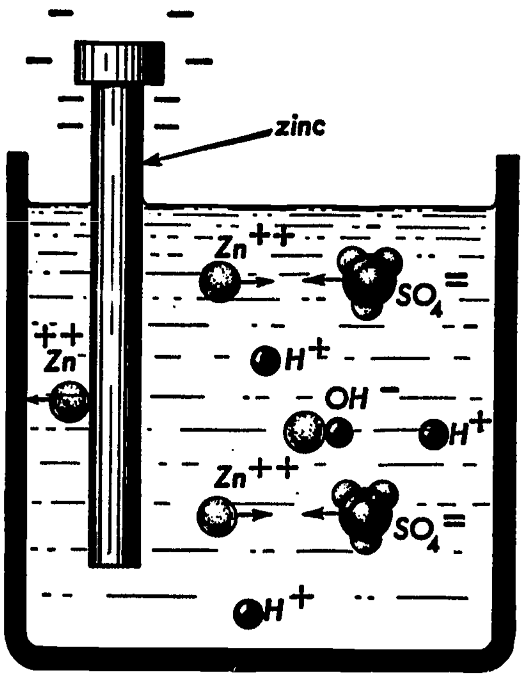


Fig. 5-60

If we now put a zinc rod into this acid solution, some of the zinc atoms tend to go into solution as positive ions, which balance the sulfate ions to give zinc sulfate, $ZnSO_4$. The two outermost electrons from each zinc atom are left on the electrode, making it negative. This can be said through an equation:

$$\underset{\text{zinc metal}}{Zn^{o}} \longrightarrow \underset{\text{zinc ion}}{Zn^{++}} + \underset{\text{electrons}}{2e^{-}}$$



A zinc metal electrode in dilute sulfuric acid.

Fig. 5-61

If instead of a zinc rod we put a carbon rod in the solution, hydrogen ions come to it. They each take an electron from the carbon, making it positive. Two hydrogen atoms normally join to make a molecule of gas (H_2), which bubbles off when the cell works.

A carbon rod in dilute sulfuric acid.

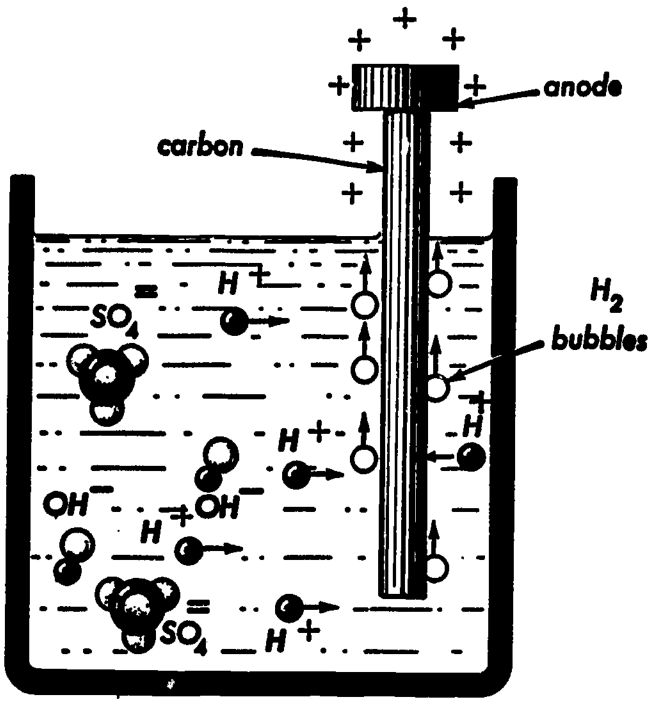


Fig. 5-62

When both electrodes are put into the solution and their dry ends are connected with a wire, the extra electrons on the zinc rod will produce a driving force that moves electrons along the wire from the zinc to the carbon rod. This <u>electromotive force</u> (emf) is measured in volts.

As the circuit is completed, electrons flow from the zinc to the carbon. As this makes the zinc less negative, more zinc atoms dissolve; as the carbon becomes more negative, more H^+ ions are attracted to it; they react and form more hydrogen gas. When the circuit is opened, no current flows and no chemical action takes place.

The emf of a voltaic cell is measured with a voltmeter.

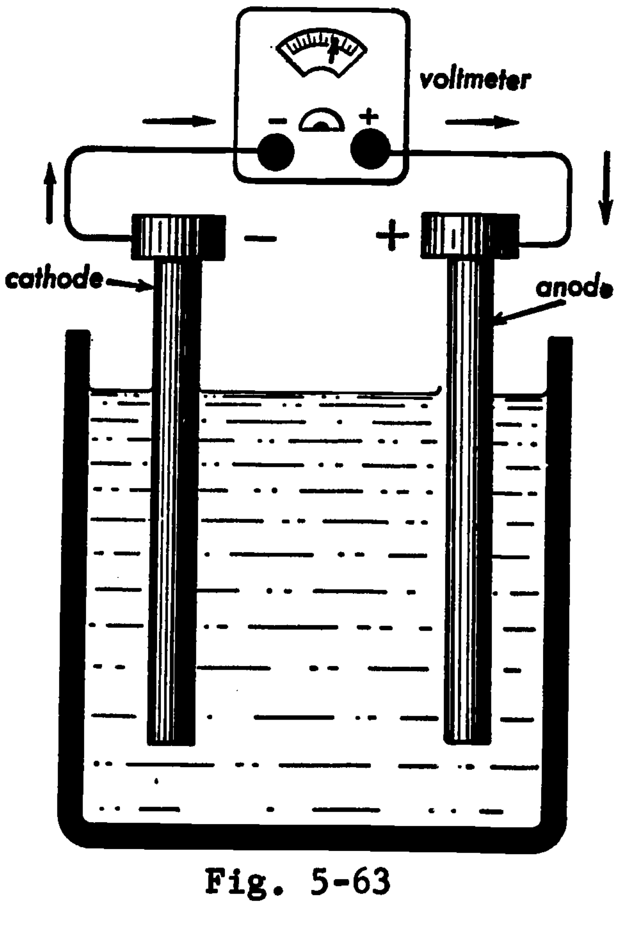


Fig. 5-63

The dry cell. You are familiar with "dry" cells. They are used to power radios, flashlights, hearing aids, and many other devices. They are not really dry at all. They are wet cells with electrodes made of zinc (the outer can) and carbon (the center rod), and an electrolyte consisting of several chemicals in a moist paste.

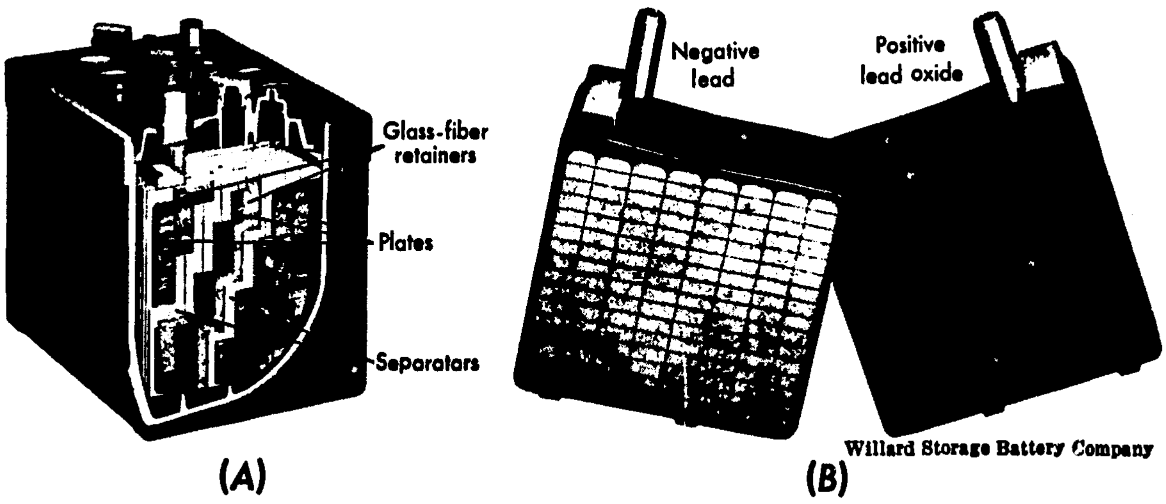
Electromotive series. Each metal has a tendency to give off electrons, some more than others. Table 10 lists the emf of some of the metals compared to hydrogen as zero. Those with a minus (-) emf are more active than hydrogen, and will replace it from acids, just as the zinc did in the sulfuric acid solution in the voltaic cell.

ELECTROMOTIVE SERIES

Element	Voltage
Lithium	−2.96
Potassium	−2.92
Calcium	−2.76
Sodium	−2.71
Magnesium	−2.40
Aluminum	−1.70
Zinc	−0.76
Iron	−0.44
Cadmium	−0.40
Nickel	−0.23
Tin	−0.14
Lead	−0.13
Hydrogen	0.00
Copper	+0.35
Mercury	+0.80
Silver	+0.80
Gold	+1.36

Table 10

Storage battery. The voltaic cell cannot be recharged by forcing an electric current in the reverse direction. It can be used only until it is worn out, like the flashlight cell. In an automobile you want a battery that can be recharged many times by current from a generator. Such batteries have as their negative plates sheets of lead. The positive plates are made of lead with a filling of lead oxide.



Willard Storage Battery Company

Lead Storage Batteries • (*A*) Several positive and negative plates are mounted side by side. (*B*) Plates from a battery

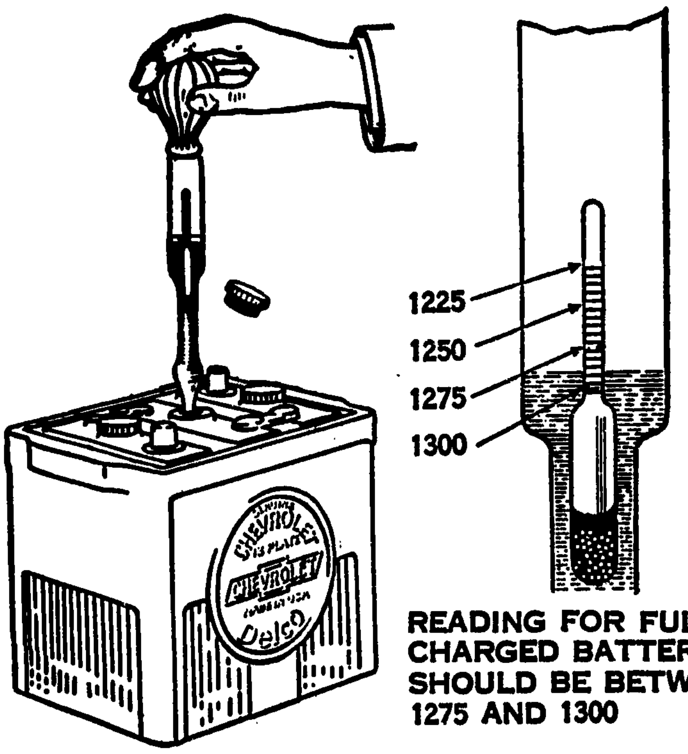
Fig. 5-64

To get the amount of current needed for starting the engine and other uses, each electrode is made up of many plates. The number and size of plates per cell is what gives the ampere-hour rating of the battery. The quality of construction and the nature of the separators between the plates give the length of life that can be expected from a battery.

Each cell of a lead storage battery gives about 2 volts, so a 6-volt battery has three cells, and a 12-volt battery has six. The cells are connected in series.

When current is taken from a lead storage battery, the negative lead plate forms lead sulfate (as the zinc formed zinc sulfate). But lead sulfate is insoluble, so it stays right where it is. Hydrogen ions and sulfuric acid react with the lead oxide on the positive plate, forming lead sulfate also. When a charging voltage is applied, these changes are reversed, and the plates turn into lead and lead oxide again.

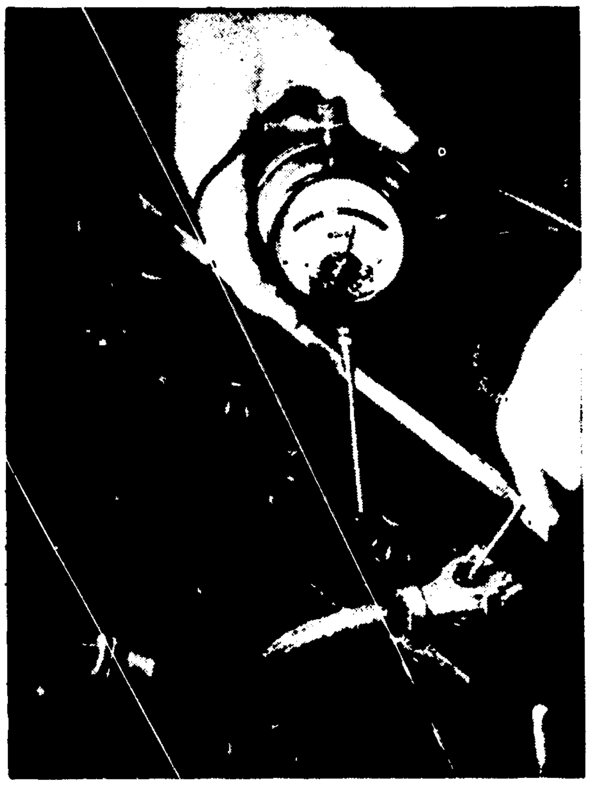
As a cell is discharged, acid is used up, reacting with the plates. The electrolyte loses this acid, so its density goes down. The condition of a cell can be estimated from the density of the electrolyte, as in Fig. 5-65.



READING FOR FULLY CHARGED BATTERY SHOULD BE BETWEEN 1275 AND 1300

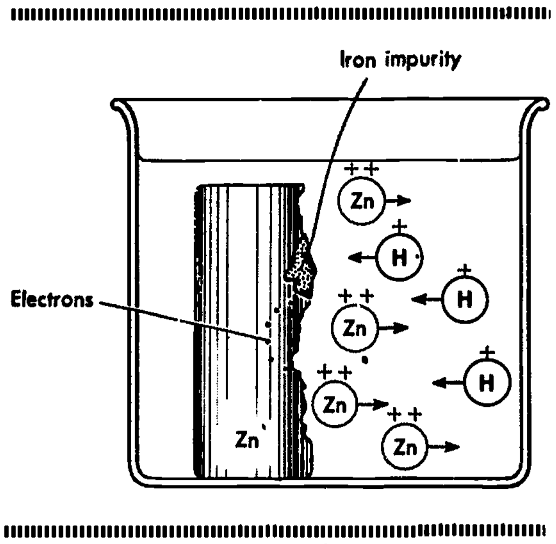
Battery testing.

Fig. 5-65



Making high-discharge test with low-reading voltmeter of battery on car. (*Delco-Remy Division of General Motors Corporation*)

Fig. 5-66



Local Action • The zinc, the iron embedded in it, and the acid solution form a voltaic cell. The zinc dissolves, forming zinc ions. They force hydrogen ions over to the iron. There each ion receives an electron and is changed into hydrogen gas

Fig. 5-67

<u>Corrosion</u>. Voltaic cells are formed whenever a metal more active than hydrogen in the electromotive series is connected to a different metal and they are wet by an electrolyte (even impure water). Fig. 5-67 shows how a bar of zinc which contains a speck of iron will form a tiny cell. Hydrogen discharges at the iron, current flows, and the zinc rapidly dissolves. This is the process of <u>corrosion</u>.

Steel, which is a mixture of iron and iron carbide, forms tiny voltaic cells whenever it is touched by an electrolyte. Salty water, a good conductor of electricity, rusts steel quickly.

Paint protects steel by keeping electrolytes from it. A perfect coating of copper or chromium does the same thing. But at any scratch or tiny pinhole, a voltaic cell is set up, and rusting is speedy.

<u>Plating</u>. When a metal dissolves in a voltaic cell, as we said, the atoms give up electrons:

$$Zn^o \longrightarrow Zn^{++} + 2e^-$$

If a reverse voltage is applied to the cell, it may be possible to pull metal out of the solution:

$$Zn^{++} + 2e^- \longrightarrow Zn^o$$

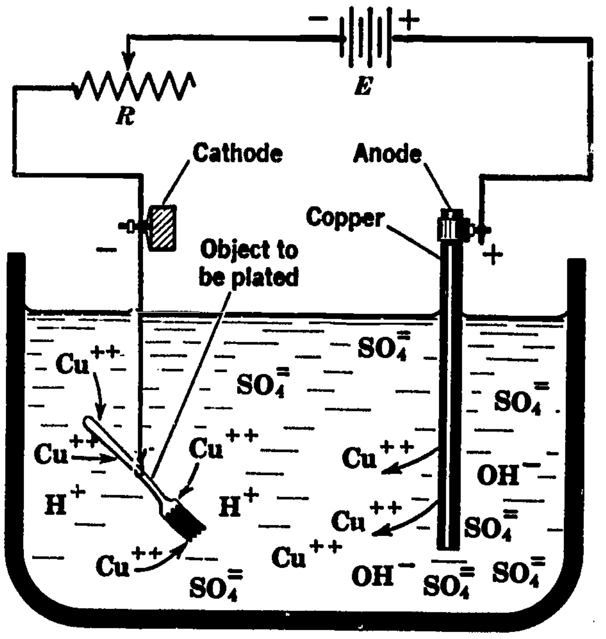
This is the process of electroplating. The object to be plated is made the negative electrode. An electrolyte is used that has ions of the metal to be plated. For example, copper sulfate is shown in Fig. 5-68, so copper can be plated. The positive electrode is usually a bar of the plating metal. At the (-) electrode, we have the reaction

$$Cu^{++} + 2e^- \longrightarrow Cu^o \text{ (copper metal)}$$

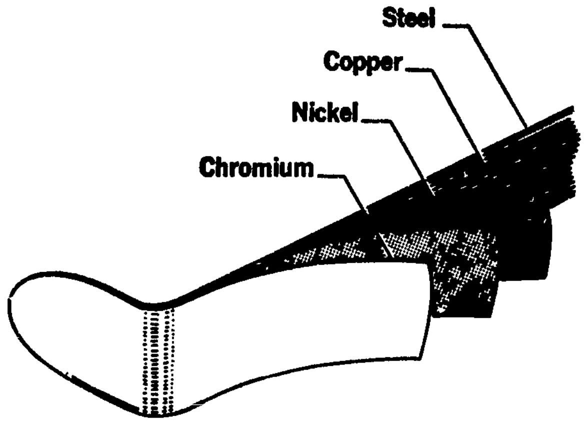
The electrons needed are taken off the metal of the (+) electrode, which dissolves:

$$Cu^o - 2e^- \longrightarrow Cu^{++} \text{ (ion)}$$

Plating is used on many automobile parts. A steel bumper is first plated with copper and nickel for corrosion resistance, then with chromium for hardness and shine.



An electrolytic cell used for copper plating. Fig. 5-68



An automobile bumper is electroplated to improve its appearance and its durability. Fig. 5-69

EXPERIMENT 30. ELECTRIC CELLS

Cells get electricity from a chemical change, that is when electrons are given by one kind of atom to another. A useful cell forces these electrons to go by way of an outside circuit and do work. Cells are useful as small, portable, cheap sources of electricity, although large amounts of power are made even more cheaply by generators. Most kinds of cells only give about 1-2 volts, but when a series of them is wired up to make a battery, higher voltages result.

In a typical cell you will find two plates or electrodes made of different metals, and an acid liquid (electrolyte). In use, one of the metals dissolves in the acid, giving up electrons that flow to the less active metal electrode through the circuit wires. This type of cell cannot be recharged by passing current in the reverse direction.

A few combinations of cells have been found in which reverse current puts the electrodes back into their original condition. This kind of cell is used to make storage batteries.

MATERIALS: Glass beaker, 5% sulfuric acid; strips of zinc, copper, iron, aluminum, and lead (2); wires; DC ammeter and voltmeter; 6-volt battery charger; buzzer; sandpaper; funnel.

PROCEDURE:

1. In your notebook copy a table like the one below to record the results of your work.

Metals	meter	volts	+	observations
zinc and copper	volt.			
zinc and copper	both			
zinc only				
copper only				
zinc and iron				
zinc and aluminum				
copper and iron				
copper and aluminum				
iron and aluminum				
lead and lead				charged 3 mins.
lead and lead				charged 6 mins.

2. Get the materials from your instructor. Work carefully. <u>CAUTION</u>: Dilute sulfuric acid can ruin books or clothing; concentrated sulfuric acid, which can burn the skin or eyes badly, will not be used. Your instructor will tell you how to handle spills and he may give you an acid-resistant apron to wear.

3. Pour the dilute acid into the beaker until it is a little over half full. Connect wires to the zinc and copper strips. Put the strips in the acid, not letting them touch each other. Is there any sign of action on the strips? Connect them to the voltmeter. Which strip is positive? Record this, and the amount of EMF in volts.

4. Rewire the cell and voltmeter to include an open connection for the ammeter. Touch the wires to the ammeter terminals. With the circuit closed through the ammeter, what can be seen to happen at the electrodes?

5. Pull one electrode out of the acid. Then put it back and take the other one out. What happens to the current?

6. As suggested in the table, try various combinations of electrodes. Measure the voltage between each pair, being sure they do not touch each other. Whenever you finish with an electrode, wash it off and put it aside on a paper towel.

7. Sand the two lead strips clean and put them in the acid. Test them with the ammeter and voltmeter.

8. Leaving the voltmeter connected, pass current through the cell from the charger for about 3 minutes. Does either plate change its color? What else can you see on the plates?

9. Disconnect the charger. What now happens at the plates? Does the voltmeter show anything?

10. Connect the buzzer and ammeter in series with the cell. How long does it ring?

11. Charge the cell for twice as long. Test the voltage. How long does it ring the buzzer now?

12. Remove the plates and wash them off. Carefully pour the acid back into the bottle through the funnel.

<u>CONCLUSIONS</u>:

1. When a zinc-copper cell has been used until it doesn't work any more, how could you get more current out of it?

2. What two ways have you seen to keep a cell from discharging? Which is better?

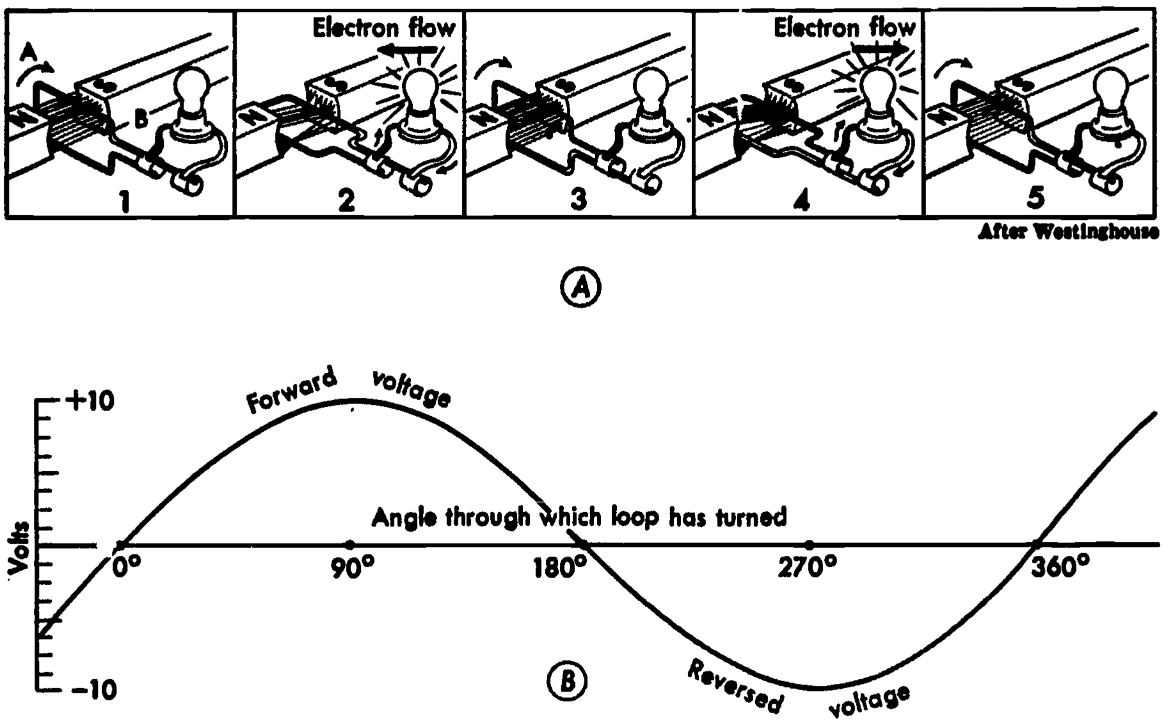
3. What determines the voltage of a cell?

4. What would be the effect of copper parts on the steel fenders of a car?

7. ALTERNATING CURRENT

We have seen that the two main ways of making electricity are with cells and generators. Cells give a smooth, direct current, which flows steadily in one direction.

In the generator (Fig. 5-70), the wires in the armature cut the field flux in one direction for one half of the cycle, and then cut it in the other direction the other half. This gives a voltage that changes direction back and forth--alternating current.



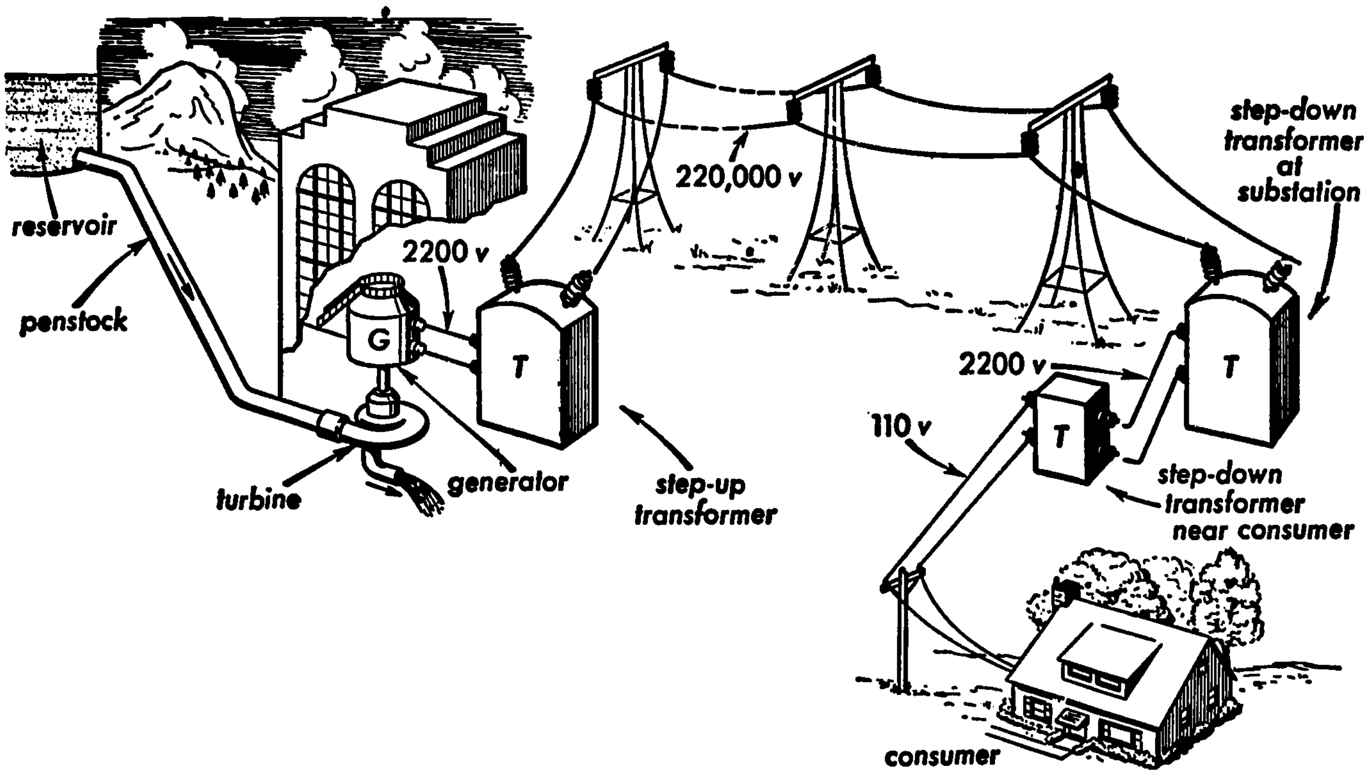
After Westinghouse

(*A*) **Showing How a Revolving Loop of Wire Generates Alternating Voltage** • (1) The wire *AB* moves parallel to the field and cuts no lines. The induced voltage and current are zero. (2) The wire moves across the field and generates maximum voltage. (3) The wire again moves parallel to the field. (4) The wire moves across the field again, generating maximum voltage. (5) The wire is back at the starting point, and again the voltage and current are zero. (*B*) **Showing the Variation of the Voltage as the Loop Rotates**

Fig. 5-70

Storage batteries give direct current, and need it for recharging, so the electrical systems of most cars are built for DC. Automobile generators have a commutator (look back to Fig. 5-52) to deliver DC. Some cars have alternators which give AC (Fig. 5-55). These have rectifiers in them that pass current only one way, changing AC to DC.

Transformers. In your house you have AC, which is supplied by the power companies to homes and industry. Power companies like AC because it can be carried cheaply at high voltages and stepped down through a transformer to a low, safer voltage such as 115 V.



Illustrating the use of transformers in the transmission of electrical energy from the power house in the mountains to the consumer in the distant city.

Fig. 5-71

A transformer has an iron core and two coils or windings. Current is put through the primary winding. It makes a magnetic field which cuts the secondary winding, inducing a voltage in it. Once the current becomes steady, the magnetic field stops moving. You will recall that voltage is induced only when the field moves past a wire, so you can see why a steady DC current cannot be transferred to another place by a transformer. Since AC changes all the time, the magnetic field in the transformer moves in and out through the secondary coil all the time. This makes an AC voltage in the secondary all the time, too.

Diagram of an open-core transformer.

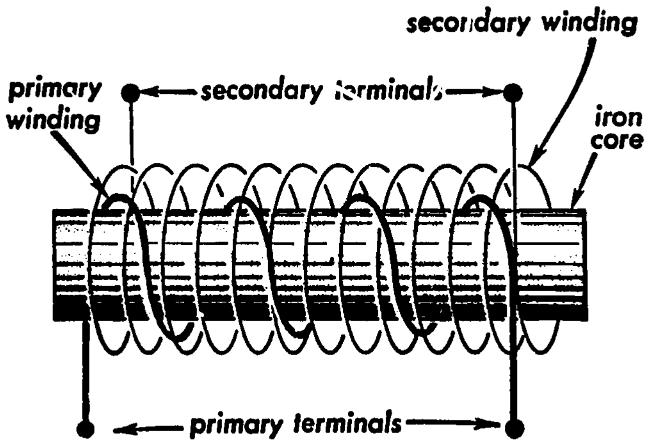
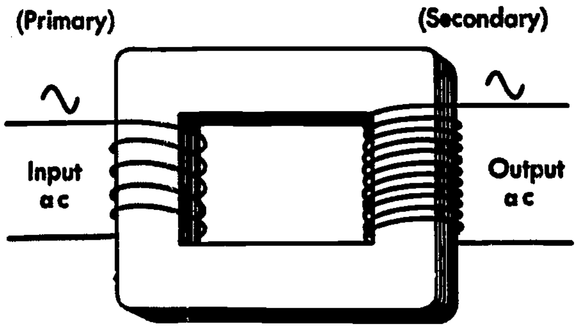


Fig. 5-72

Transformers can step up voltage or step it down. Fig. 5-73 shows 5 turns in the primary and 10 in the secondary. This is a ratio of 2 to 1. If 100 volts were put into the primary, there should be 200 in the secondary. On the other hand, Fig. 5-74 shows a transformer with more turns in the primary than in the secondary, so it would step the voltage down.



A Step-Up Transformer · Its output (secondary) coil has more turns than its input (primary) coil

Fig. 5-73

A Step-Down Transformer · The output wattage is slightly less than the input wattage because of heat losses. The efficiency is 98 per cent

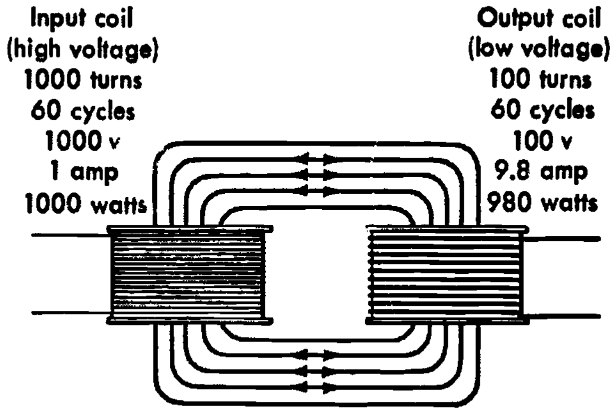
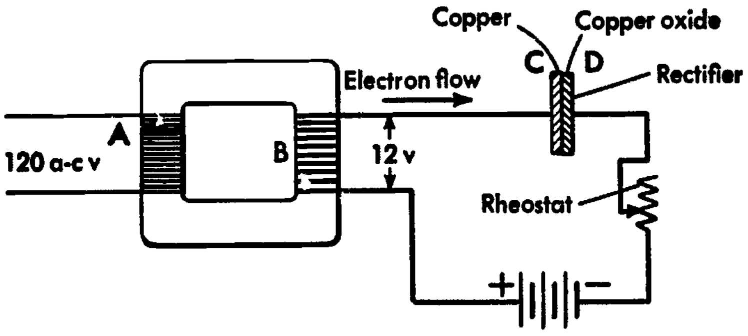
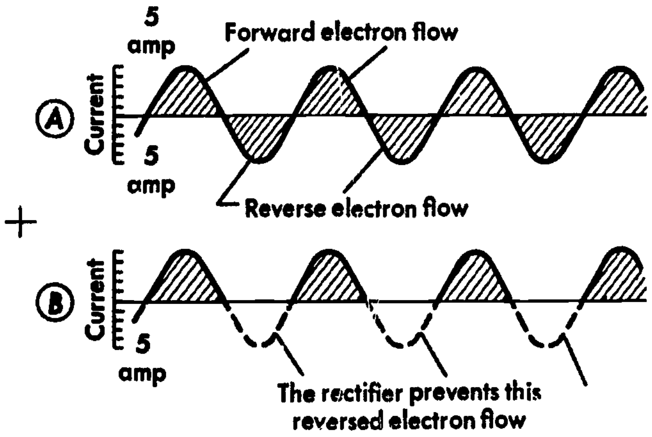


Fig. 5-74

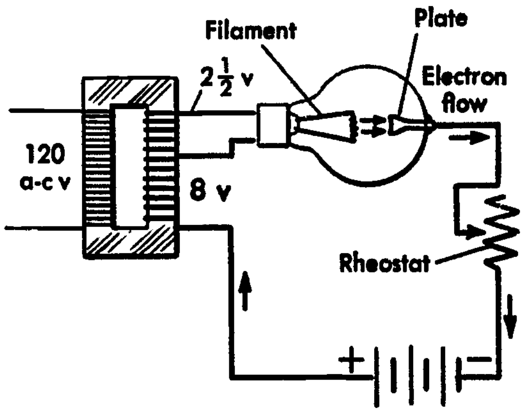
Battery chargers are made up of two parts. First, a transformer to step down 120 volts to 12. Second, a rectifier, to turn AC into DC. Fig. 5-75 shows circuits using copper oxide and vacuum tube rectifiers (which we will study in a little while).



A Battery-Charger · The transformer lowers the voltage. The rheostat limits the current. Electrons can flow from the copper plate, *C*, to the copper oxide plate, *D*, but not in the opposite direction. The plates change alternating current to direct current



(*A*) **Alternating Current Flows through the Transformer's Input Coil.** (*B*) **Direct Current Flows through the Rectifier and Battery**



A Vacuum-Tube Battery-Charger · The transformer causes current to heat the filament, so that it boils off electrons. They can flow from the filament to the plate, but not in the opposite direction. Thus the tube rectifies the current that charges the battery

Fig. 5-75

Automobile radios with vacuum tubes need over 100 volts to operate. This is made by a special transformer called a vibrator, shown in Fig. 5-76. It has an armature on a flexible steel spring, which is the real vibrator. Current goes to the primary through the post and armature. It makes a magnetic field which pulls the armature away from the post, opening the circuit. The magnetic field collapses. The vibrator moves back again, closing the circuit. In this way it goes back and forth hundreds of times a minute, breaking the primary current. The changing field induces a high voltage AC in the secondary.

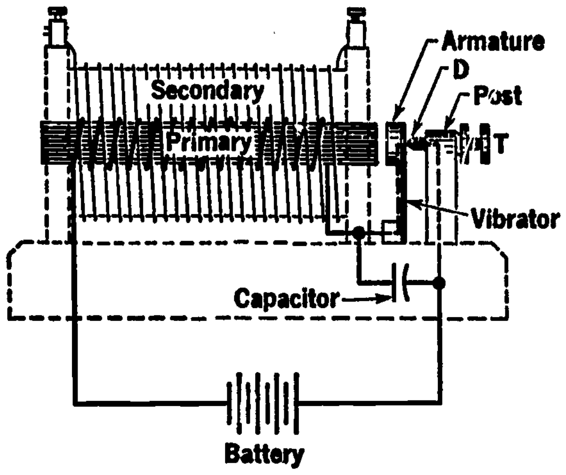


Fig. 5-76

8. ELECTRONICS

Until now we have said that electrons are carried mainly in metals. The study of electron flow in vacuum, gases, and semi-conductors is called electronics. This field is complicated, and only a few of its main points can be touched here.

Diagram of a Fleming valve, or rectifier tube. Such tubes are now called diodes.

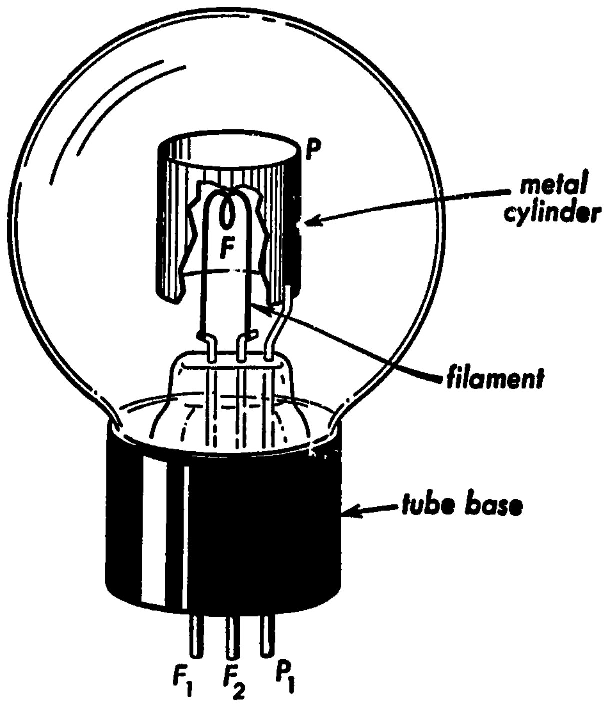
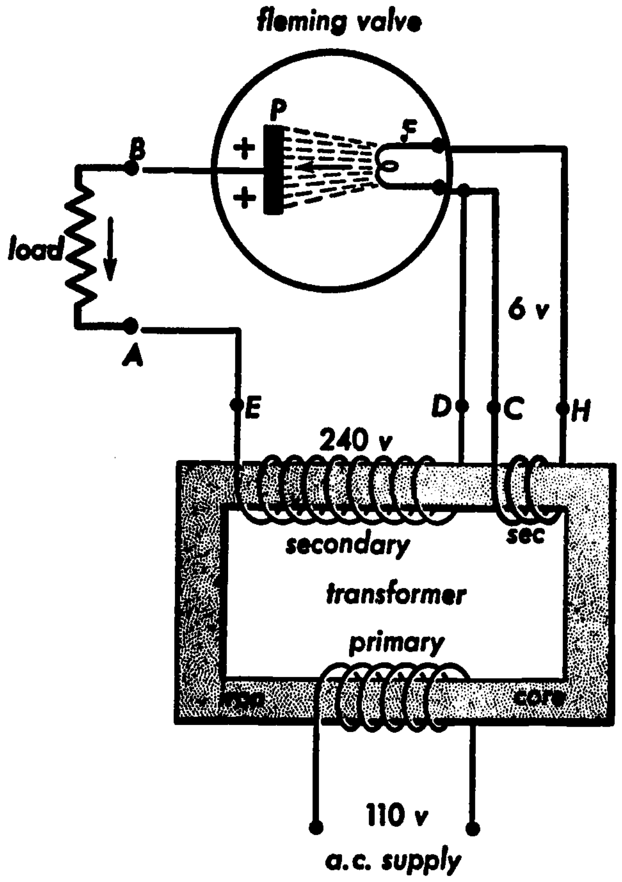


Fig. 5-77

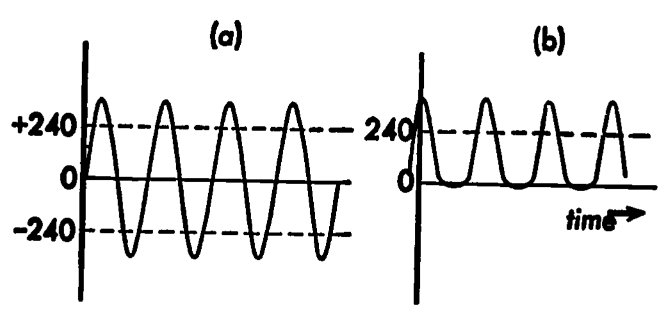
Diodes. A very simple electronic device is a diode rectifier tube (sometimes called a Fleming valve). It works because electrons come off hot objects. It is a glass bulb with all the air pumped out of it, and in it are sealed two pieces of metal--a filament, which being very thin, can be heated by passing current through it, and a large piece of metal called a plate.



Circuit diagram of a Fleming valve rectifier.

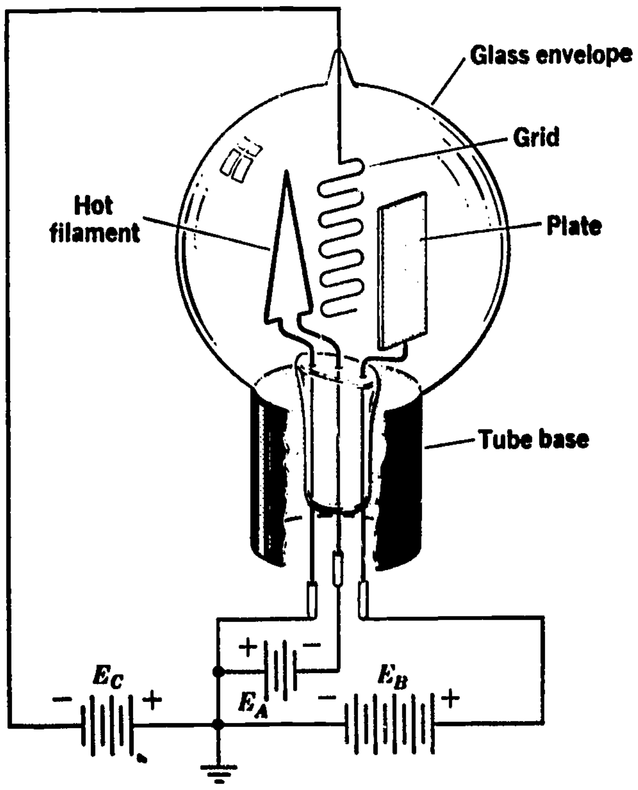
Fig. 5-78

Current is passed through the filament till it is red hot, by connecting it in a circuit like that shown in Fig. 5-78. Then a positive charge is put to the plate. Electrons come off the filament and go over through the vacuum to the plate. But when the alternating current from the transformer makes the plate negative and the filament positive, no electrons flow, because the plate is cold. In this way the tube acts as a rectifier. Fig. 5-79 shows how the alternating current is cut down, so it flows only when the plate has a positive voltage charge.



Alternating current as rectified by a Fleming valve, or diode.

Fig. 5-79



De Forest's three-element vacuum tube, the triode.

Fig. 5-80

Graph showing amplifier operation.

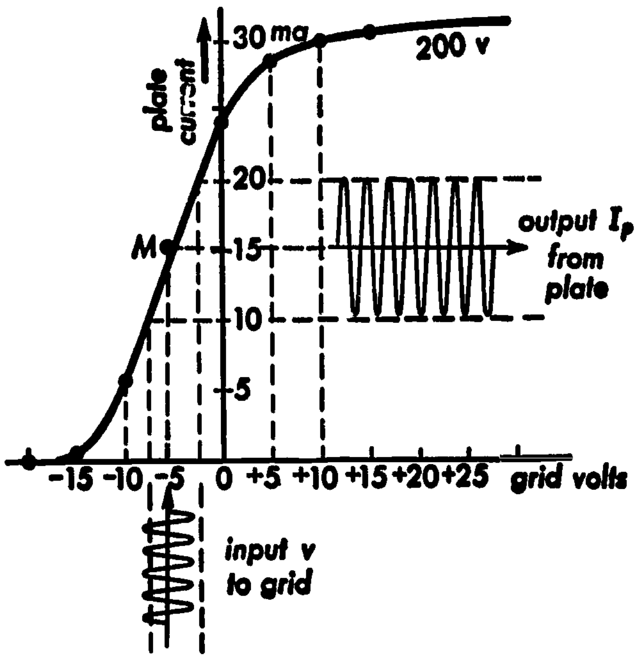


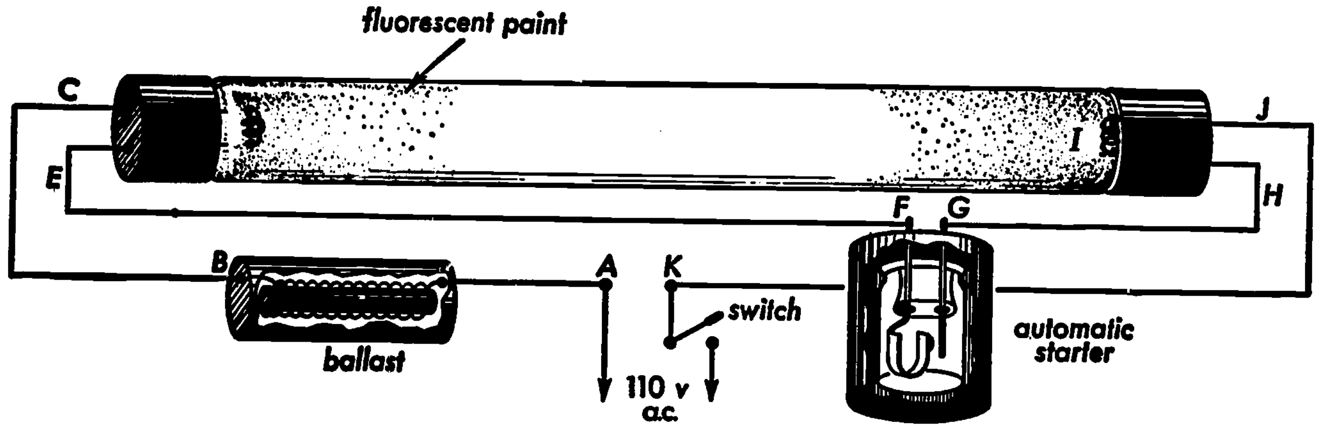
Fig. 5-81

Triodes. A tube having a filament, a plate, and a grid wire between them is called a triode, because it has three parts. It was invented by Lee De Forest and became the key to radio. As in the diode, electrons can flow from the hot filament to the plate. In this tube the grid is given a small electric charge.

As shown in Fig. 5-81, small changes in grid voltage have a big effect on the current flow to the plate. Triodes can be used as amplifiers and to make very high frequency AC (radio) waves.

Another electronic invention that does some of the same things as the tubes we have described is the transistor. It is in common use today in many devices, and it may have still other uses in cars of the future. To find out about the uses of electronics in radio, TV, and hi-fi you should get a book dealing just with that subject.

A completely different use of an electron tube is in fluorescent lamps. These are long tubes filled with argon and mercury gas and coated on the inside with a fluorescent paint. Electrons flow from a filament at one end, through the gas to the other end. On the way they knock electrons loose from the atoms of the gas. When the atoms get the electrons back strong rays of ultraviolet light shoot out. These rays hit the fluorescent paint and turn into visible white light. This type of lamp gives whiter light than ordinary bulbs, and gives more light per watt of power.



Section diagram of a fluorescent light and accessories.

Fig. 5-82

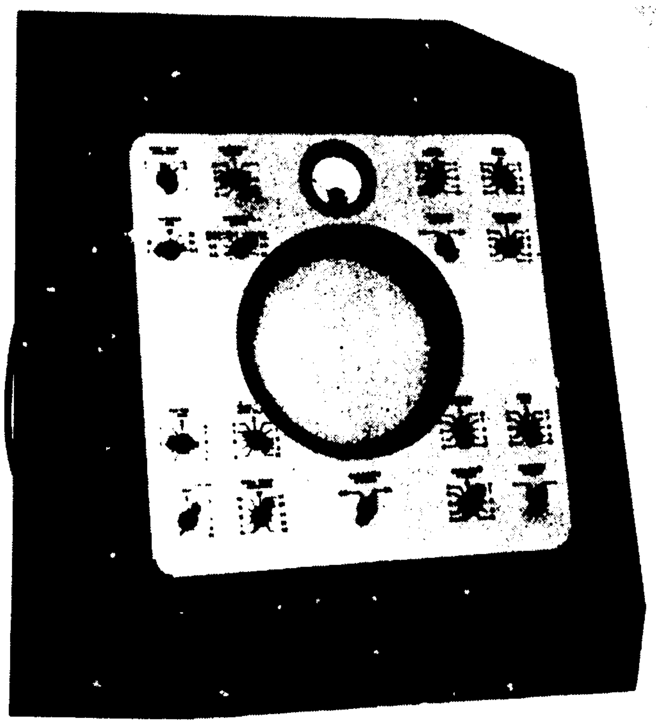


Fig. 5-83

Picture tubes. A vacuum tube with fluorescent paint on the end is used not only in television sets (Fig. 5-84) but also in oscilloscopes for checking ignition systems (Fig. 5-83).

In these tubes electrons come off a filament in the electron gun in a narrow beam. They hit the end of the tube and make a bright spot on the screen of fluorescent paint. An AC voltage is put on the horizontal plates H (+ and -).

Diagram of a kinescope or television picture tube.

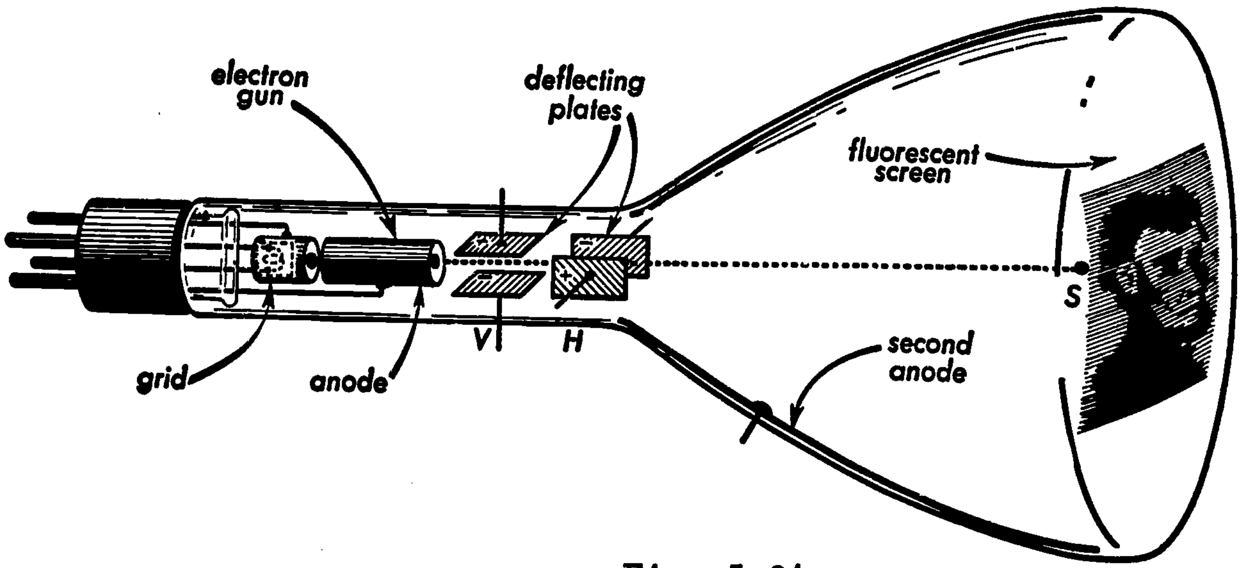


Fig. 5-84

Whichever plate is minus pushes the electron beam away; the one that is plus pulls it over. The AC voltage changing at high speed makes the beam zigzag back and forth from one side of the screen to the other in a line. Now if a voltage is put on the vertical plates V, it will move the line up or down. If it is gradually changed at the same time as the horizontal voltage, the line will slant. As an example, Fig. 5-85. shows how the line moves if the oscilloscope is hooked to the primary circuit of the ignition coil of the car. While the points are closed, current flows into the coil, gradually building up a magnetic field; the line goes up gradually. When the points open, the voltage in the primary drops quickly as shown by the steep line on the 'scope. You can learn a great deal about the ignition system of a car from the line on an oscilloscope.

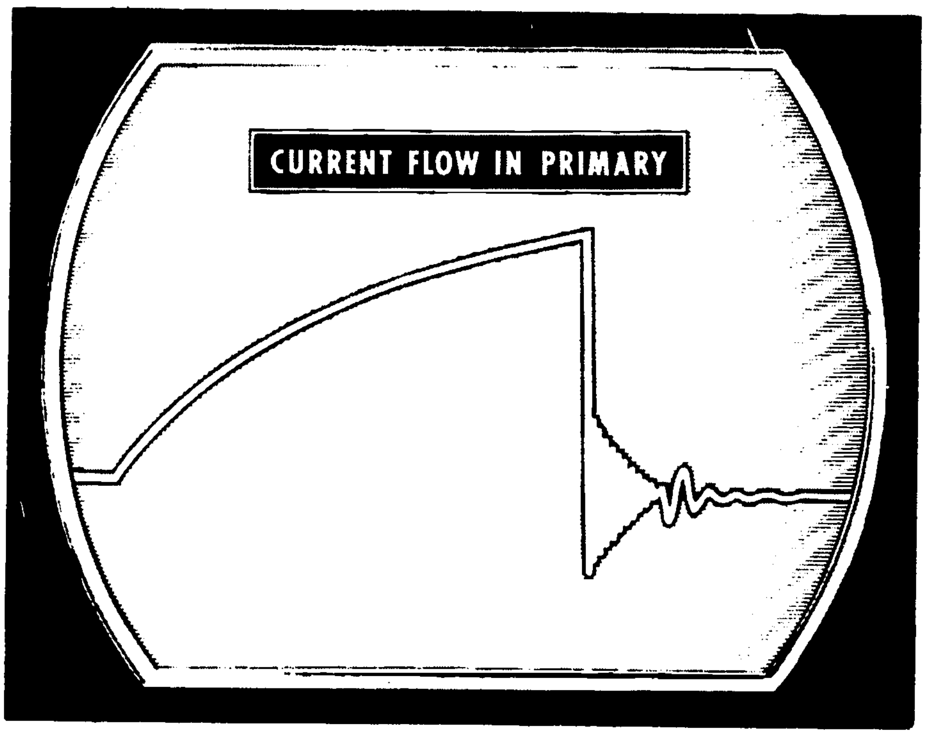
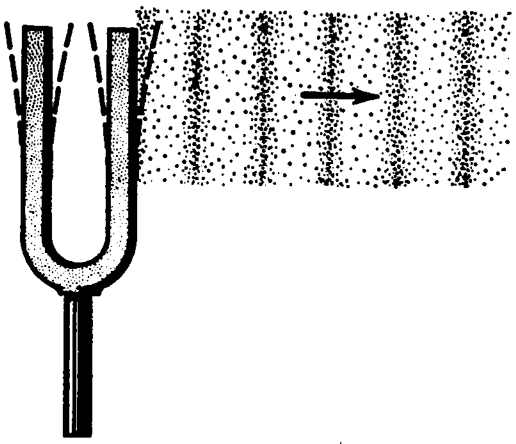


Fig. 5-85

UNIT 6. SOUND

1. NATURE OF SOUND

Any disturbance in matter that can be heard by the ear is sound. Quick movements of air compress it, sending out waves of different pressures (Fig. 6-1). Single waves exist, but most sounds are a series of waves made by something that vibrates back and forth, like the fork shown.



Sound waves

Fig 6-1

A bell ringing in a vacuum cannot be heard.

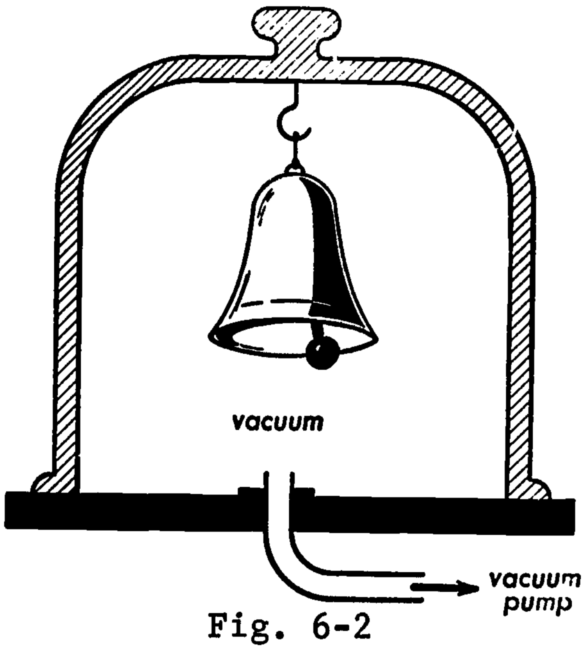
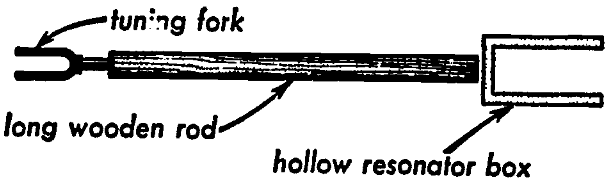


Fig. 6-2

Sound is carried by matter. Most of the sounds we hear are carried by air. If the bell in Fig. 6-2 is rung, it can be heard even with the glass jar over it. But if the air is pumped out, it cannot be heard. The sound cannot travel through a vacuum.



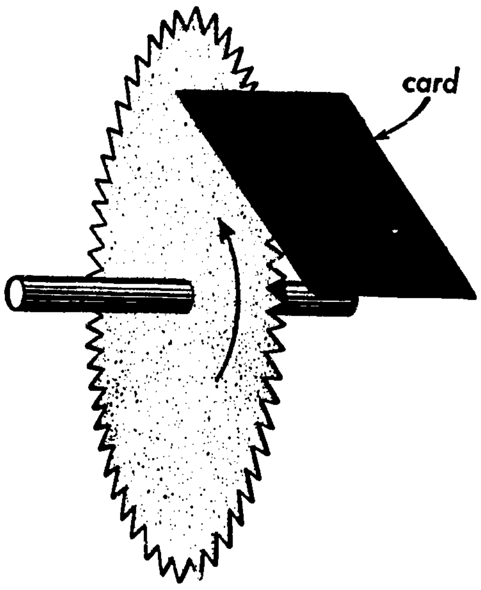
Demonstration of sound waves traveling through wood.

Fig. 6-3

Sound travels well through liquids and solids. If a fork is started vibrating, as in Fig. 6-3, the sound can be heard loudly in the hollow box.

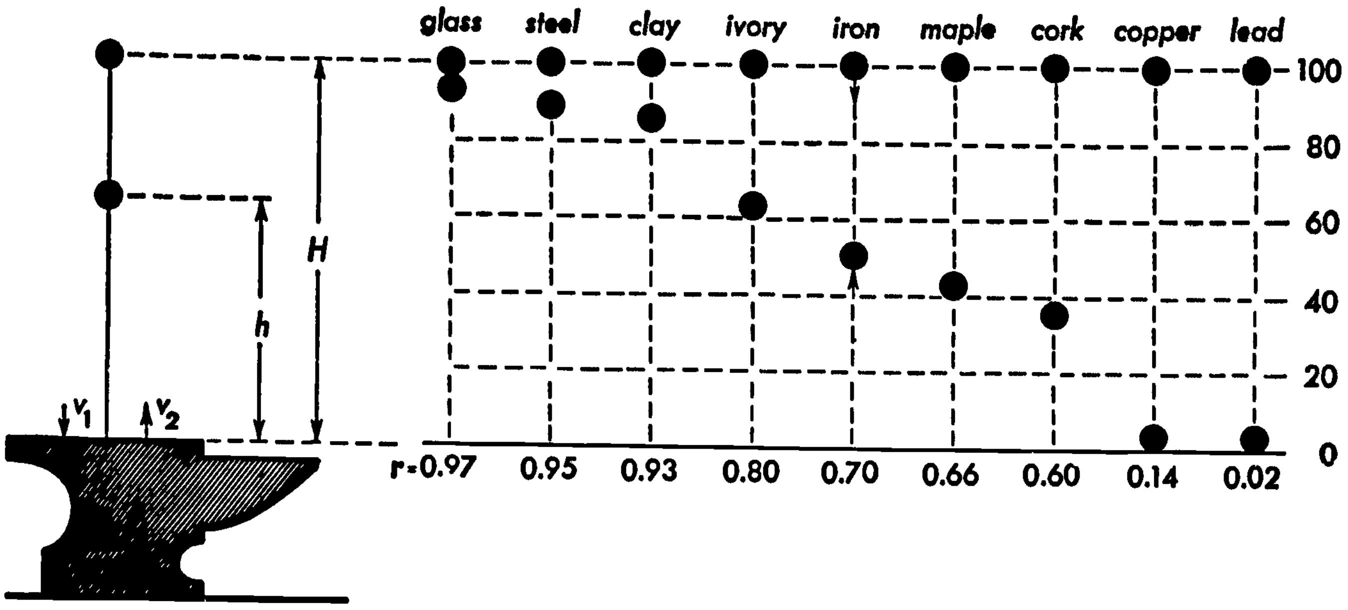
A listening rod can help you find where an engine noise is coming from. It is a long, thin stick. Put one end in the ear and touch the other end against the engine. You will hear sounds from that part of the engine loudest. This is how you can locate a noisy bearing or a broken ring.

Pitch. Sound can be made by vibrating the card in Fig. 6-4. If the wheel is run slowly, the sound will be low. If run fast, it will give a high note. The frequency of this sound (number of vibrations per second) depends on how fast the teeth of the wheel hit the card.



A card held against the teeth of a rotating wheel produces a musical note.

Fig. 6-4



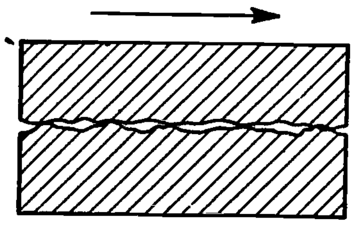
The bouncing marble experiment illustrating the resilience of different substances.

Fig. 6-5

When hit just once and then left vibrating, most things have a natural frequency of vibration--large, heavy ones vibrate slowly; small, light ones vibrate fast, as we learned in Fig. 3-14. Our ear "knows" this, so we ignore the tinny rattle of a loose air cleaner but worry about a heavy bearing knock.

Sound absorbers or insulators. We have seen that sound comes from bending things back and forth. How long does a thing keep vibrating? This depends on its elasticity or resilience. Fig. 6-5 shows how the elasticity of glass, steel, clay, etc. makes a marble bounce when it is dropped on an anvil made of these different substances. Very hard materials are elastic, giving back most of the energy put into them in bending. Such materials vibrate a long time. Soft ones--like cork or lead--absorb rather than give back energy that is put into them. They do not ring, like steel or glass, but have a dull sound. Sound absorbers are made of soft materials.

Squeaks. Friction sometimes makes things squeak. You will recall that all surfaces are rough, and slide a series of points past one another (Fig. 6-6).



Irregularities on surface obstruct sliding motion.

Fig. 6-6

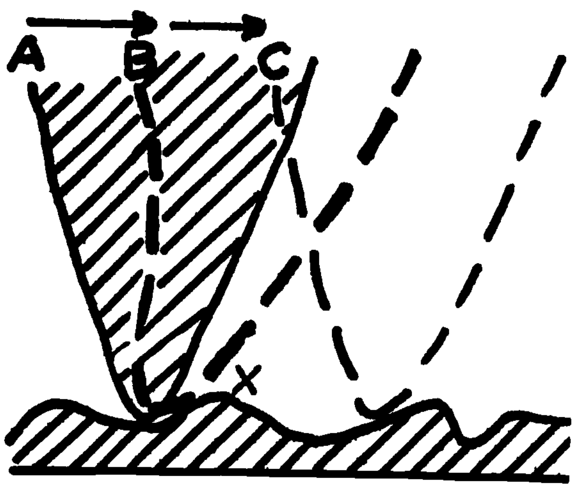


Fig. 6-7

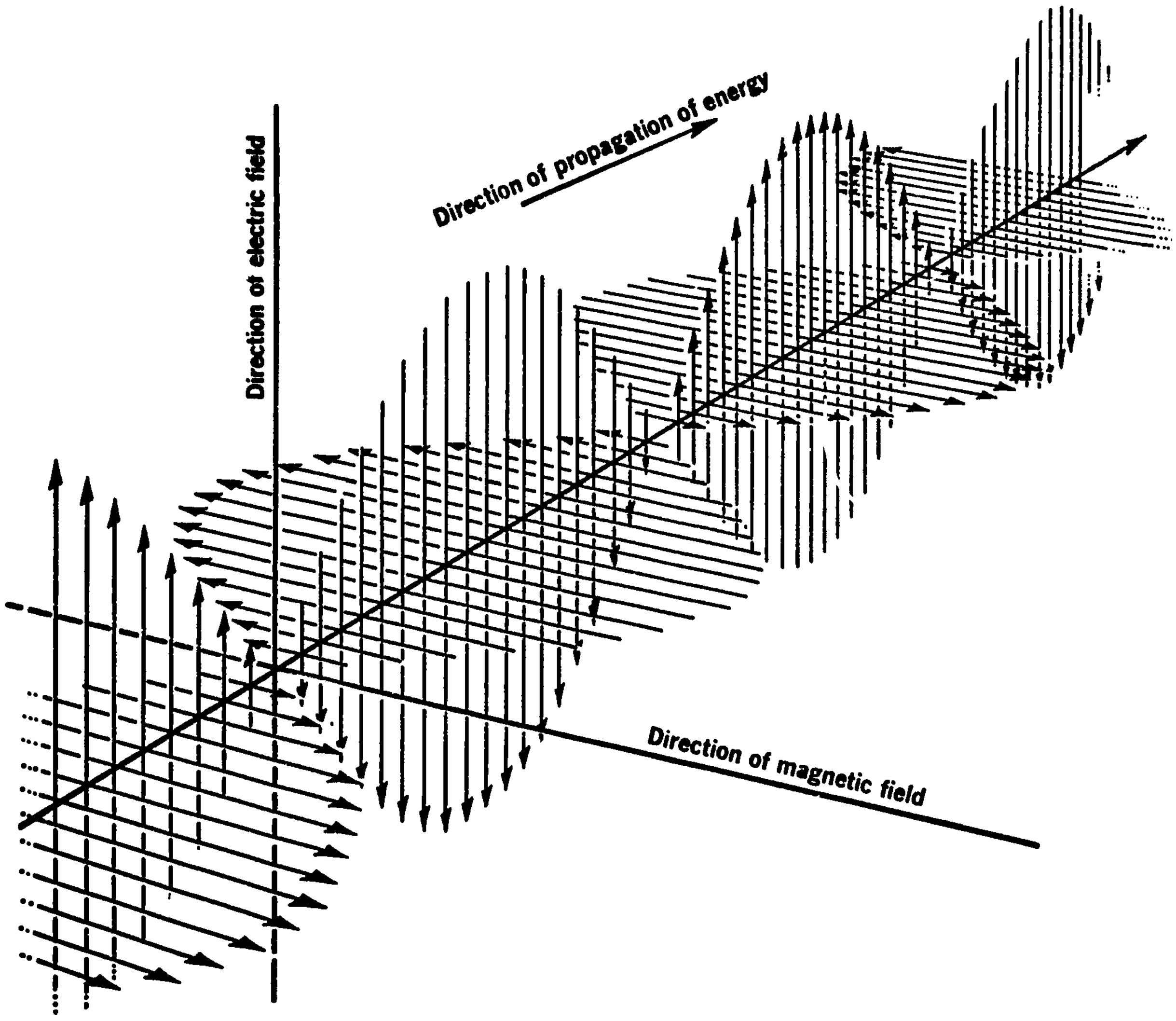
If we think of one point as we slide the object along from A to B in Fig. 6-7, the point is caught at X and bends. When the stress on it builds up, it finally bends enough to slide over X, or it bends or breaks off one of the points; then it jumps to C. When materials slide by this kind of stop-go-stop-go motion, your ear hears it as a squeak.

UNIT 7. LIGHT

1. WHAT IS LIGHT AND HOW IS IT MADE?

Most of the things you know have come to youby light--you have seen or read them by light that came into your eyes. Some things--sun, stars, lamps, and fireflies are sources of light. We see most things, like the moon or the objects around us, by light from other sources that these objects reflect to our eyes.

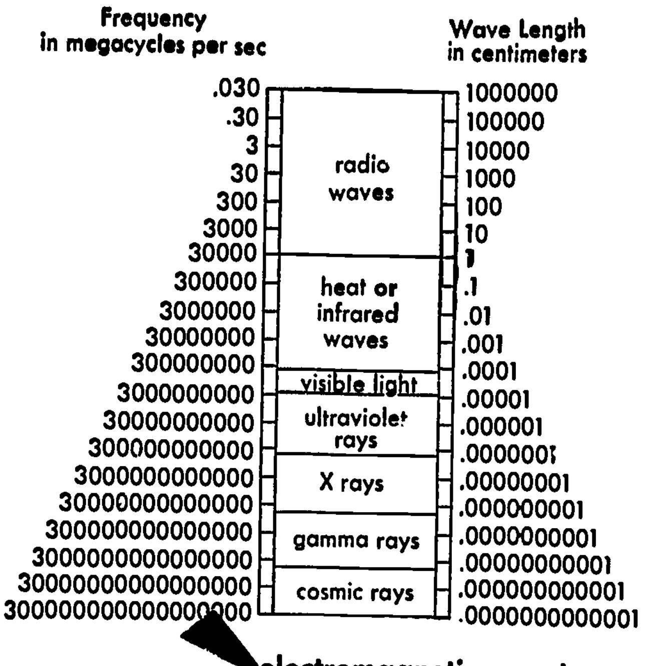
Light is a form of energy. To explain many things about it, scientists think it is the wave motion of a very high frequency alternating electromagnetic field.



An electromagnetic wave consists of an electric field and a magnetic field at right angles to each other. Both are perpendicular to the direction in which the wave advances.

Fig. 7-1

Visible light, that you can see, is only one part of a vast range of these electromagnetic waves. Fig. 7-2 shows the frequency and wavelength of different forms of electromagnetic energy. So far as we know, all of these forms differ from each other only in this way. That is why we sometimes speak of infra-red "light" or X-ray "light."



electromagnetic spectrum.

Fig. 7-2

Schematic diagram of Bohr's quantum hypothesis of the radiation of light from an hydrogen atom.

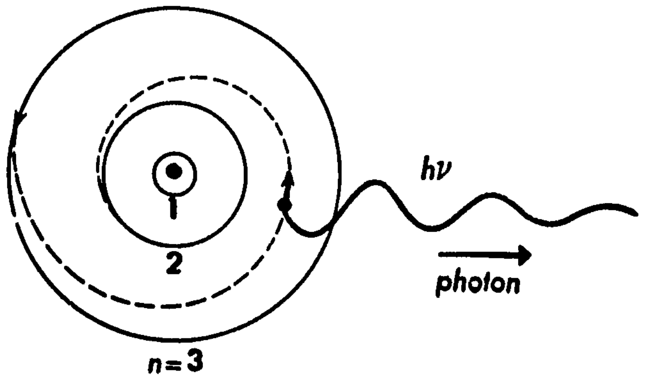
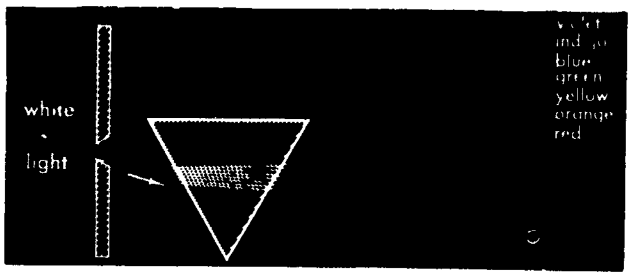


Fig. 7-3

Light is made when an electron is boosted to a high energy level and drops back to a low one. Fig. 7-3 shows a hydrogen atom. Its electron is usually in orbit 1, relatively close to the nucleus. If the atom is heated, perhaps by a spark, an electron can jump up to orbit 2 or 3. It is immediately pulled back by the nucleus, and gives off its "extra" energy as a tiny speck or photon of light.

Actually, light with different amounts of energy is given off. This is due to the various electron shifts that are possible. (Fig. 7-5 is a diagram of an atom of mercury, with its 80 electrons.)



White light consists of different colors.

Fig. 7-4

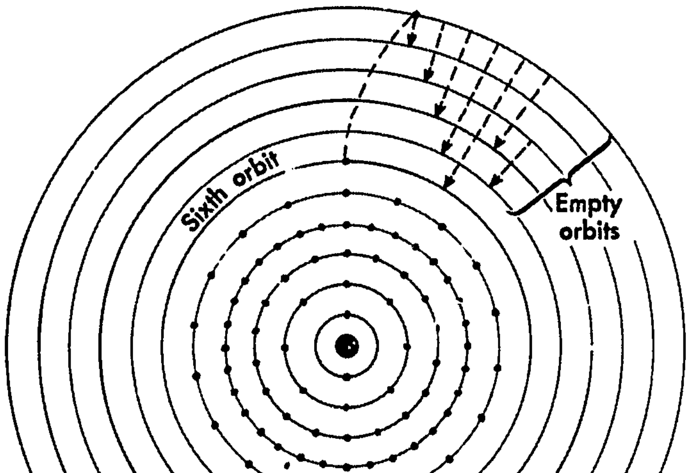


Fig. 7-5

It is mainly through the study of light that scientists have come to know how atoms are put together. Light from each element is different. Sodium atoms give off mainly yellow light, while mercury atoms give off mainly blue-green, and neon atoms give reddish-orange light. The colors are due to differences in their electron orbits, which produce light of different wavelengths.

To pull electrons away from the nucleus of an atom takes energy. Most sources of light do this by heat--as when you burn fuels--or by electricity, as in incandescent or neon or mercury lamps.

Light waves travel in straight lines, which makes it possible to form an image. (Fig. 7-6)

Illustrating the principle that light travels in straight lines.

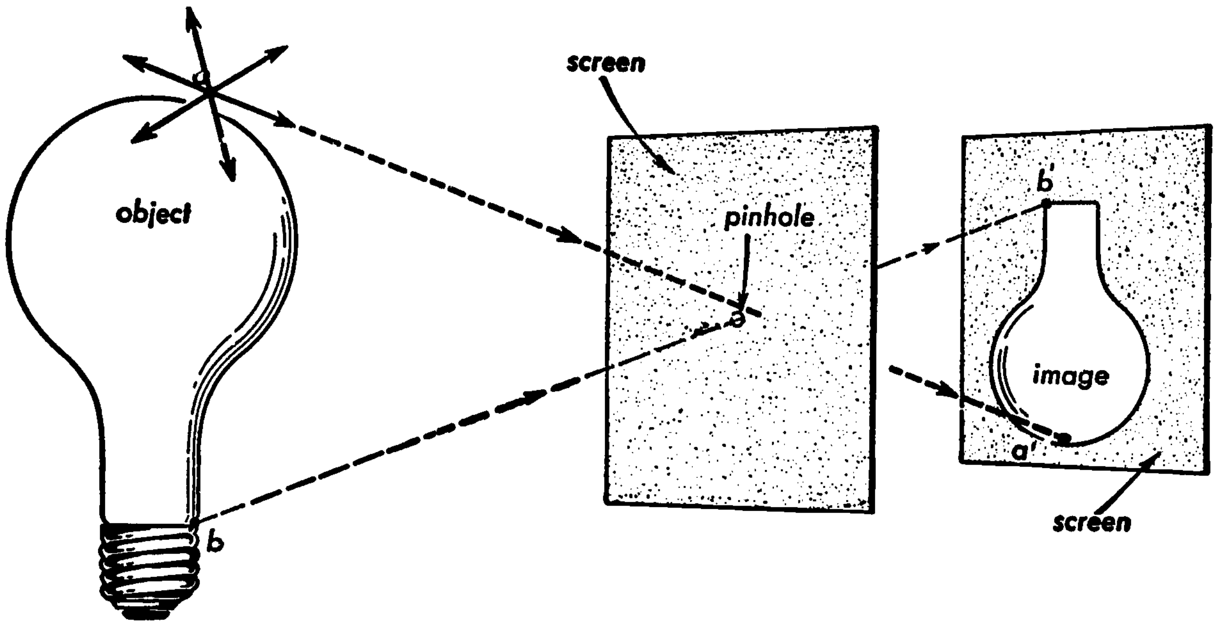
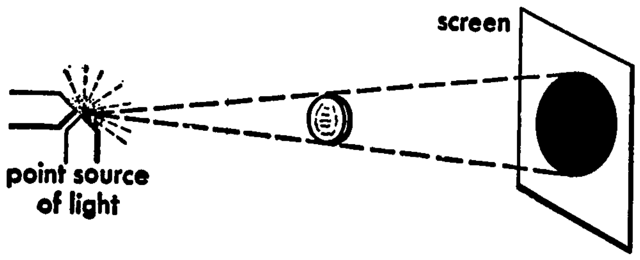


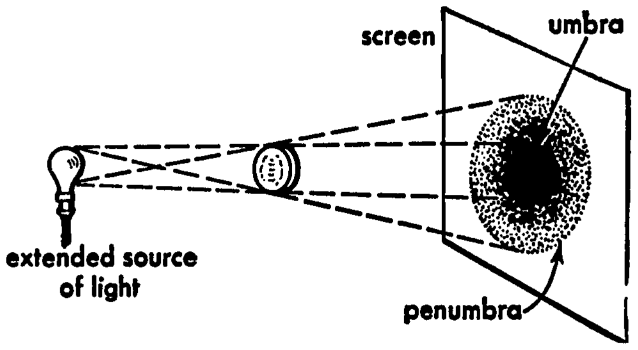
Fig. 7-6

This also explains why there are shadows. Very small (point) sources give sharp rays and shadows, while large lights give diffused rays and shadows.



The shadow cast by a point source.

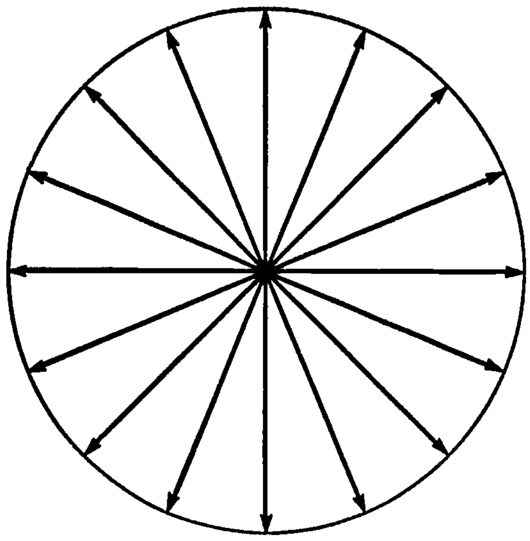
Fig. 7-7



The shadow cast by an extended source.

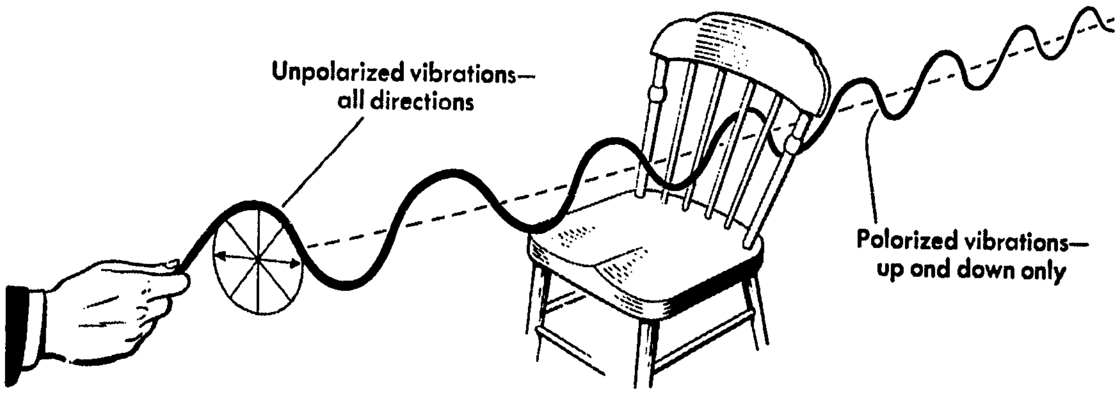
Fig. 7-8

Polarized light. Ordinary sources give light whose waves travel in all planes--up-and-down, sideways, and at all angles (Fig. 7-9). Imagine these waves "strained" through a series of slits, as in Fig. 7-10. This will absorb rays in all but one plane. Such rays are called polarized light.



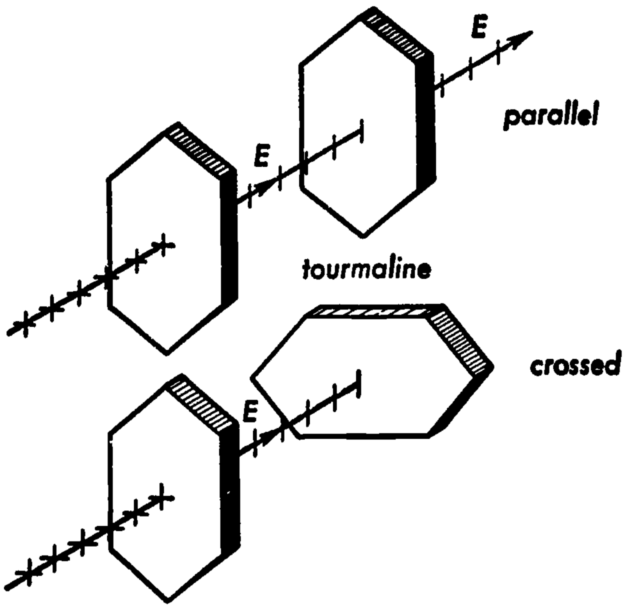
End-on view of a beam of unpolarized light illustrating schematically the equal probability of all planes of vibration.

Fig. 7-9



Producing Polarized Waves • The slit permits only vertically polarized, transverse waves to pass through

Fig. 7-10



Tourmaline crystals polarize light.

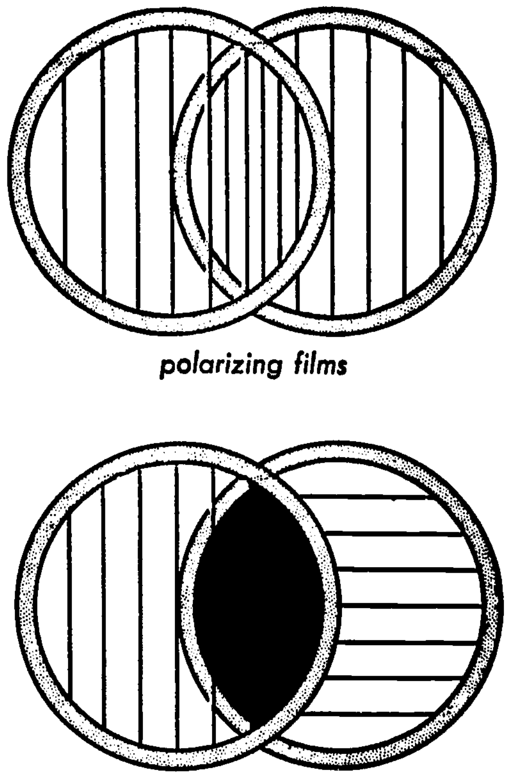
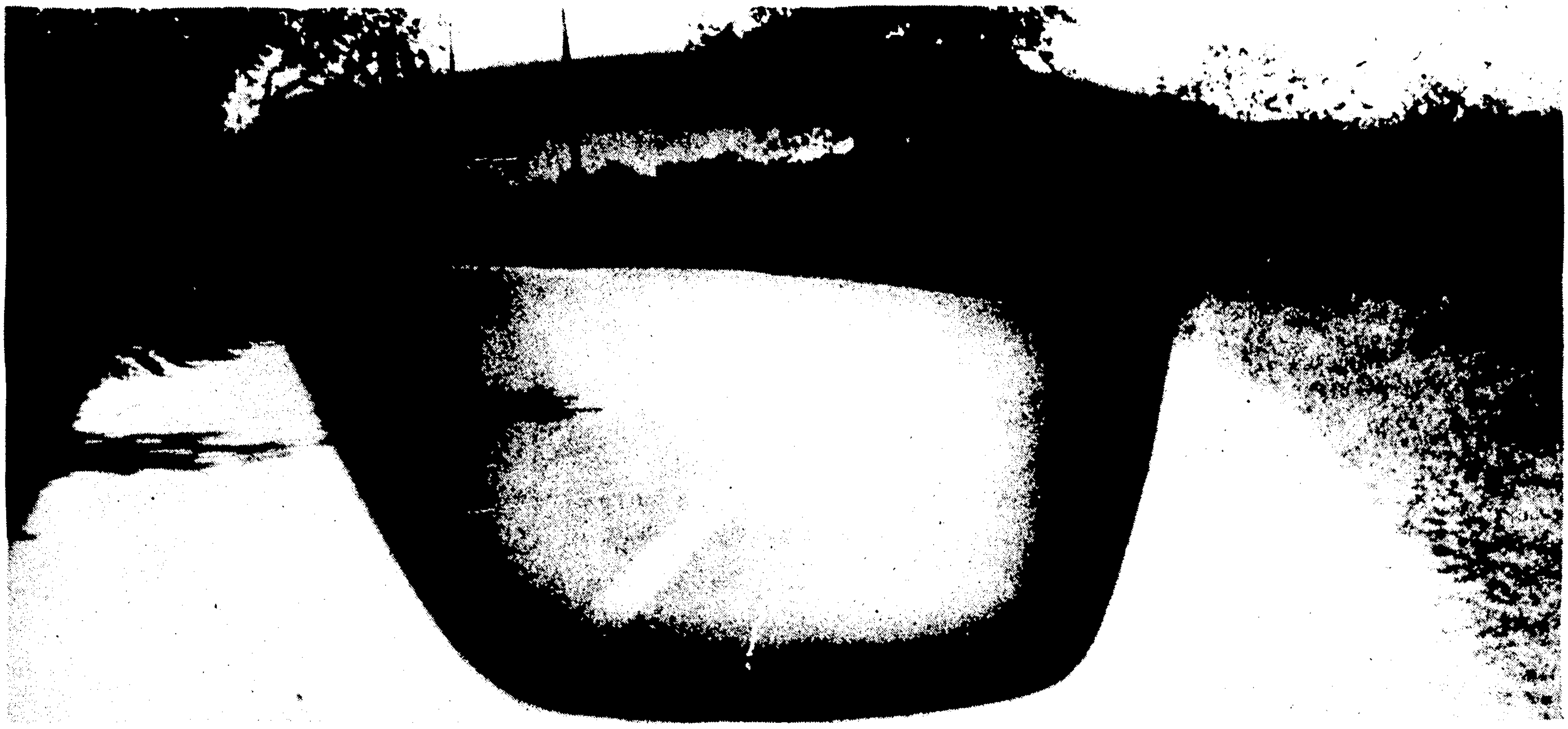


Fig. 7-11

Polarizing films in the parallel and crossed

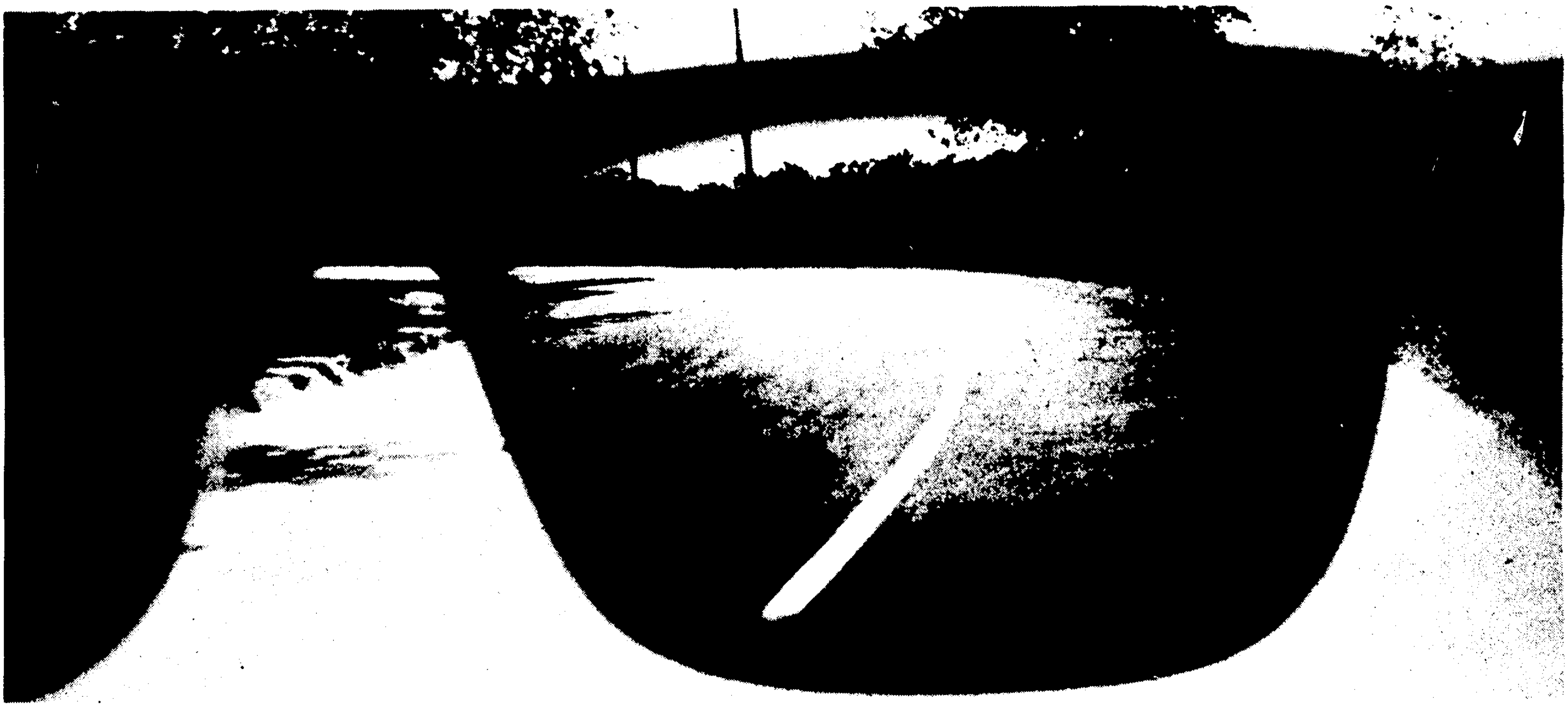
There are crystals which polarize light. If a plastic film is made with crystals of this kind, all lined up, it will pass light polarized in one plane, and block light in another plane (Fig. 7-11).

Polarizing films are used to block out glare which comes when light is reflected at certain angles.



Ordinary sun glasses--note the glare.

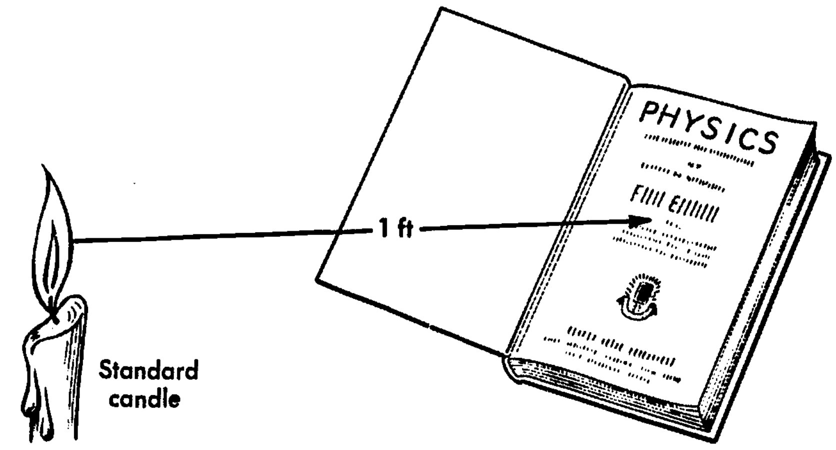
Fig. 7-12A



Polaroid glasses absorb most of the reflected light and reduce the glare.

Fig. 7-12B

Light quantities. The standard unit of light output is the candlepower. The illumination (or brightness) of an object is the amount of light that actually reaches the object. The amount of illumination depends on the power of the source of the light and also the distance of the object from the light. One candlepower will produce one foot-candle of brightness a foot away.

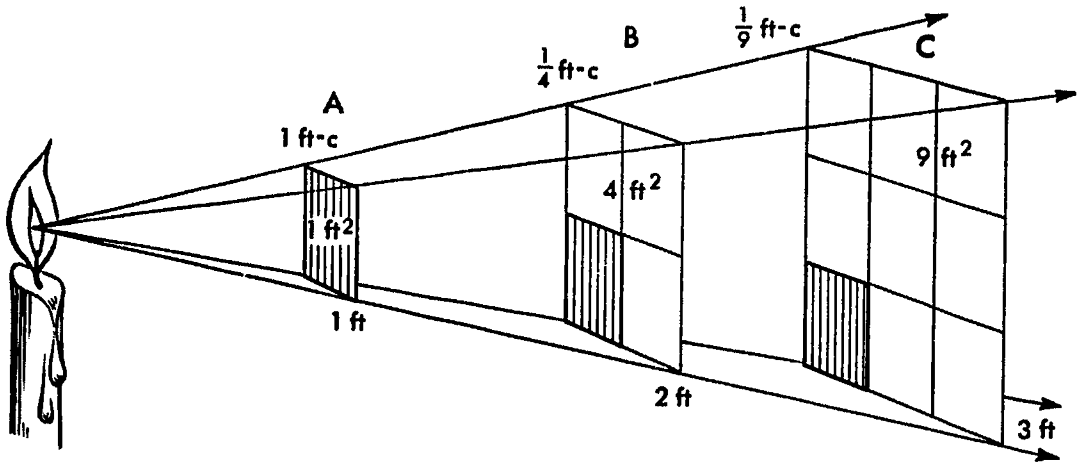


One Foot-candle Is the Illumination at a Surface Every Point of Which Is 1 Foot from a Standard Candle

Fig. 7-13

At two feet, the same amount of light is spread over four times the area. So

Illumination decreases as the square of the distance from the source of light.



The Light That Strikes Screen *A* Would Reach Screen *B*, Which Is Four Times as Large as *A*. The Illumination at *B* Is One Fourth That at *A* • Illumination varies inversely as the square of the distance from the source

Fig. 7-14

The eyes need a certain amount of illumination to see by, or they get tired quickly. Table 11 shows how much light is needed for some types of work:

ILLUMINATIONS	
For night baseball or football	30–50 ft-c
For sewing and other work requiring close inspection	30–35 ft-c
For reading	10–20 ft-c
For hospital operating rooms	70 ft-c
Noon sunlight	5000–10,000 ft-c
Bright moonlight or street-lighting	$\frac{1}{40}$ ft-c

Table 11

These are low values and more light is often recommended.

As safe driving calls for 5-10 foot-candles, you can see why a good headlamp system is needed. Night driving, on an equal-mileage basis, kills three times as many people as daytime driving.

2. COLOR

Visible light, as you know, can be any color of the rainbow. White light is a mixture of all these colors of light. Fig. 7-4 shows how a prism bends some colors more than others, thus splitting a beam of white light into all the colors of the rainbow.

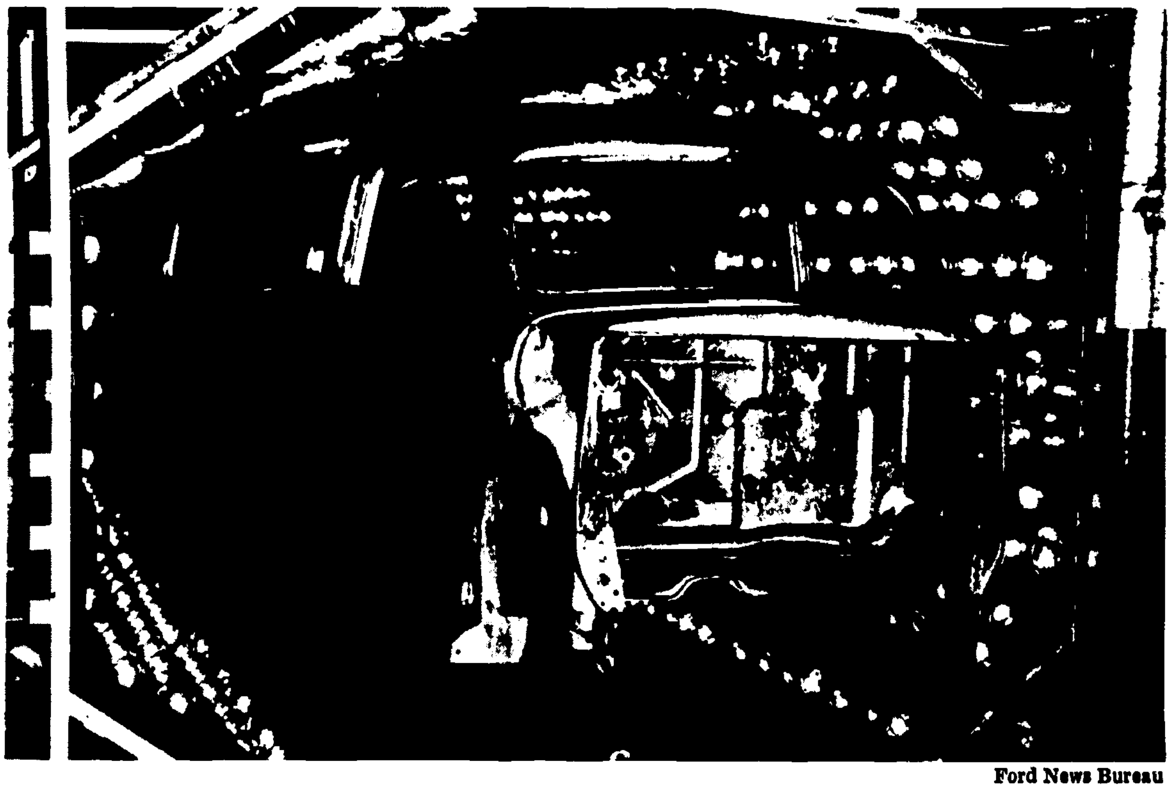
When a solid object, like a wire in a lamp or a speck of carbon in a flame, is heated hot enough, the electrons are excited at so many different levels that all colors of light are given off. This is seen as white light.

Color and temperature. Actually, temperatures below the "glowing point" give mainly infrared rays that cannot be seen but which turn to heat when they are absorbed by an object. Fig. 7-15 is a picture taken by a film sensitive to infrared light. The two hot irons have heated the statue enough so that it, in turn, gives off infrared light (white parts of the picture).

Fig. 7-16 shows an infra-red baking oven for auto bodies.

A Photograph of a Statue, Made by Infrared Rays from Two Hot Irons

Fig. 7-15



Ford News Bureau

Infrared Rays Dry the Lacquer in 4 Minutes

Fig. 7-16

If a solid object is heated to about 1200°F., electrons are excited enough to give off red light, and we say it is "red-hot." As it gets still hotter, it also gives off orange, then yellow, then green and blue. The combination of all of these produces white light, and we say the object is "white-hot," or incandescent.

Still higher temperatures add ultraviolet light, which you cannot see. It is powerful enough to break molecules apart. Ultraviolet light from the sun goes through the skin and "sunburns" you; a welder's arc gives off ultraviolet light that can kill the eye nerves and blind you.

Absorption of light. When light hits something, it can:

1. Be absorbed. Dark objects turn most of the light that hits them into heat or other kinds of energy.

2. Be reflected. Shiny metals and bright objects bounce light back.

3. Be carried through. Air, some plastics, glass, and water transmit light. It may be bent (refracted) on the way through.

Some materials have electrons that are easily shifted. When light hits them with enough energy, it will move them, and be used up in the process. Black objects take up all kinds of light; the excited electrons move faster, so we say the object is hotter. Ultraviolet light, when it is absorbed, may break down the electron bonds that hold molecules together. It is one of the main things that break down paint, as well as damaging skin and eyes.

Illustration of the absorption of blue and violet light by yellow paint and the emission of red, orange, yellow, and green.

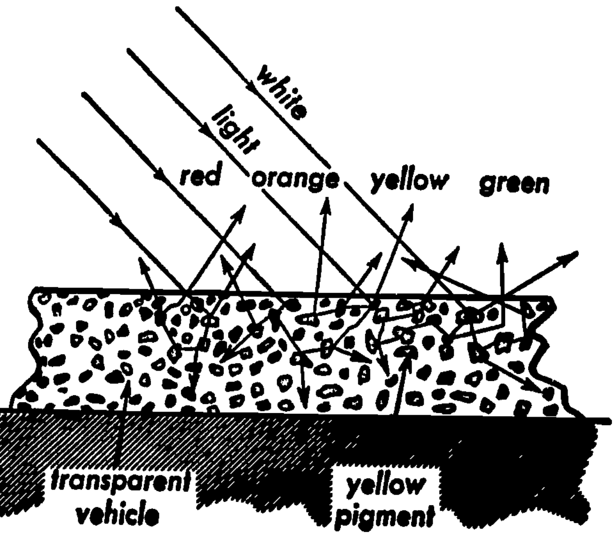


Fig. 7-17

Colored objects absorb some colors of light and reflect or transmit others. The color that we see depends upon the particular colors that are reflected. Yellow paint, for example, absorbs the blue and violet rays out of white light and reflects the yellow light, together with some of the orange, green, and red light. The net effect that we see is a yellow color. In the same way a blue object is blue because it reflects the blue rays of white light--together with some violet and green.

The color triangle shows how this works:

The corners--red, green, and blue--are additive primary colors. Lights of red and blue, for example, give magenta (purple), which is between them on the triangle. Red + green + blue light give white.

The sides are subtractive primary colors. They are used in mixing paints. Mixing two of these gives the color between them. When blue and yellow paints are mixed, yellow-green results (Fig. 7-19).

Diagram of the color triangle, with the additive primaries at the corners and the subtractive primaries at the sides.

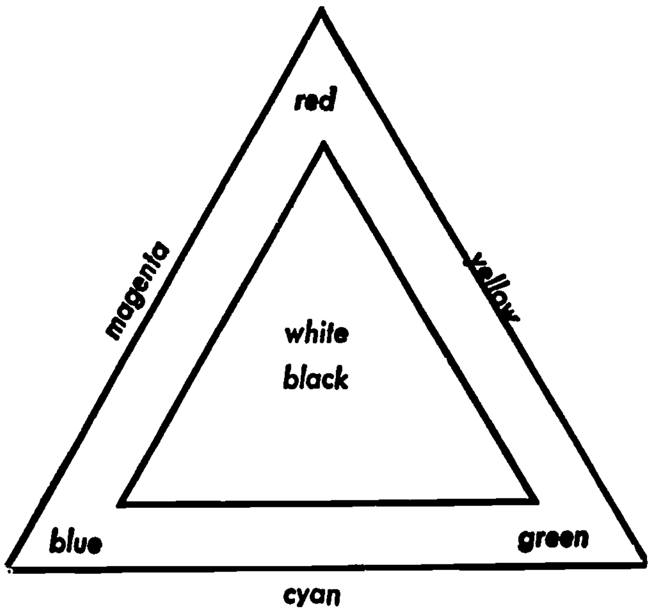
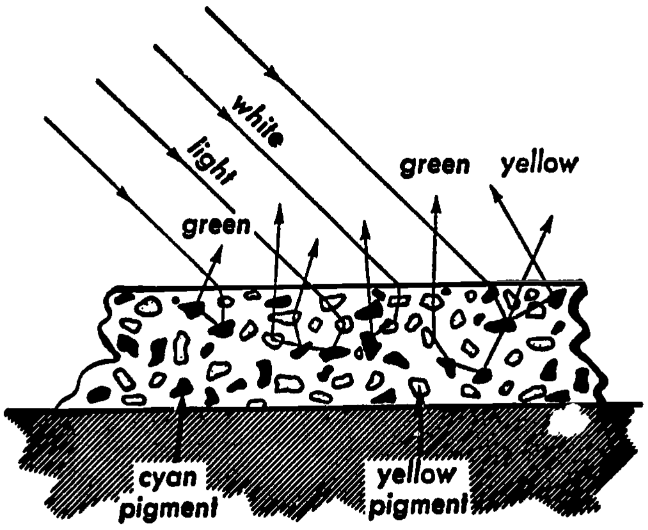


Fig. 7-18

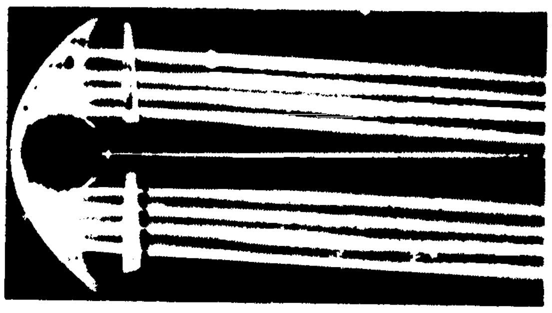


When blue and yellow paints are mixed together, green and yellow are the only pure spectral colors transmitted by both pigments.

Fig. 7-19

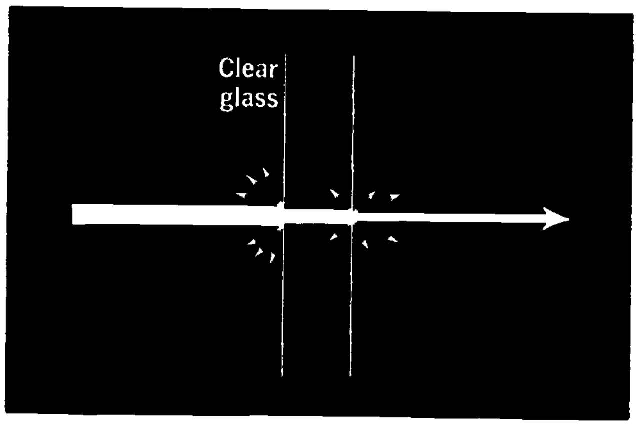
3. REFLECTION

One of the main ways in which we make use of light is by bending it or reflecting it from a surface. Photography is very helpful in studying the bending of light (Fig. 7-20).



ACTUAL PHOTOGRAPH OF BENDING LIGHT RAYS

Fig. 7-20



The transmission of light through a glass plate.

Fig. 7-21

How much light a surface reflects depends on what it is made of, how smooth it is, and the angle at which the light hits it. Even clear glass reflects some light.

White or silvery surfaces may reflect up to 98% of the light that hits them, while some black coatings like soot reflect 5% or less.

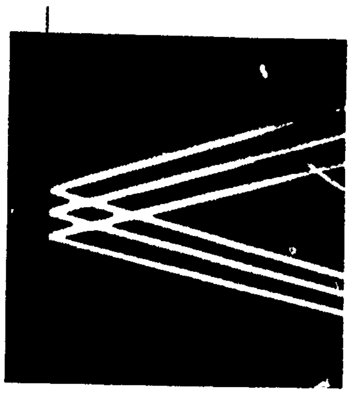
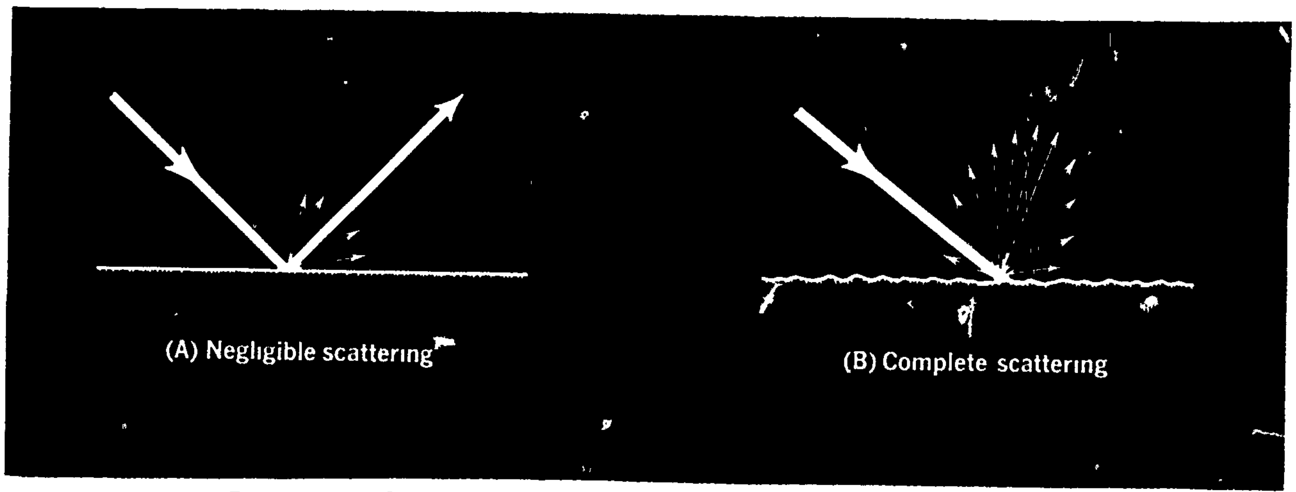


Fig. 7-22



(A) Negligible scattering

(B) Complete scattering

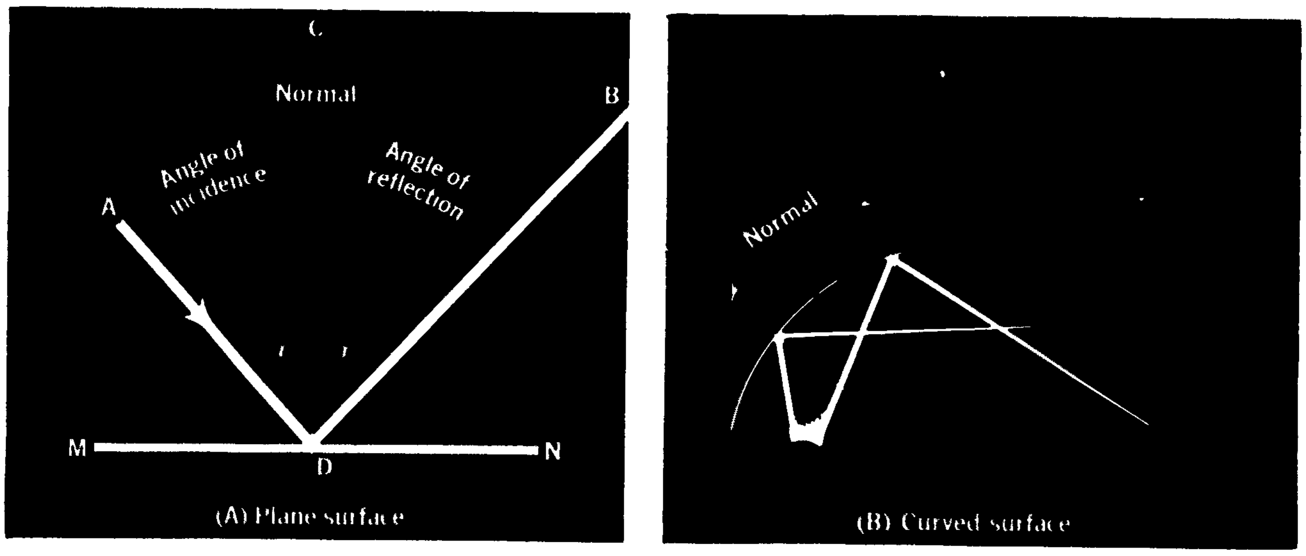
Reflecting surfaces vary in the extent to which reflected rays are scattered.

Fig. 7-23

Actual photographs show that smooth surfaces reflect light without scattering it (Fig. 7-22). Rough surfaces scatter or diffuse light in all directions (Fig. 7-23B).

If light rays hitting a surface are studied and the angles measured carefully, it is found that

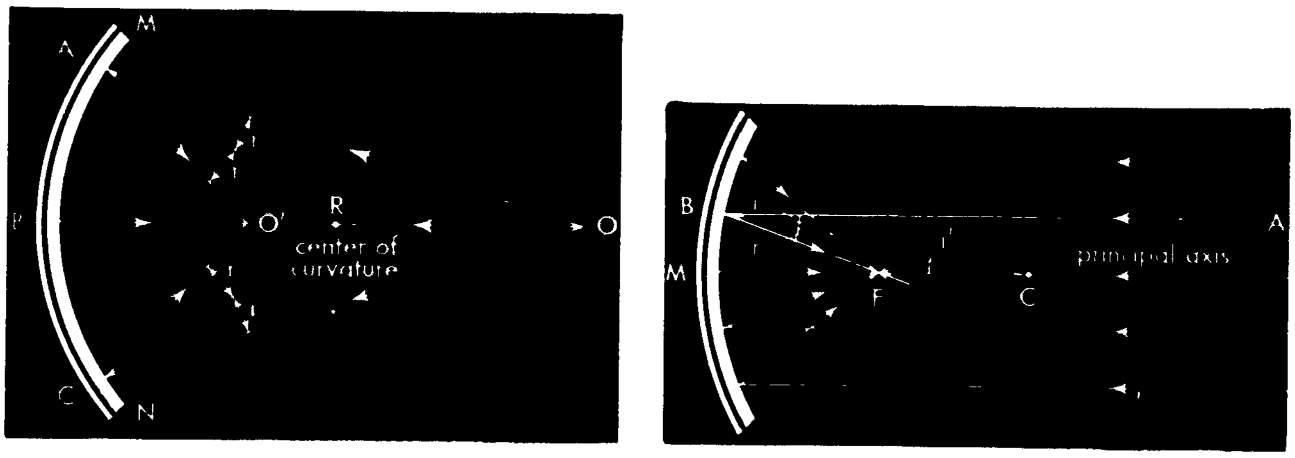
The angle of incidence is equal to the angle of reflection.



Reflection from plane and curved surfaces.
Fig. 7-24

Reflection from smooth surfaces gives good control of light, as in the reflectors of headlights, but the light is glary and strains the eyes.

Curved mirrors can bend light usefully. Rays which come at the mirror from a point on its axis, like O in Fig. 7-25A, will all pass through one point or focus, O'.



Reflection from a concave mirror (O is far from MN).

Rays parallel to the principal axis are reflected through the principal focus.

(A) Fig. 7-25 (B)

If O is moved further from the mirror, the focus O' gets closer to the mirror. When O is miles away, the rays are parallel and they are reflected through a particular spot called the principal focus or focal point (F) of the mirror (Fig. 7-25B). On the other hand, a source of light placed at F, as in a headlight, will give a parallel beam of rays reflected by the mirror.

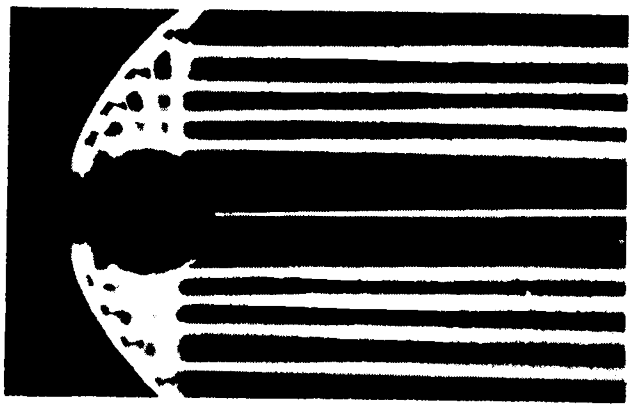


Fig. 7-26
A curved mirror with a light at its focal point sends out a beam of parallel light rays.

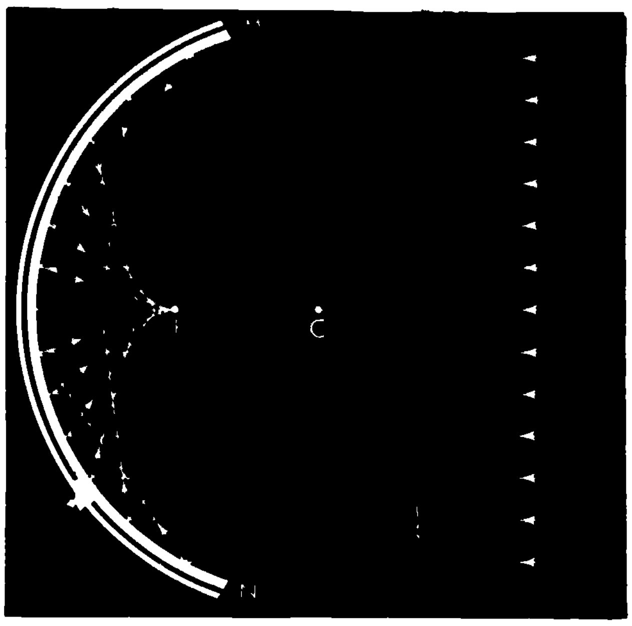
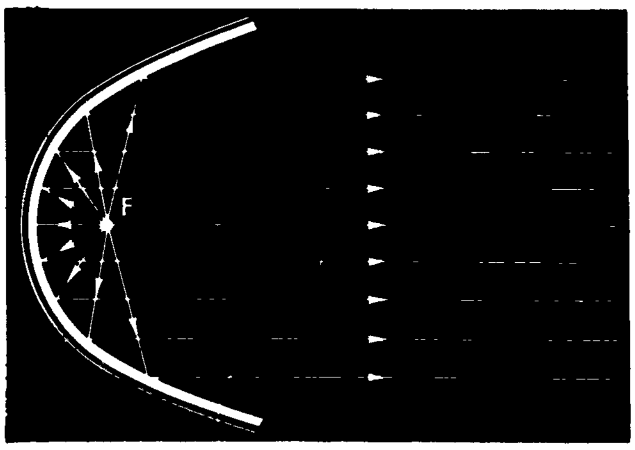


Fig. 7-27



The parabolic mirror. All rays reflected from the focus are parallel to the axis.

Fig. 7-28

A mirror which is made in a truly round shape will not focus parallel rays perfectly.

To focus parallel rays or to make rays parallel, a parabolic shaped mirror is used. (The word "parabolic" refers to a certain type of curve studied in mathematics, called a parabola.)

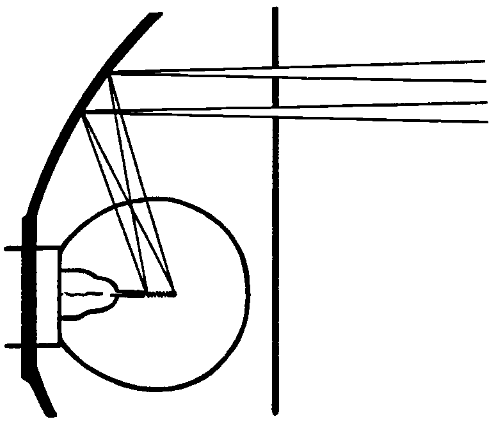


Fig. 7-29

Head lamps are made in this parabolic shape.

The beam will be widened if the lamp filament is behind the focal point.

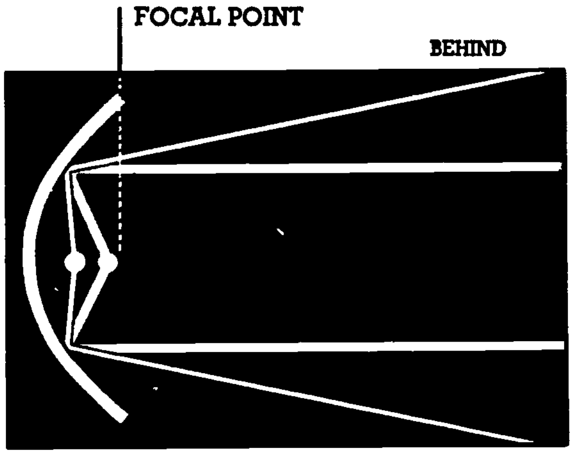


Fig. 7-30

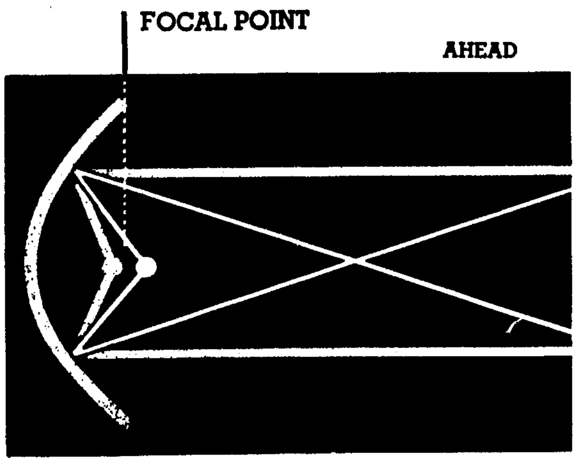


Fig. 7-31

The beam will be crossed and wide if the filament is ahead of the focal point

Filament below the focal point gives a high beam.

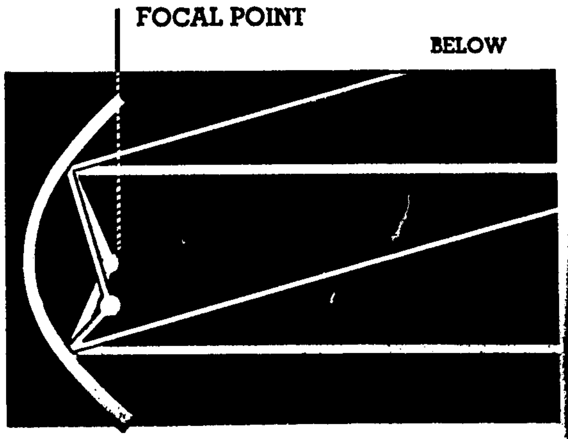


Fig. 7-32

Filament above the focal point gives a low beam.

An exact location for the filaments within the headlight reflector is one of the main features of sealed-beam lamps. They give beam patterns like those shown in Figs. 7-34 and 7-35.

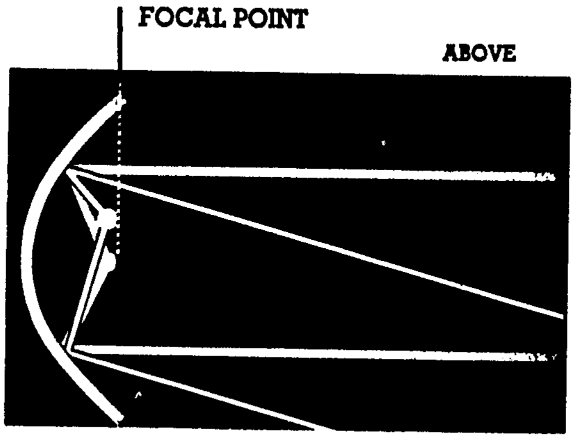


Fig. 7-33

UPPER BEAM

LOWER BEAM

Fig. 7-34

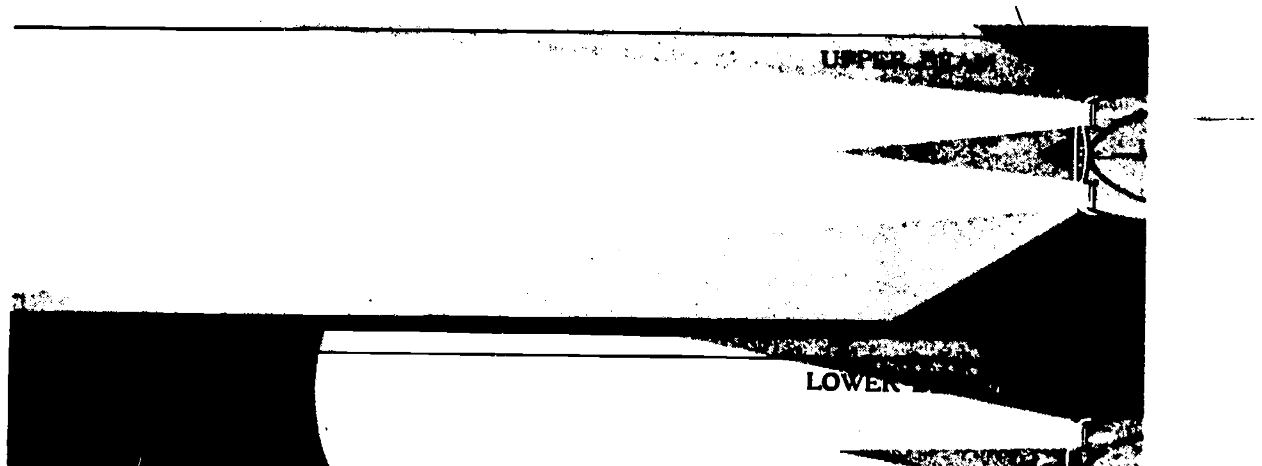
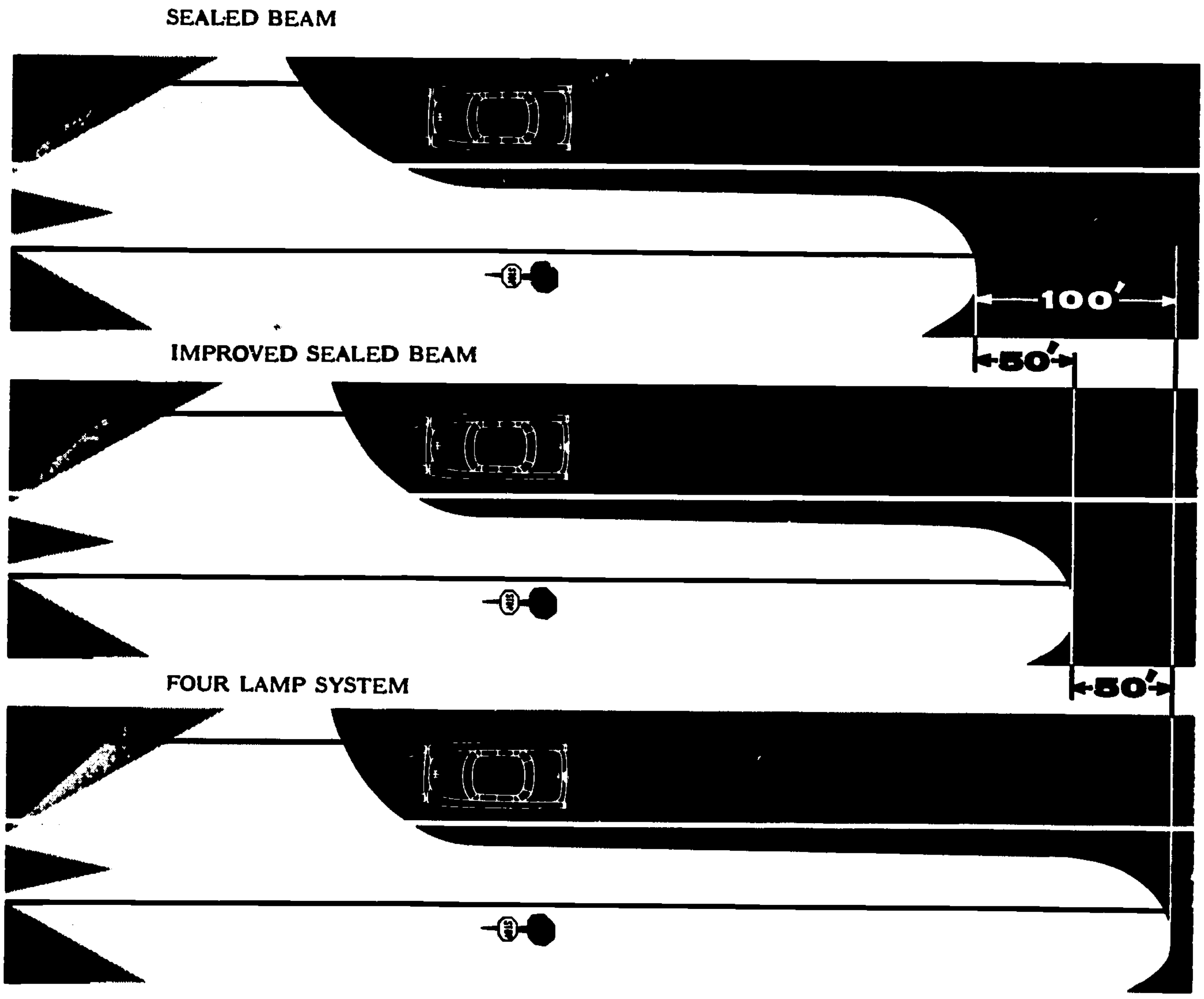


Fig. 7-35

The four-lamp system gives a pattern of bright light over an even greater distance (Fig. 7-36).



SEALED BEAM

IMPROVED SEALED BEAM

FOUR LAMP SYSTEM

Fig. 7-36

The four-lamp system uses the two kinds of headlights shown in Fig. 7-37. One is used only for the upper beam. The other, with two filaments, is used for both high and low beam.

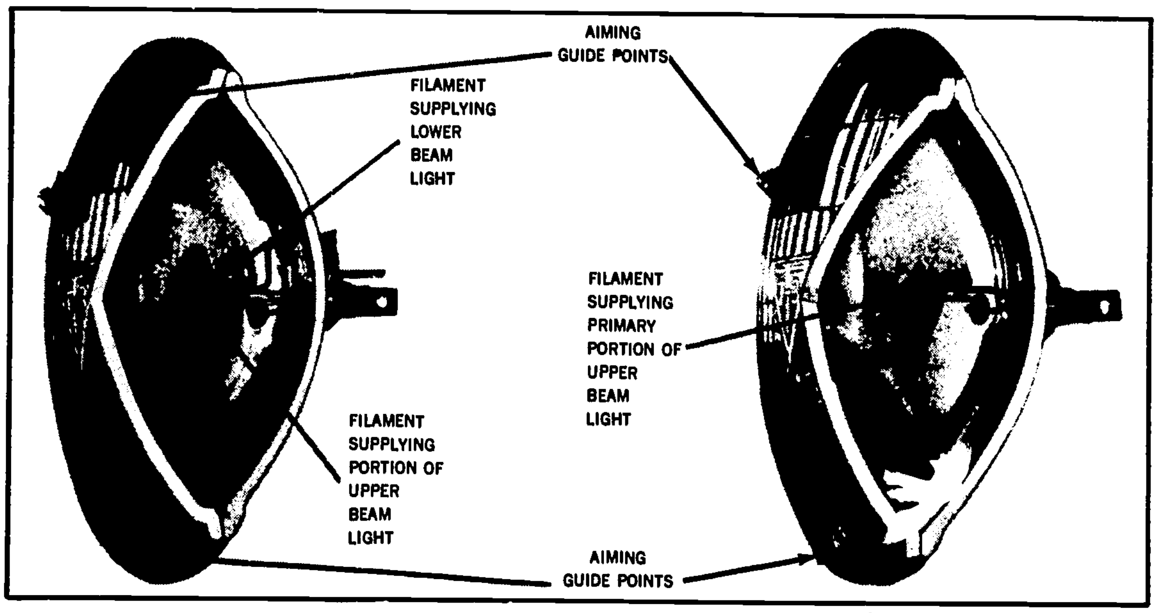
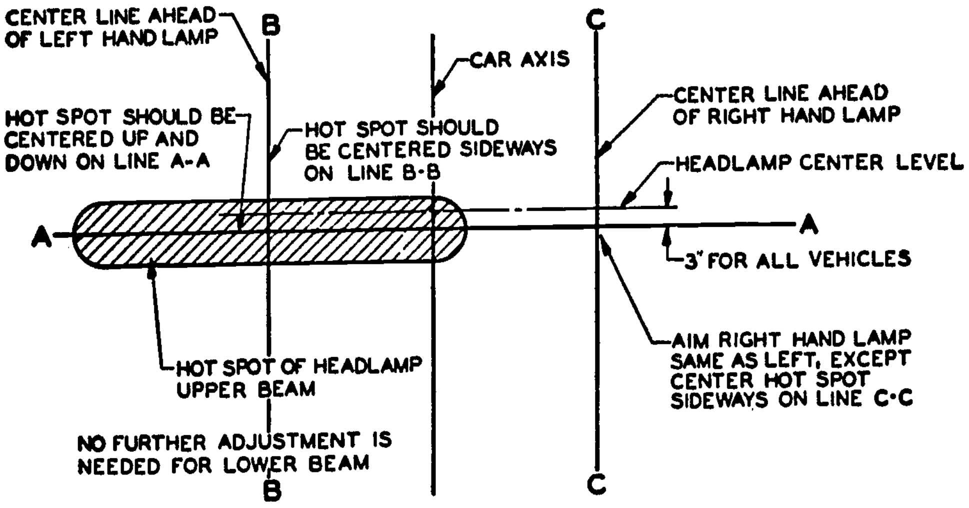


Fig. 7-37

Even the finest headlamp will not give light where it is needed, once it goes out of line because of a bumped fender or a settling spring. About half the cars on the road are said to have headlamps that are in need of aiming. This can be done with an aiming chart. (Picture the car as being 25' back of this chart, with headlights aimed at it.)



Aiming chart for all sealed-beam headlights (cover light not being aimed). Place car 25' from test screen.

Fig. 7-38

A newer method uses a mechanical aimer that is set on the three flat aiming points that were shown in Fig. 7-38.

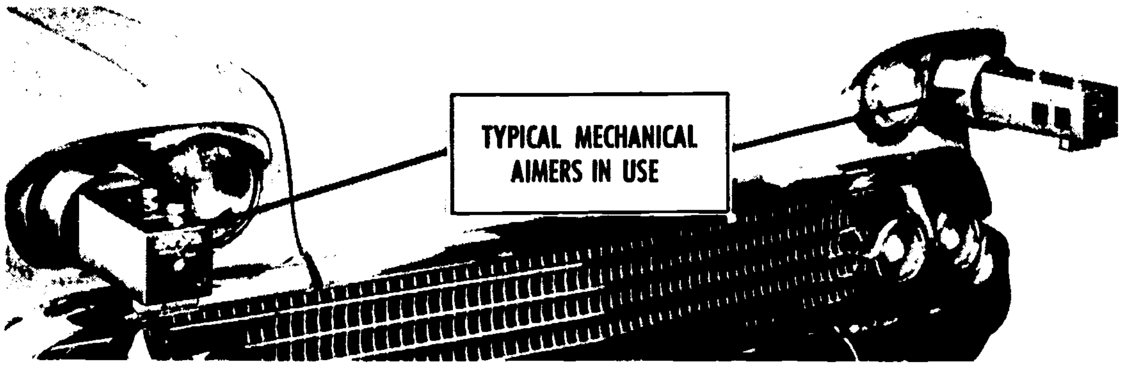
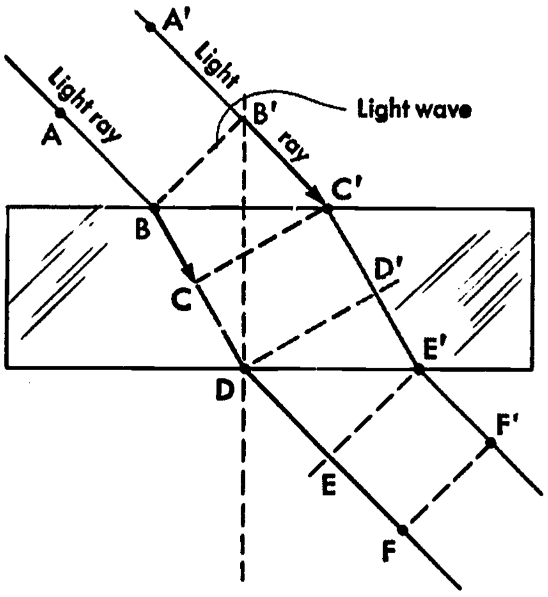


Fig. 7-39

3. REFRACTION

Light is bent not only by reflection, but when it passes through transparent things like glass or water. Lenses are made to use this principle (refraction). You are able to see things because the little lenses in the front of your eyes bend and focus the light rays that come from an object.

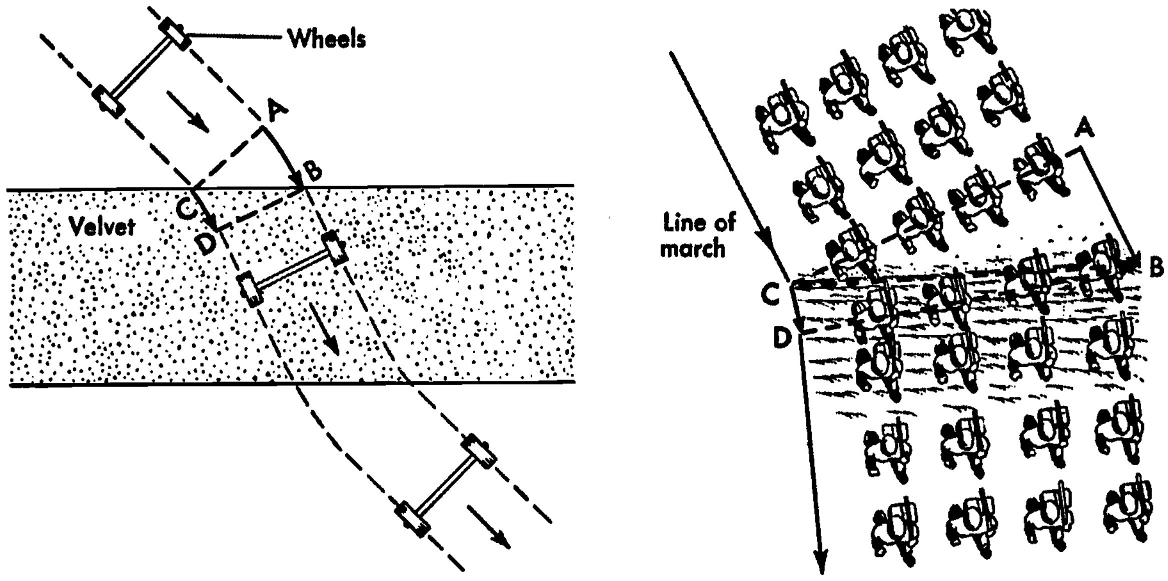
The reason light bends when it goes through glass, for example,is that it is slowed down.



Light Waves Travel More Slowly in Glass than in Air; Therefore the Waves Change Direction, or Are Refracted, when They Enter the Glass

Fig. 7-40

The same bend in direction is seen if you drag a little pair of wheels if you across a table top onto a strip of velvet, as shown in Fig. 7-41. The wheel that hits the velvet first will slow down, changing the line of the axle.

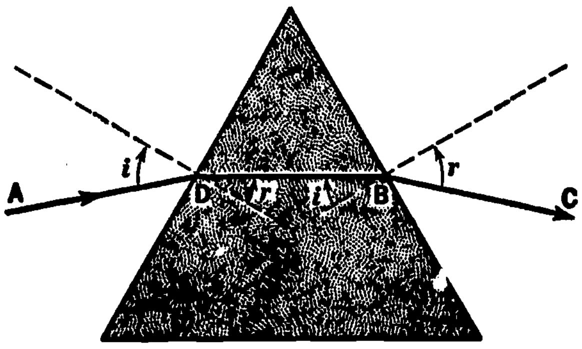


The Velvet Slows Down the Left Wheel, Which Goes from *C* to *D* while the Right Wheel Goes from *A* to *B* • Therefore the direction of travel changes

Soldiers Marching from a Parade Ground • Each man slows down as he reaches the muddy field and therefore changes the direction of his march

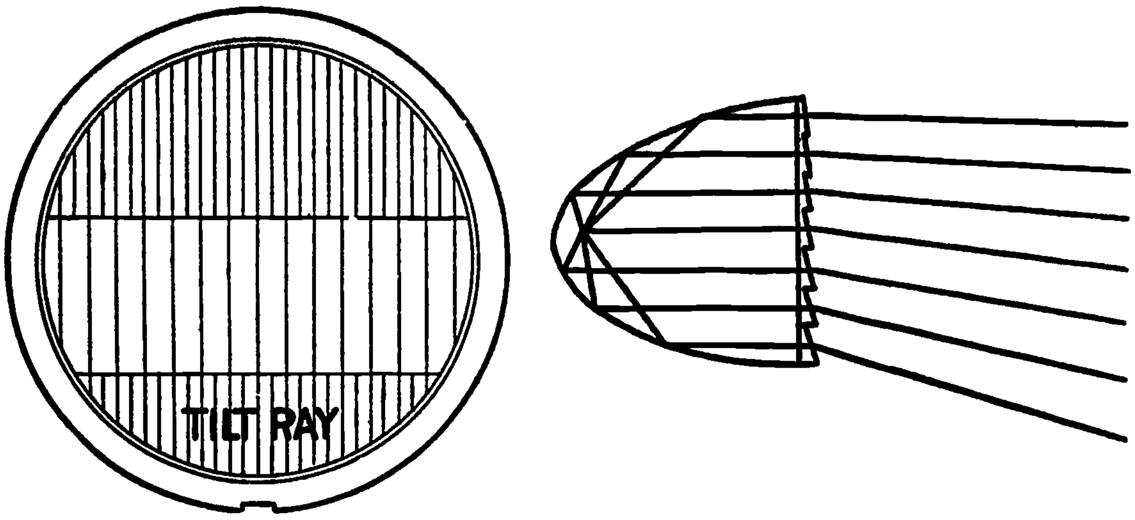
Fig. 7-41

The light as it <u>leaves</u> the plates of glass in Fig. 7-40 is bent again so its final direction is the <u>same</u> as when it entered. If the two surfaces of the glass make an angle with each other, as in a prism, the light will be bent on a <u>new</u> path. Headlamp "lenses" bend light in this way to get some of it along the side of the road (Fig. 7-43).



The path of a light ray passing through a prism.

Fig. 7-42



Tilt-ray head-lamp lens.

The rays from a head lamp are tilted by means of prismatic lenses.

Fig. 7-43

Real lenses work as if they were made up of small prisms. They can focus parallel rays or spread them apart. They are used in eyeglasses, magnifiers, cameras, and many other devices.

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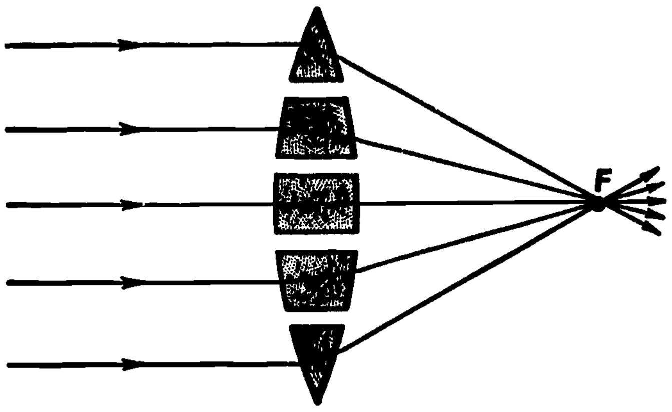
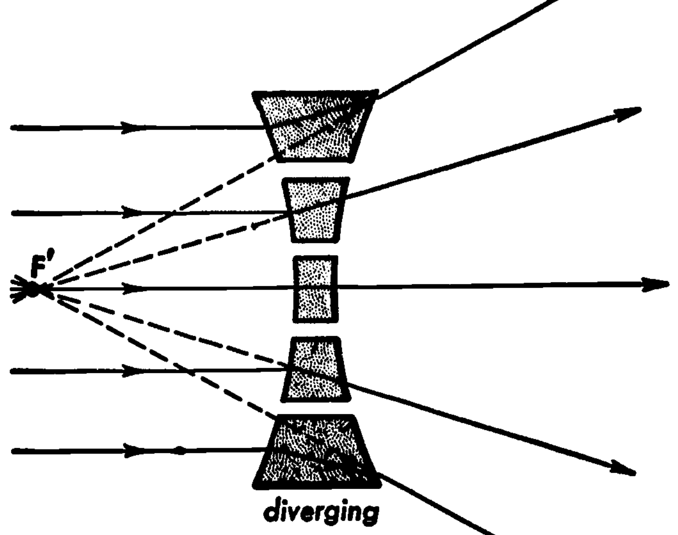
These have been some of the principles of physics and chemistry as they apply to the automobile. If you become a mechanic, you will see each year bring new uses for the principles you have been studying here.



converging



Matched sets of prisms illustrating lenslike

Fig. 7-44