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ABSTRACT

This unit consists of four sequences. The first ccnsiders the brain, the nervous system, and discrders of the brain. The second sequence deals with applicaticns of the computer in diagnosis cf brain disorders along with mathematical and statistical principles used in health applicaticns. The third sequence is concerned with drugs and their effects on the nervous system. The final sequence deals with senses, primarily sight and hearing. The prcperties of light and sound of medical importance are considered. Supplementary lessons on concepts of electricity are provided. (Author/RE)

BIOMEDICAL SCIENCE

UNIT IV

THE NERVOUS SYSTEM IN HEALTH AND MEDICINE

THE NERVOUS SYSTEM; DISORDERS OF THE BRAIN AND NERVOUS SYSTEM; APPLICATION OF COMPUTER SCIENCE TO DIAGNOSIS; DRUGS AND PHARMACOLOGY; THE HUMAN SENSES; ELECTRICITY

STUDENT TEXT

REVISED VERSION, 1976

THE BIOMEDICAL INTERDISCIPLINARY CURRICULUM PROJECT

SUPPORTED BY THE NATIONAL SCIENCE FOUNDATION

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SUPPLEMENTARY LESSONS ON ELECTRICITY

SECTION 1: THE BRAIN AND THE NERVOUS SYSTEM

1-1 Introduction to the Nervous System

It is evident that the human being is a complex organism. You have seen how humans can be studied in terms of body systems--the respiratory system, the circulatory system, the digestive system. And you have seen that these systems work together. But what regulates these systems? What coordinates their interactions? To answer such questions, we must consider the nervous system, particularly the part of the nervous system called the brain. This is the subject of this unit.

Unit IV consists of four sequences. The first sequence considers the brain, the rest of the nervous system and some important brain disorders. Most of the laboratory activities present clinical methods used to diagnose brain disorders. The second sequence of the unit deals with some applications of the computer in the diagnosis of brain disorders. This sequence is also an application of the topics covered in the first portion of Mathematics Unit IV. In the laboratory, a simple computer will be designed, constructed and applied to diagnostic problems. The third sequence is concerned with drugs such as aspirin, anesthetics and antibiotics. The study of drugs is included in this unit because many drugs work through the nervous system. In the laboratory, you will isolate drugs from plants and molds and study their properties. The final sequence deals with the senses--primarily seeing and hearing. Those properties of light and sound that are of medical importance will also be considered.

The nervous system is of great importance in medicine. In fact, everyone suffers periodically from disorders of this system. In addition, every time you have a headache, a muscle cramp or any kind of pain, the sensation of pain is transmitted through the nervous system. Important disorders of the nervous system that will be considered in this unit include stroke (sudden restriction of blood flow in the brain), head injuries (for example, from automobile accidents) and epilepsy (a nervous disease marked by convulsions and temporary loss of consciousness).

The nervous system is also crucial in normal functions that are often taken for granted. As you read these words, thousands of impulses move along your nerves to your brain where they are translated. Everything you see or feel or hear involves the nervous system. Every time you lift a pencil or move your fingers or take a step, nerves are involved. This unit will help you to understand the role of the nervous system in health and disease.

The controlling part of the nervous system, the part that directs all the rest, is the brain. Our brains do many things. When we move a part of the body, the brain sends signals to that part to make it move. Our brains also do things without our being aware of what is happening. The brain helps control our blood pressure, for instance. Name any body system and the brain has a role to play in it. Digestive: when you salivate at the smell of your favorite food, the salivary glands have been directed to salivate by the brain. Respiratory: when you inhale or exhale, your brain is controlling the process. As you read this, your brain sends signals to your eyes to direct their every movement. The brain even plays a role in the show of emotions. In crying, for instance, the brain directs the tear glands around the eyes to release tears.

1-2 Mapping the Brain; The Motor Cortex

How do scientists pinpoint the regions of the brain that control our behavior?

José Delgado stood nervously in the middle of the ring. The bull was charging and looked enormous. Delgado held a cape in one hand like a toreador and faced the bull. In his other hand, he held not a sword, but a small radio transmitter. As the bull came close, Delgado pressed a button that sent a radio signal. Suddenly the bull stopped only meters away and trotted off peacefully.

This story is true. Delgado is not a bullfighter, but a physiologist from Yale University. In 1965, he returned to his homeland, Spain, to perform the bold experiment just described to demonstrate his theory that a certain area of the bull's brain controls aggressive behavior. Before facing the bull, he had surgically placed a radio receiver into a part of the bull's brain presumed to control agression. Fortunately for Delgado, his theory was valid. The radio signal he transmitted stopped the bull.

To understand Delgado's work more fully, we need to take a closer look at the human brain. We will begin with the brain's outer portion: the cerebrum (Figure 1). The cerebrum is the top part of the brain. It is also the largest part and is divided into right and left halves, called hemispheres (Figure 1). The surface of each hemisphere is covered with folds. At the rear and below the cerebrum is a small ball called the cerebellum, which means "little brain."

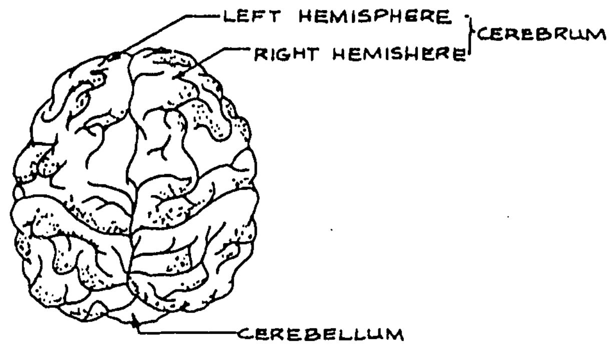


FIGURE 1: Brain, top view.

During life, much of the brain has the consistency and even the feel of gelatin dessert. Therefore, the hard-walled dome of our skulls serves well to protect the soft brains within from damage.

There have been many studies involving electrical stimulation of the human brain. One person who was stimulated was a young woman having brain surgery. The surgeon, a Canadian, touched a certain spot on her cerebrum with an electrode and turned on a very slight electric current. As soon as he did this her hand extended. When he stimulated a different point on her cerebrum, her leg extended forward.

The surgeon was Wilder Penfield. He was doing surgery to remove a scar on the woman's cerebrum which was causing convulsions. By first stimulating the cerebrum before cutting, he could make sure he wasn't about to cut into an important part, which could leave the patient with permanent damage.

Dr. Penfield stimulated the brains of hundreds of people during surgery and recorded which parts of the body moved. Using this information he compiled a map of the cerebral cortex, or outer surface, of the human cerbrum. Figure 2 shows one area of the cortex that Dr. Penfield mapped in detail--the shaded strip near the middle. When Dr. Penfield stimulated different points in this area, different parts of the body moved. This portion of the cerebral cortex is thus called the motor cortex, because it controls the movement of the body.

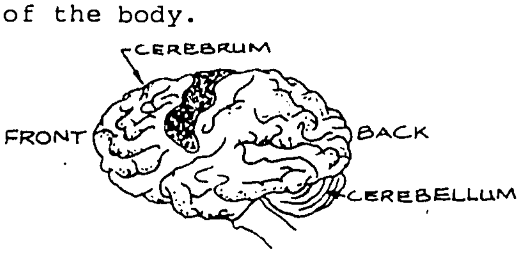


FIGURE 2: Side view of the brain. The motor cortex is shaded.

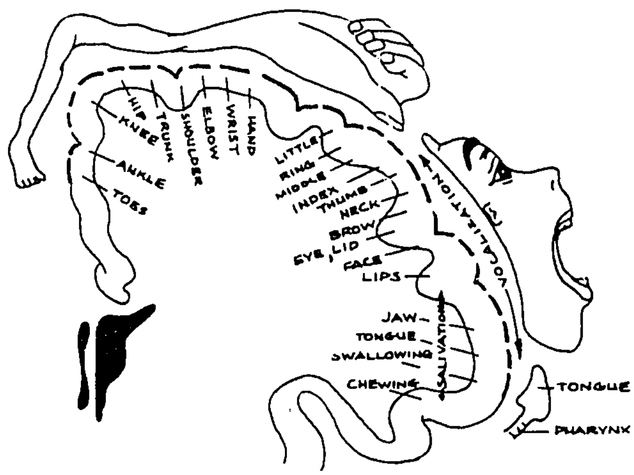


FIGURE 3: A map of the parts of the body controlled by the motor cortex. The view is of a cross section of the left hemisphere.

Figure 3 shows the map of the motor cortex that he obtained, together with a strange picture of the body. (Figure 3 can be understood by visualizing a slice of brain taken from the shaded region in Figure 2.) The most striking feature of the picture is that it is distorted. This is because the size of each body part is drawn to correspond to the size of the part of the cortex that controls it. For example, in Figure 3 the hand, including the fingers, is longer than the whole leg. Stimulation anywhere on the cortex between the words "hand" and "thumb" will cause the hand or a finger to move. The mouth and lips are also drawn large since so much of the motor cortex moves them. All this matches the fact that there are many small muscles in the hands and mouth which perform detailed and complex movements, particularly the movements of the hands in using tools and those of the mouth in speaking. Thus, it makes sense that the brain has a lot of space to control them.

What about the "little brain," the cerebellum (Figures 1 and 2)? The cerebellum controls many automatic movements. For example, when you drink a cup of water you don't have to think, "Now I must tilt my head back, now I must open my mouth," etc. You perform these movements automatically. It's the cerebellum that controls them. When you first learn to drink, however, the drinking movements are not automatic. The same is true when you first learn how to use a tool, tie shoelaces or make other movements.

When you are first learning, you must perform movements carefully and consciously to succeed. The motor cortex gives the orders for these movements. But if you practice them enough, soon the cerebellum "learns" them and it takes over and controls the movements automatically. The motor cortex no longer has to give all the orders.

1-3 Mapping the Brain: The Hypothalamus and Medulla

The motor cortex is not the only area of the brain that has been mapped. Figure 4 shows other areas that have been found on the cerebral cortex.

Many of them deal with senses. When these areas receive signals from the eyes, ears and skin we see, hear, and experience the sense of touch. Therefore damage to the part of the cerebrum labelled "vision" by a stroke or injury may leave a person partially blind. And electrical stimulation of the part labelled "vision" causes the person to see lights and patterns that aren't there. Ringing bells and clicking sounds are some of the things people have heard when the part labelled "hearing" was stimulated.

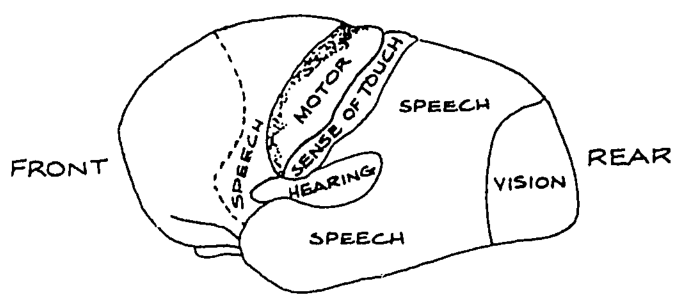


FIGURE 4: Some areas of the cerebral cortex (left hemisphere) that control various functions.

What about the other functions of the brain? Many of these functions are controlled by a tiny part deep inside the brain called the hypothalamus, shown in Figure 5 on the following page. (Figure 5 shows a cross section of the brain between the two hemispheres). This structure was introduced in the study of the kidney; it is the part of the brain that makes you feel thirsty. The hypothalamus has a host of other functions as well. It controls the sensation of hunger, it regulates body temperature and it senses the Na^+ concentration of the blood. It also controls the secretion of pituitary-gland hormones that are responsible for growth and, in women, preparing for pregnancy.

Finally look at the medulla in Figure 5. The medulla is the part that controls the heart rate, respiration and many digestive functions.

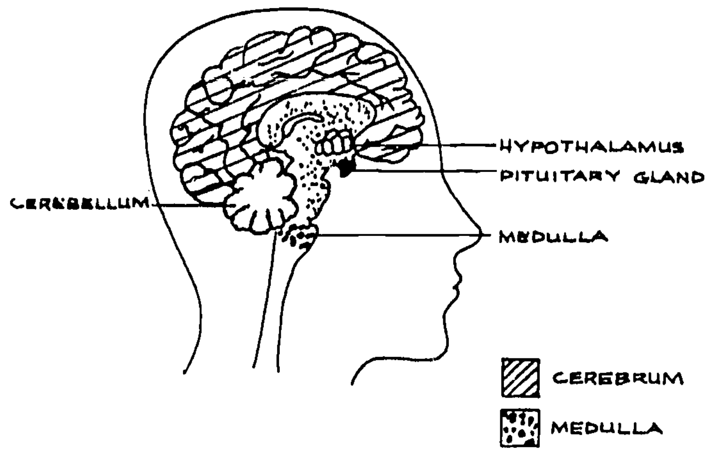


FIGURE 5: Location of the hypothalamus and medulla.

State three important disorders of the nervous system.

List at least three kinds of functions controlled by the brain.

How do surgeons map the surface of the brain?

Which two parts of the body have the largest representation on the motor cortex? How is this significant?

What are three functions of the hypothalamus? of the medulla?

Vocabulary:

cerebellum (SAIR-uh-BELL-um)--part of the brain behind and below the cerebrum that controls the coordination of movements.

cerebral (SAIR-uh-brul)--pertaining to the cerebrum; also, pertaining to the brain.

cerebrum (SAIR-uh-brum)--the largest part of the brain, consisting of the right and left hemispheres, located under the dome of the skull.

cortex (KOR-tex)--the outer layer of the brain, 1 to 4.5 mm thick in different places. Both the cerebrum and the cerebellum have a cortex.

hemispheres--the two halves of the cerebrum. The cerebellum is also divided into two hemispheres.

medulla (meh-DULL-uh)--a portion of the brain that helps control the circulatory, respiratory and digestive systems.

motor cortex--an area of the cortex of the cerebrum that controls movements. There is a motor cortex in each hemisphere.

SECTION 2: NEURONS AND THE TRANSMISSION OF IMPULSES

2-1 Nerves and Signals

What kind of cells carry electrical signals?

In the last section, we saw that different regions of the brain control different functions. When we wish to move our hand in a certain way, the brain areas that control hand muscles give the order, and the hand moves. But what kind of cells in the brain give the order? And what kind carry information from the brain to the hand? The answer to both questions is a very special kind of cell: a nerve cell or neuron.

Figure 1 is a diagram of one type of neuron.

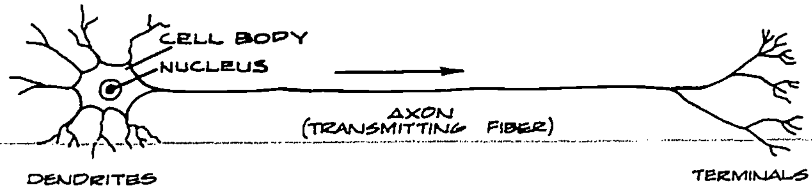


FIGURE 1: Diagram of a neuron.

In most of the body's billions of neurons, one end consists of a nucleus and cell body surrounded by a number of projections called dendrites. Dendrites have the ability to transmit electrical charge into the rest of the neuron. At the other end of the neuron are other projections, called terminals. Connecting the dendrites and terminals is a slender fiber called the axon, which transmits impulses from the dendrites to the terminals.

Where do neurons transmit impulses to? And what effect do these impulses have? A neuron's terminals may end either at a muscle, at a gland, or at the dendrites of other neurons. When a neuron's signal is transmitted to a muscle, it can make the muscle move. When it is transmitted to a gland, it can cause the gland to secrete. And when it is transmitted to other neurons, it enables them to carry the electrical signal further.

The nervous system is actually an electrical circuit. The information is carried by a flow of charges. An axon acts something like electrical wire, but not exactly. For example, a wire passes on whatever electrical charge reaches it. A neuron, however, only transmits when the electrical charge is large enough. This is true of the other stimuli that cause neurons to transmit impulses too, such as heat, cold and touch. All these stimuli have to be large enough to make the dendrites take on an amount of charge greater than a certain lower limit or threshold. Once the charge on the dendrites exceeds this threshold value, the dendrites "fire," sending a brief electrical pulse down the axon toward the terminals.

If you are wondering how heat and cold can make a neuron transmit signals, here's how: both heat and cold increase the permeability of the neuron's membrane to positive sodium ions on the outside of the cell. These Na^+ ions are normally dissolved in the fluid around the cell. When enough positively charged sodium ions pass through the membrane to the inside of the dendrites, they make the charge in the dendrites reach threshold. The dendrites then fire an electrical impulse.

The firing process may be repeated many times. If the dendrites continue to be stimulated, their charge will build up to the threshold level again and again, causing the neuron to fire repeatedly. Some neurons can fire hundreds of times per second.

Each firing of the neuron is like the last, sending a similar pulse down the axon. When the stimulus is greater, the neuron fires more often.

2-2 Structure of the Brain and Nervous System

What does the microscope reveal about the structure of nerves?

When a slice of brain or spinal cord is examined with a microscope, a dense wilderness appears. Figure 2, on the following page, shows a section of the cerebellum, near the surface. The picture indicates why scientists have such a hard time sorting out which neurons signal each other. It is because neurons are so closely packed together. The picture shows only a small fraction of the neurons actually present in this piece of tissue.

The brain is composed of billions of neurons. The brain also has an extension full of neurons called the spinal cord, which runs down the middle of the back. (Figure 3). The spinal cord is about as thick as your little finger and is inside the backbone (spine). The brain and spinal cord together compose the central nervous system (Figure 3). All other neurons or parts of neurons outside the central nervous system make up the peripheral nervous system. Much of the peripheral nervous system is made of nerves, which are rope-like structures consisting of thousands of long axons bound together. Some axons, such as the ones that go from the spinal cord to the feet, can be several feet long. All axons begin or end in the central nervous system, or else connect to other neurons that do.

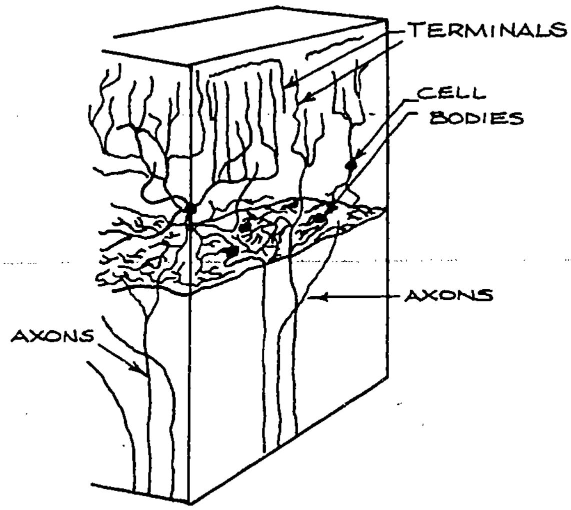


FIGURE 2: An interpretation of brain structure based on microscopic studies of sections.

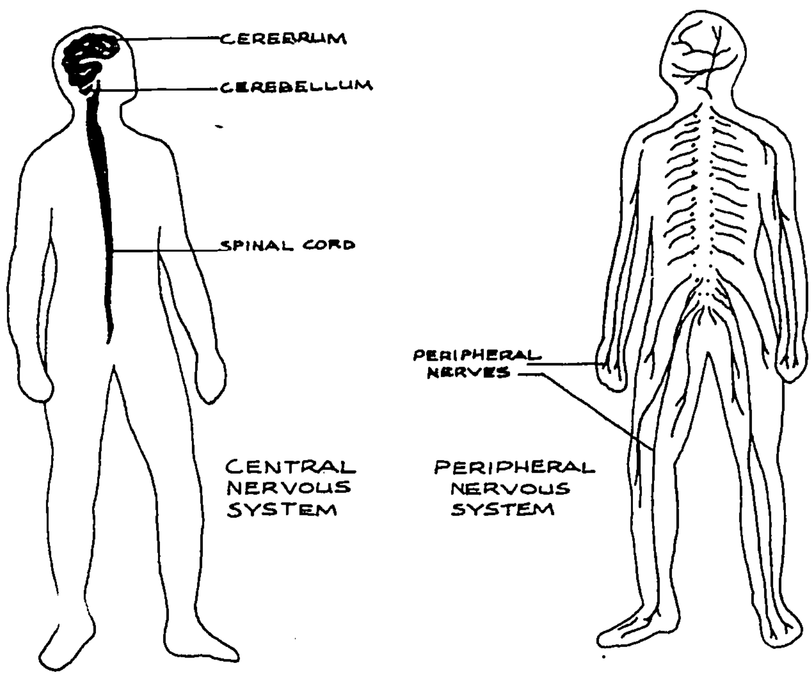


FIGURE 3: The central and peripheral nervous systems.

2-3 The Action Potential of a Neuron

What happens to a neuron when it fires an impulse?

A nerve impulse travels through the body at speeds up to a few hundred meters per second. As the impulse is transmitted, some remarkable events are taking place.

First let's consider the situation before the impulse is transmitted. Very careful chemical analysis has revealed that the Na^+ ion concentration is higher outside the cell than inside the cell and the reverse is true for K^+ ions. (Active transport is involved in maintaining this situation.) It has also been shown that the cell membrane is more permeable to K^+ ions than to Na^+ ions. As a result, K^+ ions tend to migrate out of the cell faster than Na^+ ions enter the cell. This suggests that the fluid outside the cell should be more positive in charge than inside the cell--and this too has been shown with minute electrodes. Figure 4A reviews this situation schematically.

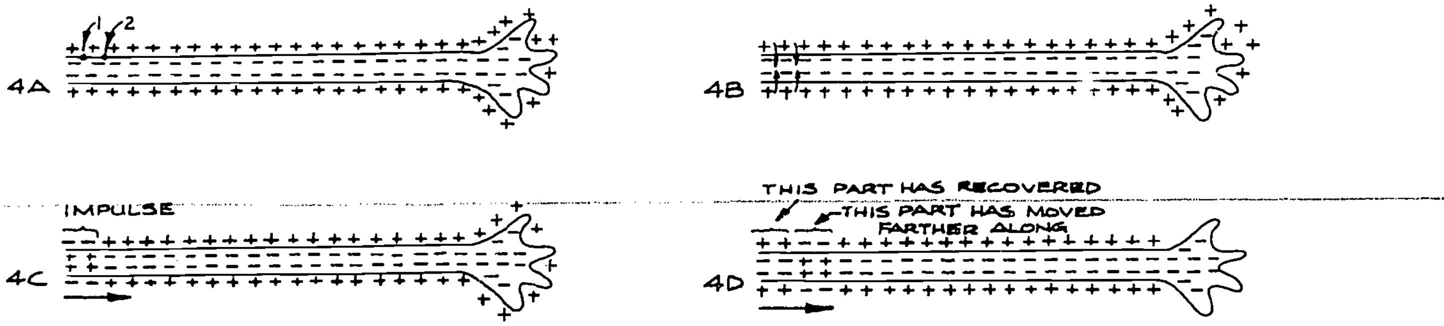


FIGURE 4: Ionic changes in the transmission of a nerve impulse.

Now let's consider what happens when a neuron is stimulated. (Although a neuron is typically stimulated at its dendrites, we will consider stimulation at Point 1 of Figure 4A in order to make it easier to understand how the impulse moves along the axon.) Neurons have a special property. When they are stimulated, the membrane becomes very permeable to Na^+ ions, which rush into the cell at the point of stimulation (Figure 4B). The rush of positively charged ions into the cell soon creates a situation near Point 1 in which the normal charge balance is reversed (Figure 4C). When this happens, Point 2, the area of the membrane next to Point 1, is stimulated. The newly stimulated region of the membrane also becomes very permeable to Na^+ ions and so the charge balance is reversed near Point 2 also. This migration of Na^+ ions into the neuron progresses along the neuron moving from the point of original stimulation to the end of the neuron. And it is this movement of Na^+ ions sweeping into the neuron that constitutes a nerve impulse.

This leaves one major problem: how does the nerve cell recover its original balance of ions? As the impulse moves along the neuron, the membrance near Point 1 recovers its original properties. The membrane becomes once again more permeable to K^+ ions than to Na^+ ions. For a bried period, the membrane becomes much more permeable to K^+ ions than before stimulation, and the cell quickly recovers its original balance of ions (Figure 4D). Then Point 2 and the rest of the membrane recovers following the same direction as the impulse until the neuron is charged just as it was before the impulse was transmitted (Figure 4A). That cell is now readly to transmit a new signal.

When an impulse passes any given point along the neuron's membrane, the voltage across the membrane changes. The changes in voltage across the membrane are called an <u>action potential</u>. With electrodes, a record of an action potential may be made (Figure 5).

The speed of impulses differs. Some neurons, including the ones that respond to pain, carry nerve impulses that are as slow as 0.5 meter per second. Others, including the ones that control muscles, carry nerve impulses at speeds of 100 meters per second or greater.

2-4 The Synapse

How does a nerve impulse go from one neuron to the next?

When a nerve impulse arrives at the terminal, the terminal may then stimulate other neurons to

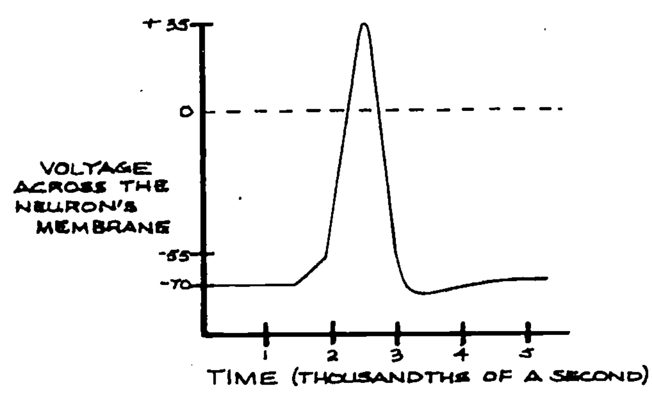


FIGURE 5: Recording of an action potential.

fire impulses that carry the message elsewhere.

How does this happen? The answer lies in the junction or <u>synapse</u> between two neurons (Figure 6). When the impulse reaches the terminal, the terminal secretes a chemical called a <u>neurotransmitter</u>. The chemical crosses the synapse and combines with <u>receptor</u> molecules in the dendrite membrane of the next neuron. This leads to a change in the charge of the next neuron. If there is enough of a change, the next neuron reaches threshold and fires an impulse. This happens either when a lot of the chemical is secreted by the first neuron, or when the next neuron is stimulated by many neurons at once. Some neurons are linked by synapses to a thousand or more other neurons.

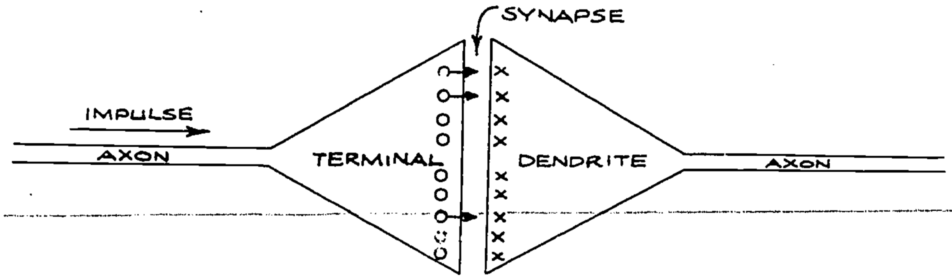


FIGURE 6: Schematic drawing of a synapse between two neurons. Neurotransmitter molecules shown by "o" symbols, receptor molecules by "x" symbols.

The kind of chemical secreted by the terminal is called a <u>neurotransmitter.</u> There are several differend kinds of neurotransmitters and they have different effects. In the nerves to the heart, for example, one kind makes the heart rate speed up and another slows it down, contributing to homeostasis.

The effects of some important drugs can be explained in terms of their action on neurotransmitters. One such drug is belladonna, which is used to treat peptic ulcers. It prevents the neurotransmitter from combining with receptors on the glands that produce stomach acid. Hence it acts to reduce acid secretion caused by the vagus nerve. The net effect of the drug is to provide some relief from ulcers. Drugs similar to belladonna are used in cold remedies because they also reduce mucus secretion by acting on glands in the nasal passages. Other drugs cause paralysis by preventing neurotransmitters from reaching the receptors on muscles. We will take up the subject of drugs in more detail in future lessons.

What is the general function of neurons?

What is the longest part of a neuron? What are the other parts of a neuron?

Describe the changes in the membrane of a neuron that cause an impulse to occur.

What is the anatomical distinction between the central and peripheral nervous systems?

How does a nerve signal travel from one neuron to the next?

Describe how the effects on the nervous system of some drugs can be explained.

<u>Vocabulary</u>:

<u>action potential</u>--the change in voltage across a membrane occurring with a nerve impulse.

<u>axon</u> (AKS-ahn)--the long, narrow part of a neuron that conducts a nerve signal toward the terminals.

<u>central nervous system</u>--the part of the nervous system that includes the brain and spinal cord.

<u>dendrite</u> (DEN-drite)-- the branched part of a neuron that receives signals from other neurons or originates signals itself when stimulated.

neurotransmitter--a chemical released by the terminals of a neuron that affects a muscle, gland or other neuron.

peripheral nervous system--all the nervous tissue outside the central nervous system.

receptor--a structure in a cell membrane that combines with chemicals. The chemicals are often secreted by other cells.

spinal cord--the long extension of the brain. It is composed of neurons, and is housed inside the backbone (spine).

synapse (SIN-aps)--the junction between two neurons across which nerve impulses are transmitted from one neuron to the next.

terminal--the branched structure at the end of a neuron that sends the signal to a gland, muscle or other neuron.

threshold--the minimum charge that a neuron must take on for it to "fire" a nerve impulse.

SECTION 3: ELECTROENCEPHALOGRAPHY AND BRAIN WAVES

3-1 Case History: Male, Age 23

The patient was a 23-year-old construction worker who came in for examination because he had "passed out" two days before. A friend who came along helped to provide some of the history.

The construction worker had evidently always been in good health. The day before the episode he had an argument with his wife and he started drinking heavily. According to the friend he went to bed "thoroughly drunk" and the next morning had a bad hangover. He didn't feel hungry, but started drinking black coffee. About noon he seemed very shaky, then suddenly fell to the floor, all the while jerking his arms and legs. The friend noticed he stopped jerking after about a minute but seemed "out of it." Gradually, about ten minutes later, he "came to" and asked what had happened. He seemed confused for several more minutes. The friend suggested he see a doctor, but the patient decided to wait another day until he felt better.

The examining doctor asked a few more questions. Had it ever happened before? No. Did he bite his tongue? Probably. His tongue did feel very sore. Had he had a head injury? No.

The doctor did a complete neurological exam: tested reflexes, coordination, sensation, etc. He ordered visual field testing, skull x-rays, an EEG and a spinal fluid exam. All exams and tests were negative except the EEG, which showed "a few abnormal waves consistent with a convulsive disorder."

The doctor said, "You've probably had an epileptic attack, triggered by too much alcohol and coffee. You should be thoroughly checked again in three months. Meanwhile, stay off liquor and don't drink coffee, tea or any cola drinks. I don't think you need any medication at this time." He then explained what epilepsy is and what the patient should do if he felt another attack coming.

Notes:

1. Epilepsy sometimes shows no signs until triggered by alcohol and/or stimulants like caffeine. (In other cases, however, seizures occur spontaneously. Emotional stress may also contribute to a seizure.)

2. Temporary mental confusion almost always follows an epileptic seizure.

3. Tongue-biting is quite common during a seizure.

4. A repeat complete examination is usually done to check for the possibility of a brain tumor, because the initial evidence in a brain tumor is often a seizure.

In the very early stages, a brain tumor may also show all negative findings on neurological tests.

3-2 The Electrical Brain

What is an EEG? What does it measure?

The EEG that suggested to the doctor that his patient was epileptic was simply a record of some of the patient's brain waves--a record of the electrical activity in his brain.

The voltages that activate the heart muscle, measured by the electrocardiogram, probably provide the most familiar and most useful electrical record of body function. But the voltages from the brain, recorded on an electroencephalogram (EEG), give another electrical record that can sometimes be as useful in revealing diseases of the brain as the ECG is in revealing diseases of the heart.

In the usual EEG, a number of electrodes are placed at matching sites on either side of the head. Then voltages are measured between each of the various sites. Up to eight voltages are recorded simultaneously on the EEG.

The surface of the cerebral cortex is a mat of dendrites periodically firing. At any spot on the surface, the voltage rises and falls as a result of this action. The EEG electrodes pick up these changes in voltage.

Ordinarily each electrode senses the voltage of a large number of neurons. If the neurons were all acting independently, the voltage changes would tend to cancel out. But apparently the neurons in a region are sufficiently coordinated to give a general change for the region.

3-3 Sorting Out Brain Waves

What sorts of patterns do brain waves make? How are they related to our thoughts?

The patterns traced out on an EEG are rarely an orderly display of waves. But often it is possible to see a reasonably constant pattern. And often changes from one kind of pattern to another are abrupt and can be associated with a change in thought pattern.

Ordinary thought is associated mainly with rapidly occurring waves called beta waves. Mental relaxation increases the number of slower waves (Figure 1). The slower waves of a relaxed mind, termed alpha waves, usually appear on the EEG of a person whose eyes are closed and whose mind is relaxed and free of troubling thoughts or puzzling problems.

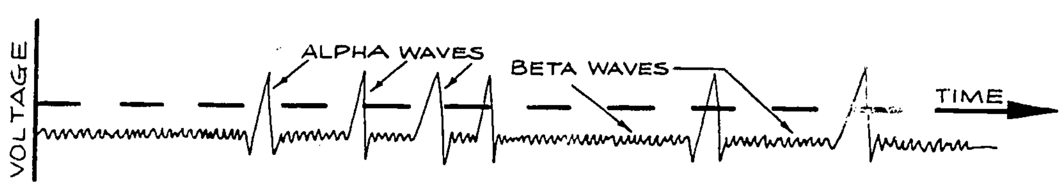


FIGURE 1: A mixture of alpha and beta waves.

Even slower theta waves are sometimes observed in awake adults and may be associated with periods of emotional stress. However, in children they may appear during rest and do not imply emotional strain.

The slowest of the brain waves are called delta waves. Although they may be seen in the awake baby, in the normal adult they are registered only during sleep.

Sleep doesn't always bring on delta waves. The sleeping mind usually switches back and forth between the slowest (delta) and the fastest (beta) brain waves every now and then. During periods of REM sleep, which gets its name from the rapid eye movement of the sleeper, the brain puts out beta waves predominantly. It is during such REM sleep that we have our dreams. In non-REM periods, the brain slows to the leisurely delta pace, and dreaming stops. REM periods average about twenty minutes each, although they are usually longer toward the end of the night's sleep. Between the REM periods, the brain usually rests in the delta state for an hour or more.

Merely studying the four types of brain waves is rarely helpful in diagnosing brain disorders such as epilepsy. Problems are more likely to be revealed by abnormally large voltages at some or all sites, or by pronounced differences between voltages measured on the left and right sides.

3-4 Epilepsy--An Ancient Disease

What is epilepsy? How is it treated?

Although epilepsy is not a highly publicized disease, it is surprisingly common. The exact number of individuals with this disorder is not known, but estimates range from two to four million in the United States.

The term "epilepsy" comes from the Greek word for "seizure." It should be pointed out that there are different forms of epilepsy and epileptic seizures. Seizures range from a barely noticeable momentary blackout to the more dramatic convulsions commonly associated with epilepsy. Thousands of years ago, people believed that an evil spirit sometimes invaded a body and made the person undergo the characteristic convulsions or other symptoms of epilepsy. The person invaded was said to be "seized." Over the last two thousand yeras, numerous theories about the nature of epilepsy have been offered. But only in the last few decades has epilepsy been traced to neurons in the brain.

Epilepsy is a brain disease that affects the cortex of the brain, the part that gives rise to the EEG record. In epilepsy, certain neurons in the brain fire more easily than they should, bringing forth the characteristic body responses. Typically, rapid-fire signals are sent along motor neurons to the muscles, leading to convulsions. Some brain-wave patterns that correspond to epilepsy are shown in Figure 2.

Since epilepsy arises from an abnormally low threshold in some of the brain's neurons, drugs that lower the threshold of neurons may bring on an attack. Alcohol is such a drug, which explains why epilepsy in adults is often associated with alcoholism. Epilepsy may also be brought on in a susceptible person by excessive intake of coffee, tea or cola, since those drinks contain caffeine, which also lowers the firing threshold of neurons.

If seizures cannot be controlled by limiting or stopping the intake of alcohol and caffeine, physicians will often prescribe a mild sedative or other drugs for epilepsy. Sedatives are drugs that reduce the activity of the nervous system without causing sleep. In most cases, seizures can be completely eliminated through proper medication. Occasionally, surgery is employed to prevent further seizures of certain types, for example, by removing a blood clot from the brain. Sometimes, epileptics stop having seizures for no apparent reason--they are spontaneously cured.

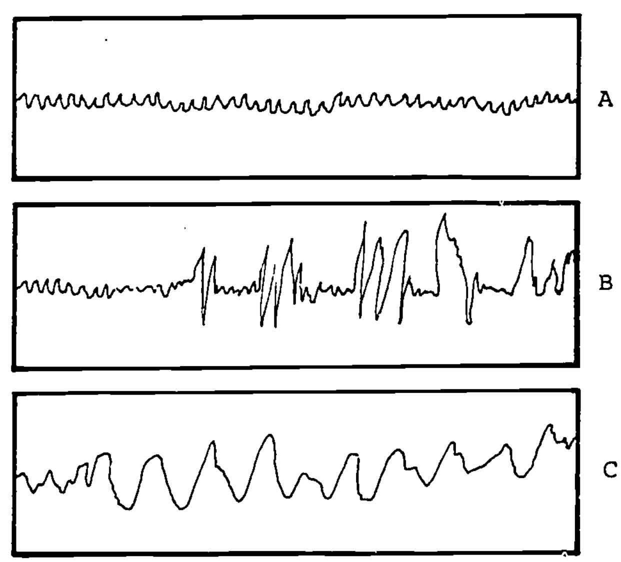


FIGURE 2: Three brain wave patterns. A-normal pattern, mostly beta waves; B-brain waves characteristic of an epileptic attack following normal brain waves; C-brain waves characteristic of a different kind of epileptic attack.

Most people with epilepsy live normal, productive lives. This statement is supported by the spectacular successes registered by some famous epileptics. These include Pythagoras (a Greek philosopher-mathematician who lived about 2500 years ago), Julius Caesar (the Roman general and emperor), Van Gogh (the artist), composers such as Handel and Tchaikovsky, writers such as Dickens and Dostoevski, and many others.

What factors led to the seizure of the construction worker in the case history? Why was the worker told to return for a thorough examination in three months?

Describe the appearance of four different normal brain waves. Under what conditions are each of these waveforms most likely to be observed?

What happens in the brain during a seizure? What is the effect of a seizure on the EEG pattern?

How is epilepsy treated?

Vocabulary:

convulsive (kun-VUL-siv)--pertaining to a convulsion, which is an involuntary spasm or contraction of muscles.

electroencephalogram--abbreviated EEG. A record showing the changes in voltage between different parts of the brain; the record is made by an instrument called an electroencephalograph.

encephalo-(en-SEF-uh-lo)--a word element referring to the brain.

epilepsy (EP-uh-LEP-see)--nervous disease marked by seizures with convulsions and loss of consciousness.

neurological (NEW-ro-LOJ-ik-ul)--pertaining to the nervous system.

REM sleep--sleep during which there is rapid eye movement; this kind of sleep is associated with dreaming.

sedative--a drug that reduces activity of the nervous system without causing sleep.

seizure (SEE-zhur)--sudden attack.

SECTION 4: BIOFEEDBACK TRAINING

4-1 Case History: Migraine Headache

How can you stop migraine headaches with a thermistor?

Mr. Jones had been suffering from intense migraine headaches for three years. One day a friend suggested that he look into the possibility of biofeedback training. Mr. Jones made an appointment with Dr. Alice White, a psychologist who had worked successfully with a number of people suffering from migraine headaches.

Dr. White asked that Mr. Jones visit the training center twice a week. During the sessions she wired Mr. Jones to a thermistor that monitored the temperature of the middle finger of his right hand. She told him that the object of the training sessions was for him to learn how to increase the temperature in that finger. The thermistor was wired to a digital display instrument, from which Mr. Jones could tell when the temperature in his finger was increasing. Dr. White told Mr. Jones that the way in which he would increase the temperature in his finger was by increasing the flow of blood to that finger.

Mr. Jones was skeptical at first. He didn't really believe that he could increase the temperature of his right middle finger just by sitting there and looking at his finger. And even if he could do that, he didn't see what it had to do with his migraine headaches. But Dr. White assured him that the therapy worked for many people, and he decided to give it a try.

After several weeks, Mr. Jones was able to increase the temperature in his right middle finger any time he wanted to, without being wired to the thermistor and the digital display. When he had a migraine headache, he was able to stop it by increasing the temperature in his finger. And in many instances he could avoid the headaches altogether by sensing when one was coming on and applying the technique he had learned in biofeedback training.

Notes:

1. A migraine headache is an intensely painful headache, usually confined to one side of the head. Other symptoms sometimes associated with the headache include nausea and blurred vision. The symptoms of migraine headache do not respond well to drugs or other conventional remedies.

2. The pain of migraine headache comes from nerves that are wrapped around some of the arteries just under the skull, on the outside of the brain. These nerves sense pain when the arteries are dilated (stretched).

3. Just how the arteries become dilated is not well understood. However, it is known that the dilation and contraction of these arteries is under the control of the autonomic nervous system, and it is supposed that the dilation of these arteries (and the consequent pain) is somehow brought about by something happening in the autonomic nervous system.

4. When biofeedback training is used to cure migraine headaches, the method is to train the patient to increase the flow of blood to some part of the body. Different parts of the body work best for different patients. For example, some learn to stop migraine headaches by increasing the flow of blood to the side of the head that is free of pain; others do it by increasing the flow of blood to one hand or the other, or to other parts of the body.

5. Just as the cause of migraine headaches is not thoroughly understood, so the cure is somewhat mysterious. Increasing blood flow to another part of the body requires making something happen in the autonomic nervous system, which controls the flow of blood in all parts of the body. Apparently, when the patient increases the flow of blood to the hand, the events that occur in the autonomic nervous system set off other events in that system, and one or more of these events cause the arteries in the head to contract back to their normal size. When they do that, the pain stops.

4-2 Case History: Tension Headache

How can tension headaches be stopped without analgesic drugs?

Mrs. Lederman suffered from tension headaches. When she went for biofeedback training, she was wired to an instrument something like an electrocardiograph. The electrodes were attached to her forehead, and they sensed the contraction or relaxation of a muscle in the forehead called the frontalis muscle. The instrument was also wired to a light, which went on when this muscle was relaxed.

In training, Mrs. Lederman watched the light and learned how to make it go on when it was off, and how to keep it on when it was on. She learned that whenever the frontalis muscle relaxed, the muscles of her scalp, neck and shoulders also relaxed. She was also told that it was tension in these muscles which was causing her headaches.

After training, Mrs. Lederman was able to relax her frontalis muscle whenever she felt herself getting tense or felt a headache coming on. By relaxing the frontalis she could make a tension headache go away or prevent one that was just coming on.

4-3 Feedback: A Review

What is feedback? How does natural feedback maintain homeostasis in the body?

In biofeedback training, the patient is wired to instruments that monitor certain processes in his body and also give him continous information about these processes. The patient learns to use this information about his own body to control the processes that are being monitored. Most of the processes that are monitored are things that a person is ordinarily unaware of and ordinarily has no conscious control over--things like the flow of blood to different parts of the body, the generation of different kinds of waves by the brain, or the heart rate.

Before you investigate biofeedback training further, you should recall some of the things you already know about feedback processes that occur naturally (without training) in the normal human body. Feedback is a process in which information about the result of some activity is carried back to whatever controls that activity, and that information influences the way in which the activity is controlled. For example, consider a room with a heater controlled by a thermostat. The thermostat includes a sensing device that monitors the temperature of the air in the room. When the temperature falls below a certain level, the thermostat sends a message that turns on the heater, thus raising the temperature of the air in the room.

Feedback is involved in most of the mechanisms by which your body maintains homeostasis. For example, we have discussed the feedback processes by which your brain changes your heart rate and thus controls your blood pressure. Nerves ending in certain parts of your heart and in certain blood vessels respond to changes in the pressure in different parts of your circulatory system. These nerves bring information about blood pressure to two centers in your brain that control your heart rate--one that accelerates it and one that inhibits it. When the accelerating center receives information that the right atrium is filled with a large quantity of blood, it sends out messages that cause the heart rate to increase. When the inhibiting center receives information that your aorta is filled with blood at high pressure, it sends out messages that cause your heart rate to decrease.

Control of your heart rate is carried out by two feedback "loops," one of which works to speed up and the other to slow down your heart. Both of these loops are in operation at all times, and they work against each other to maintain a finely adjusted homeostasis in your circulatory system.

4-4 Feedback and Biofeedback Training

How is biofeedback training different from natural feedback in the body?

When Mr. Jones was in biofeedback training to learn how to stop his migraine headaches, and when Mrs. Lederman was in training to learn how to stop her tension headaches, both of them were wired to instruments that gave them information about certain processes in their bodies, and they used that information to learn how to control those processes.

Consider Mr. Jones, who had a thermistor wired to his right middle finger and was watching a digital display of the temperature in that finger. As he learned to control the flow of blood to that finger, he was involved in a feedback loop somewhat similar to the loop between your heart and the accelerating center in your brain. However, there are some important differences between those two feedback loops.

1. In biofeedback training, Mr. Jones' brain did not receive information directly from his finger, through the neural pathways that connect his finger to his brain. The information was relayed from his finger, through the thermistor and the digital display instrument, to his eyes, and thus to his brain.

2. Mr. Jones did not remain unaware of the information his brain was receiving. When Mr. Jones' accelerating center receives information that his right atrium is filled with a large quantity of blood, Mr. Jones does not become conscious, or aware, of the information. But when the digital display told him that the temperature in his right middle finger was increasing, he was aware of that information.

3. Mr. Jones made some sort of conscious effort to increase the flow of blood to his finger. When Mr. Jones' accelerating center sends out the messages that speed up his heart rate, it does so without any conscious effort, or act of will, on his part. But in biofeedback training, Mr. Jones was not only consciously receiving information about the temperature in his finger, but also consciously trying to make that temperature go up.

4. Mr. Jones may have been consciously aware of certain sensations that occurred in his body when the temperature in his finger changed. Mr. Jones' accelerating center controls his heart rate even when he is asleep; he does not have to be aware of any bodily sensations in order for it to work. But in biofeedback training, Mr. Jones could tell when he was successfully increasing the flow of blood to his finger. Because he was aware of this change, he could eventually use this technique of stopping his migraine headaches without the aid of the thermistor and the digital display of temperature.

Figure 1 below illustrates these differences between (1) the natural feedback loop by which the accelerating center in your brain monitors the pressure in your heart and speeds up your heart rate and (2) the feedback loops that Mr. Jones was involved in when he was in biofeedback training. You should be able to draw (1) a diagram showing the feedback loops that Mrs. Lederman was involved in when she was in biofeedback training to control her tension headaches and (2) a diagram showing the feedback loop that Mr. Jones was involved in <u>after</u> biofeedback training, when he had learned to control the flow of blood to his finger by attending to sensations within his body, without the use of the thermistor and the digital display.

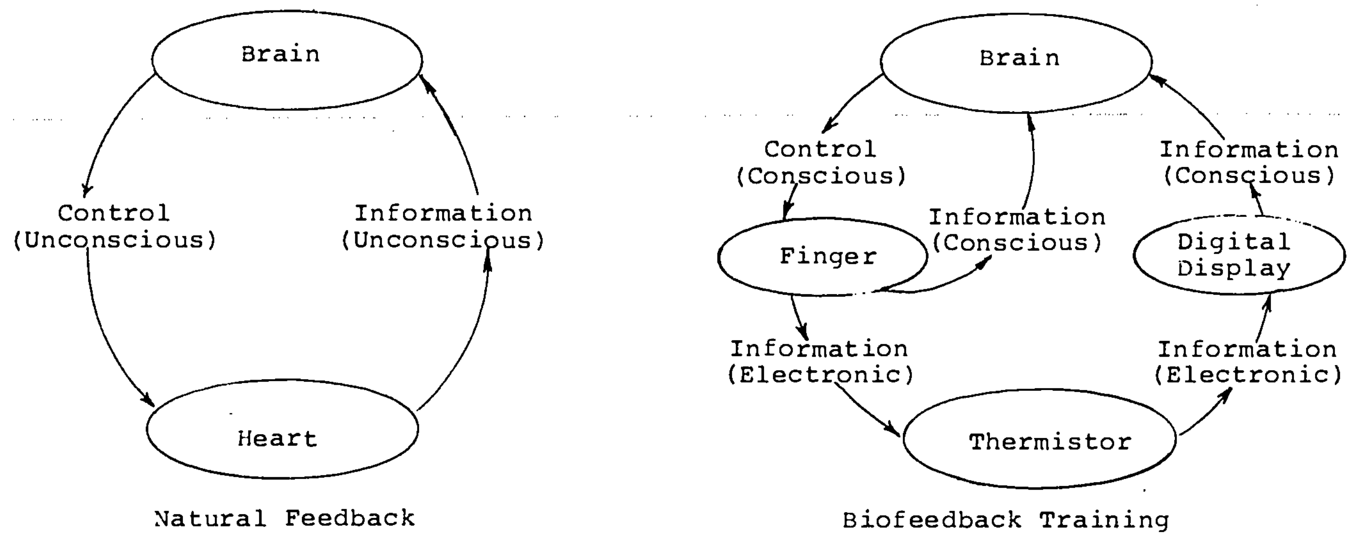


FIGURE 1: Feedback loops.

4-5 <u>Some Other Uses of Biofeedback Training</u>

What kinds of things can biofeedback training be used for?

People have learned through biofeedback training to control a variety of processes in their bodies over which people ordinarily have no conscious control. One such process is the generation of brain waves. Many subjects have been wired to electroencephalographs and to instruments that indicate to the subject when brain waves of a particular kind, such as alpha waves, are being generated. For example, the subject might see a light go on or hear a low musical tone whenever the EEG detects alpha waves. Through this kind of training, many subjects have learned how to "turn on" their alpha waves at will. They begin by noticing what goes on in their bodies when the light is on--what they do to make it go on, and how they feel when it is on. Eventually they become able to increase alpha-wave production simply by attending to these sensations, without using the EEG and the display.

Biofeedback training is at the present time an experimental tool in both preventive and therapeutic medicine. It has been used successfully with some subjects in controlling not only migraine and tension headaches, but also hypertension, muscle tics (spasms), asthma, insomnia and anxiety. For some patients, particularly those with migraine headaches and hypertension, biofeedback training appears to be more effective than other methods that have been developed for the control of these problems.

Biofeedback training is very similar to some other, much older techniques for controlling the internal processes in the body. These are techniques that have been developed over centuries in Asian cultures, particularly in India. Through rigorous training and strict discipline, some people in these cultures have learned to control--without the use of any instruments--the same sorts of processes that are now beginning to be controlled through biofeedback training.

Practitioners of the Asian arts of self-control have met with scientists experimenting with biofeedback training, and they have found that they have much to learn from each other. The scientists have learned that these practitioners could in fact control their brain waves, their heart rate, their blood flow and many other internal processes, and could do so even more rapidly and effectively than people who had gone through biofeedback training. The Asian practitioners, on the other hand, have learned something about the internal processes that they control. One swami, for example, told experimenters that he was going to "stop his heart." When the scientists monitored his ECG as he performed this feat, they found that what he had actually done was to increase his heart rate in one beat from about 70 per minute to about 300 per minute. At that rate--a condition called atrial flutter--the swami's heart was "beating" at its highest possible rate, but the chambers were not filling properly and the valves were not working properly.

This swami also made use of biofeedback training equipment in another way. He took some of it back to India with him. He intended to use the instruments in two ways: to speed up the training of young yogis (since the biofeedback training for controlling some of the simpler processes is much faster than the traditional ways of learning to control them without instruments) and also to detect phony yogis who said they could control their brain waves, blood flow, etc., but who couldn't really do it.

4-6 Biofeedback Training and the Autonomic Nervous System

What is the autonomic nervous system? How is it related to biofeedback?

Many of the physiological processes that can be controlled through biofeedback training are regulated by a branch of the nervous system known as the autonomic nervous system. Recall that the central nervous system is composed of the brain and spinal cord. Many nerves extend from the brain and spinal cord to different parts of the body, and some of these nerves make up the autonomic nervous system. You have seen that the central nervous system is the seat of conscious thought, speech and the control of such processes as muscular contraction and bodily movement. The autonomic nervous system controls many other vital processes, such as respiration, circulation and digestion. Basically, the autonomic nervous system is divided into two branches, each branch exerting influences that balance those of the other branch. In other words, the two branches have opposing effects. The two branches are known as the parasympathetic and the sympathetic systems. Some of the effects of each are listed in the table below and shown schematically in Figure 2 on the following page.

ORGAN OR SYSTEM AFFECTED	SYMPATHETIC EFFECT	PARASYMPATHETIC EFFECT
heart	accelerate	decelerate
digestive system	decrease peristalsis	increase peristalsis
bronchioles	dilate	constrict
circulation	decrease blood supply to digestive organs, increase to heart and skeletal muscles	increase blood supply to digestive organs, decrease to the heart
pupils (of eyes)	dilate	constrict

As you can see from the table and the diagram, the autonomic nervous system plays an important role in maintaining homeostasis in the body. The effects it may produce on the body are widespread and many times complex. In general, however, there are a few basic rules that will help you understand how this system functions.

1. Almost all the organs controlled by the autonomic nervous system are connected to nerves of both the parasympathetic and the sympathetic branches.

2. The effects of the parasympathetic and the sympathetic systems generally are opposed to one another. For example, the parasympathetic system causes the heart rate to decrease and the sympathetic system causes it to increase. This arrangement provides for a high degree of precision in homeostatic control.

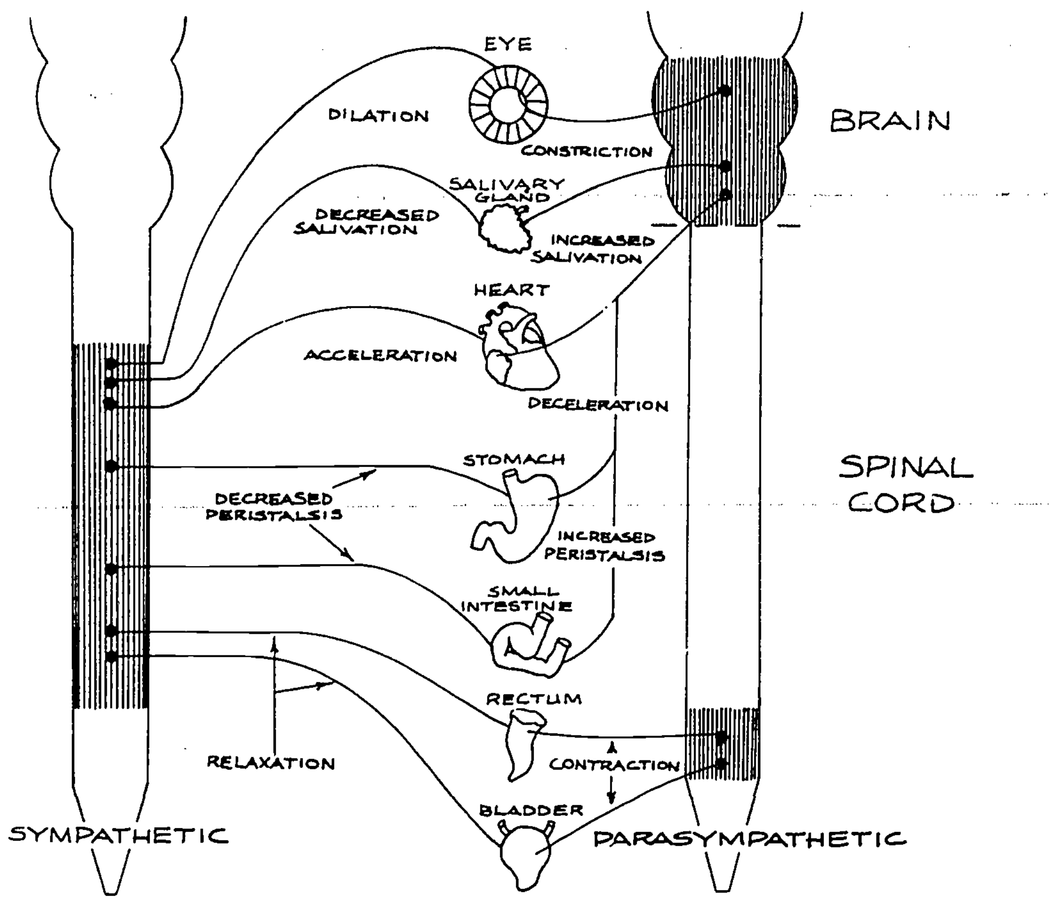


FIGURE 2: The two branches of the autonomic nervous system, the sympathetic on the left, the parasympathetic on the right.

3. The sympathetic nervous system generally helps the body to respond to external stresses, while the parasympathetic system is more involved with internal changes.

4. The sympathetic nervous system predominates in situations involving stress or strong emotions such as anger and fear. It is responsible for the famous "fight or flight" response. When you are confronted with a threatening situation, the sympathetic nervous system takes over. It increases the heart rate, pumping out more blood to the muscles. It increases the rate of cell respiration and production of ATP. It prepares the muscles for action. It dilates the pupils of the eye, admitting more light and thus enabling you to see more acutely in a dimly lit environment.

5. In contrast, the parasympathetic nervous system is most important when you are recovering, or resting. The heart rate slows down. Digestion may be taking place. A portrayal of the "parasympathetic person" might show someone who has just eaten a good meal and is relaxing in a comfortable environment, perhaps even napping.

Autonomic responses usually occur without conscious thought or control. In fact, the autonomic system has also commonly been called the "involuntary nervous system," because until recently it was thought that the functions of this system could not be controlled voluntarily. For example, it was believed that one could not increase one's heart rate simply by thinking, "Heart beat faster." However, as research in biofeedback training has progressed, it has become clear that the title "involuntary nervous system" is incorrect.

Medical research has shown that more and more disorders are associated with the body's response to stress. For this reason, the ability to develop control over the autonomic responses is enormously useful in medicine, for prevention as well as therapy. The development of biofeedback training is being watched with increasing interest.

What is biofeedback training? How is it different from feedback processes that occur naturally?

Give an example of the use of biofeedback training to treat a medical disorder.

How do the autonomic and central nervous systems differ?

Why is the title "involuntary nervous system" not an appropriate name for the autonomic nervous system?

What is the advantage of having two opposed branches of the autonomic nervous system?

How is the autonomic nervous system related to homeostasis? to biofeedback training?

Vocabulary:

autonomic nervous system (AW-tuh-NOM-ick)--the branch of the nervous system that controls heart rate, respiratory rate, peristalsis rate and other vital bodily functions. It is composed of many of the nerves that extend from the brain and spinal cord.

biofeedback training--the process in which (1) information about internal bodily processes is relayed through external equipment to the conscious awareness of the subject and (2) the subject learns to control consciously the internal process about which he or she is receiving information, often for the purpose of preventing or treating disease.

parasympathetic nervous system--the branch of the autonomic nervous system that (1) generally increases secretion, increases heart rate, and dilates blood vessels and (2) is mainly involved in maintaining homeostasis by responding to internal change; opposed to the sympathetic nervous system (see).

sympathetic nervous system--the branch of the autonomic nervous system that (1) generally reduces secretion, decreases heart rate and constricts blood vessels and (2) is mainly involved in maintaining homeostasis by responding to external stresses; opposed to the parasympathetic nervous system (see).

SECTION 5: REFLEXES AND MULTIPLE SCLEROSIS

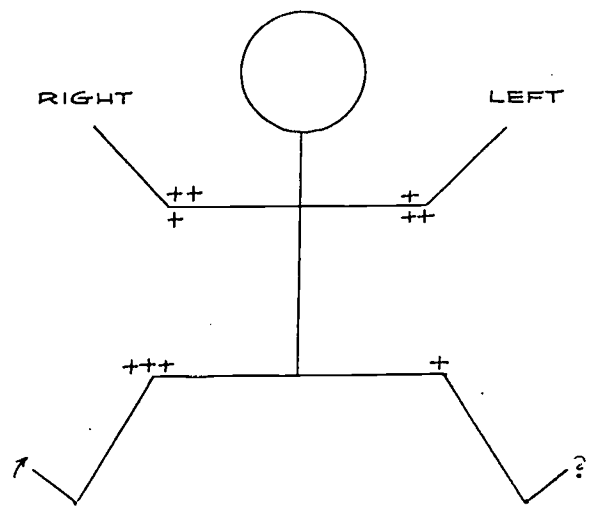
5-1 Case History: Female, Age 36

The patient was a 36-year-old woman who had come to the physician because she was "seeing double." Generally, she said, she felt fine. About three years ago she "saw double," but the problem disappeared in a few days and she did not go to the doctor. About a year ago she saw double for a few days and also saw a few "spots" in her right eye. She also noted a little numbness and tingling in her left arm as if she'd "slept on it." These symptoms lasted a few days but were not severe and were gone by the time of her medical appointment, so she cancelled the appointment.

Today, though, she was concerned. She had been seeing double so badly that she needed to cover one eye--it didn't matter which one. She also noted a slight lack of coordination. She kept bumping into things, but thought she did so because of the vision problem.

The doctor did a careful neurological exam. She held up one finger--"How many fingers?" Two. She then covered the patient's left eye. "Now how many?" One. The doctor continued testing, this time the reflexes. She drew a little stick figure that looked like the one on the following page to summarize her observations.

(In a diagram such as this, a single + indicates a normal response; ++ indicates that the response is exaggerated but still within normal limits; more than ++ indicates a response that is stronger than normal. The arrow at the toe of the right foot indicates the plantar response. This is produced by stroking the sole of the foot from the heel to little toe. The normal response is for the toes to curl downward. The upward-pointing arrow near the right foot means that this patient curled her toes upward. The question mark by the left foot indicates that there was no response in this case--either up or down--or that the response was not clearly determinable.)



There were reflex abnormalities on both sides, more on the right than on the left. The finding that the right plantar response was upward was definitely abnormal.

The doctor tested the patient's coordination--finger to finger, finger to nose, etc.--and it was borderline, suggesting that the patient had slight but definite impairment.

"Well, we will need to get some further tests done at the clinic."

Over the next two weeks these studies were made.

Skull X-rays: negative (no breaks or obvious damage)
EEG: negative (no abnormal patterns)
Spinal fluid: slightly increased gamma globulin
Visual fields: defects in each eye

The reports supported the doctor's earlier impression of multiple sclerosis. She really dreaded having to tell the patient of the diagnosis.

"What did you find?" the woman asked. "I'm really much better now and don't see double anymore."

The doctor sat back in her chair and reflected for a moment.

Eventually she said, "I'm glad you are feeling better. I don't think there is anything we should do now. Your X-rays and EEG's were fine. But you have had symptoms like this before and it may happen again. If you have further problems, I want you to be sure to come back again. All right?"

Later the doctor left the office with an uneasy feeling, wondering whether she should have told the patient that multiple sclerosis was suspected.

Notes:

1. Spontaneous disappearance of symptoms in multiple sclerosis (MS) is very common--but recurrence (new attacks) follows months or years later. Recurrence may be triggered by emotional stress.

2. In MS, a wide variety of impairments can occur--in the brain and, to a lesser extent, in parts of the spinal cord.

3. By and large, this disease does not affect higher mental processes (thinking).

4. There is at present no satisfactory treatment for MS.

This case raises some thorny ethical problems. Given what you know about multiple sclerosis and especially that it is an incurable disease, what would you have told the patient? What if the patient had asked what was wrong?

5-2 The Knee Jerk and Other Reflexes

What is a reflex? How can we move without thinking about it?

Picture yourself in each of the three situations described below and imagine your response to each situation.

1. While you are relaxing on a soft chair, your kid brother sneaks up directly behind you and shouts, "DINNER TIME."

2. You get up and walk toward the dining room. Suddenly, you sense the aroma of your favortite dish, pizza with mushrooms.

3. Minutes later, at the dinner table, you are eagerly gulping down slices of pizza. A small flake of crust somehow finds its ways into your trachea.

Your response to the above situations may vary. In the first situation, you may be tempted to throw something at your kid brother. But there are some things you will do in each situation without being aware that you are doing them. What's more, these actions that are done without thought will be virtually identical in all normal individuals.

In the first situation, the normal response to a loud, unexpected noise is to blink your eyes and jerk your head. In the second instance, your reaction to the pizza will be for your salivary glands to produce saliva. And in the last example, the pizza in your trachea will cause you to cough. The plantar reaction in the case history is another example of a reaction that occurs without thinking. Such automatic responses are known as reflexes.

Reflexes are automatic actions of the nervous system that require no thought. However, your brain is involved in their operation. And sometimes when the brain is damaged one reflex or another becomes abnormal, no longer behaving in its customary manner. Recall the patient with multiple sclerosis and her response to stroking the sole of her foot. She also had other abnormal reflexes.

Reflexes perform many valuable services in our daily functioning. Many reflexes have a protective role. For example, when an object comes close to one of your eyes, you will blink that eye. Other reflexes, such as the salivating response, prepare your body for digesting food. Another reflex mechanism--the coughing reflex--protects you from choking when food gets into your trachea. Reflexes also permit your body to regulate its heart and respiratory rates when you are sleeping.

The ways reflexes work is demonstrated by one of the most familiar: the "knee jerk." This reflex involves the quadriceps muscle of the thigh. This muscle is used in straightening the leg. The quadriceps is connected to the shin bone of the lower leg by fibrous tissue (a tendon). When the quadriceps contracts the pull on the shin bone causes the foot to kick out.

Contraction of the quadriceps is controlled by neurons that go to muscles--motor neurons. These neurons may pick up electrical signals from several sources and fire impulses down their axons to activate the muscle.

One source of these signals is the brain. If you want to extend your leg, your brain can send a message to the quadriceps to contract. But there are many times when it is desirable for the quadriceps to contract without your paying much attention--without your brain continuously sending messages. That's where the quadriceps (knee-jerk) reflex comes in.

Embedded in the muscle are the dendrites of sensory neurons (Figure 1). These neurons respond to an initial stimulus by transmitting impulses to the central nervous system. In the quadriceps muscle reflex, the initial stimulus is the "knee" tap. The tap stretches the quadriceps muscle and triggers sensory neurons to send impulses to the spinal cord. The impulses are then transmitted to the dendrites of motor neurons and travel down the axons of these neurons, back to the same muscle. The muscle responds by contracting and pulling on the shin bone, causing the leg to jerk and the foot to kick out. And all of this happens within a fraction of a second. Note that the impulse caused by the stimulus goes to the spinal cord, not to the brain. This is what we mean by a reflex action.

The entire route of an impulse during a reflex action is called a reflex arc. What happens in a reflex arc is summarized in the box below and in Figure 2.

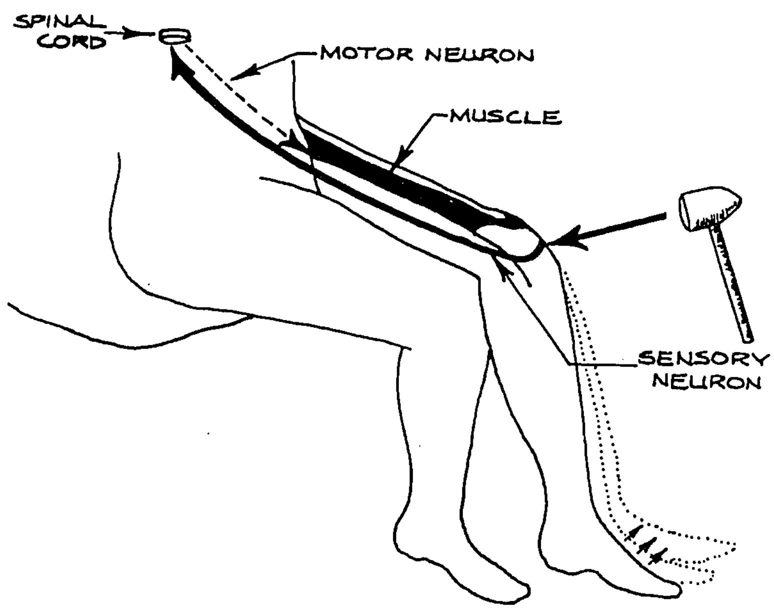


FIGURE 1: The "knee-jerk" reflex.

1. Something in the environment (internal or external) stimulates a sensory neuron to fire.
2. A nerve impulse is sent along the sensory neuron to the spinal cord.
3. The impulse is transferred to a motor neuron.
4. The impulse is sent along the motor neuron to the muscle (or organ or gland).
5. The muscle (or organ or gland) responds.

The result of the quadriceps reflex arc is to tend to keep the quadriceps muscle in whatever state of contraction it is put in. If you are standing and your knee starts to bend, the quadriceps muscle will extend. And the extension stimulates the sensory neuron to send more impulses to the spinal cord. These will be picked up by the motor neuron and cause it to send more impulses back to the muscle. The muscle will then contract to straighten the leg.

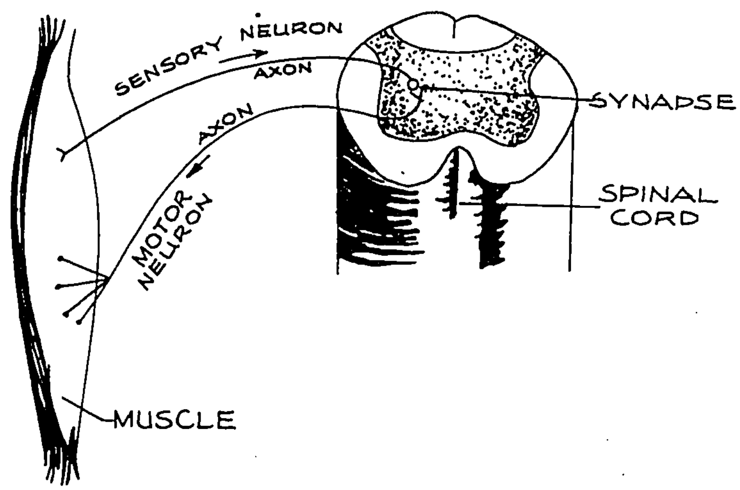


FIGURE 2: Schematic representation of a reflex arc. (Note: The sizes of parts of the diagram are not in correct proportion. Also, this is a simple reflex arc--most other arcs are more complicated.)

There are several ways in which the brain may influence reflex actions. The commonest is by influencing what goes on at the synapses in the reflex arc. (Recall that the synapse is the region between the terminal of one neuron and the dendrite of the next.) The transfer of an impulse across a synapse may be either excited or inhibited (helped or hindered). And this is where the brain enters the picture. In the typical reflex, the brain inhibits the impulse. This gives the brain a means of adjusting the reflex. By changing the degree of inhibition, it may cause the motor neuron to respond more strongly or more weakly to the sensory neuron.

In this way, the brain may adjust the tension of one or more muscles to match a different posture.

Because the brain inhibits most reflexes, brain damage often results in stronger-than-normal reflexes in some area of the body. The reflex arc is left to perform its function with little or no inhibition from the brain. Note again the reflex chart for the woman in the case history.

5-3 Multiple Sclerosis: Disease With No Known Cure

How do the symptoms of multiple sclerosis come about? Why do they often go away?

Although abnormal reflexes suggested to the doctor that her patient might have multiple sclerosis, they were hardly proof. Any disease that destroys or incapacitates a portion of the central nervous system or other nerves may affect one or more of the body's many reflexes.

The cause of MS is not understood, and there is no cure. The disease involves degeneration of the outer parts of neurons (the parts that carry neural impulses), eventually making them stop doing their job. MS may attack various parts of the nervous system in the same individual. It may result in paralysis, blindness, speech impairment, poorly coordinated movements, and other motor and sensory difficulties.

A typical characteristic of MS, at least in its early stages, is spontaneous remission--apparent recovery without treatment. MS usually proceeds so slowly that other neurons have time to take over the function of any disabled neuron before another one meets the same fate. Such compensation explains the remissions.

But the degeneration of neurons eventually becomes so widespread that remission becomes impossible. Most "wheelchair cases" not caused by injury are caused by multiple sclerosis. Eventually the patient becomes bedridden and helpless.

A distinguishing feature of MS is found in the spinal fluid of most patients. As we discussed in the unit on the circulatory system, gamma globulins are proteins that are associated with antibodies and immunity. MS patients often have an abnormally high concentration of gamma globulin in their spinal fluid. This suggests that multiple sclerosis may be in some way related to a malfunction of the immune system, or may be a response to an infecting agent such as a virus.

Review the case history. What symptoms indicate a nervous-system disorder? What was abnormal about the patient's reflexes? Why did the symptoms spontaneously disappear (remission) and reappear?

Give three examples of reflexes.

What are some valuable services performed by reflex actions?

Describe the path of the nerve impulses in the quadriceps reflex.

How does the brain adjust the strength of a reflex?

Vocabulary:

motor neuron--a neuron that terminates in a muscle; it is stimulated to fire either by a sensory neuron (in the central nervous system) or by another motor neuron (from the central nervous system).

multiple sclerosis (skleh-ROW-sis)--a disease involving degeneration of the impulse-conducting parts of neurons.

plantar (PLAN-tar)--relating to the sole of the foot.

plantar response--curling the toes downward in response to stroking the sole of the foot from the heel to the little toe.

reflex arc--the circuit traveled by the sensory and motor impulses that produce a reflex action.

remission (re-MISH-un)--disappearance of symptoms.

sensory neuron--a neuron that responds to initial stimuli, causing impulses to travel to the central nervous system.

SECTION 6: CEREBRAL HEMORRHAGE AND HEAD INJURIES

6-1 Case History: Male, Age 61

"This 61-year-old retired, male appliance salesman was admitted to the hospital because of unconsciousness, possibly of several hours' duration," recited the doctor, as he began tape recording the case history for transcription later. If any diagnosis was routine, this one had seemed to be. The patient had had high blood pressure for years. "Blood pressures as high as 180/110 were frequently recorded and were relatively unresponsive to increasing medication," he noted.

Some dramatic effect of the high blood pressure seemed inevitable, and now it had happened. "Shortly before hospital entry, the patient was found unconscious in the bathroom. His wife found him upon returning home after an absence of several hours. She called an ambulance and arrangements were made for immediate hospital admission." And now, hours later, the patient lay in a coma in the intensive care ward, "prognosis...very guarded."

The doctor made routine tests. The patient's blood pressure was now very high, at 205/120, and the doctor saw more evidence of hypertension when he used an ophthalmoscope to study the blood vessels visible inside the patient's eyeballs. The doctor also noted "a slight blurring of the optic disks"--those regions in the back of the eyeballs where the optic nerves attach--which pointed to abnormally high pressure inside the skull.

He had tested some of the patient's reflexes and found abnormalities there, too. "There are some muscle reflex differences," he dictated, "with all reflexes being slightly more active on the right side than on the left." The patient, it seemed certain, had suffered some sort of localized brain damage. In view of his history, the best guess was a cerebral hemorrhage--a burst blood vessel in the brain that had damaged some part of the brain.

The diagnosis of cerebral hemorrhage was confirmed the next day by a lab test of a sample of spinal fluid drawn from the lower part of the patient's spine. Noted the doctor, "...the spinal fluid--was slightly bloody."

With the conclusion that the patient had suffered a cerebral hemorrhage, the doctor's active involvement in the case was largely over. The patient would remain under intensive care "at least until vital signs stabilize." Routine tests would be made to determine whether surgery was indicated. Ending his report, the doctor noted: "...and so a neurosurgical consultation will be obtained as soon as possible."

(The doctor's full report is included at the end of this section.)

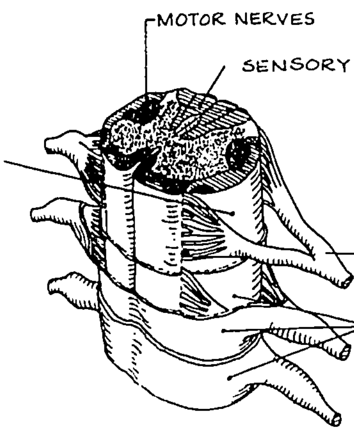
6-2 Cerebrospinal Fluid

What is cerebrospinal fluid? What is its function?

Cerebrospinal fluid (CSF) is produced within the brain, surrounds the brain and spinal cord with a "water bath" and serves primarily to prevent the brain from being damaged by blows to the head. (Recall that the skull also performs this function.)

Most of the CSF is produced inside the large cavities in the brain, called ventricles. (The ventricles of the heart are also large cavities.) CSF is produced by the flow of water, oxygen and nutrients across the walls of blood vessels inside the ventricles. CSF fills the ventricles, and it also fills a space between two of the meninges that surround the brain and spinal cord.

The meninges are three layers of membrane that completely enclose the brain and spinal cord. In the head, the outer membrane is connected directly to the skull and follows its shape. The middle membrane follows the shape of the outer one, and is separated from it only by a very thin layer of fluid. The inner membrane, however, follows the shape of the brain rather than the skull. The space between the middle and inner membranes contains many nerves and blood vessels which connect the two layers of membrane and which hold the brain in position in the skull. In addition to this suspension system, the space between the middle and inner membranes is filled with CSF. CSF thus surrounds the brain (and the spinal cord), providing a "water bath" in which the brain literally floats. When a blow is delivered to the head, the CSF allows the brain to move, deform and rebound without directly absorbing the force of the blow.



CSF is not the same as the interstitial fluid (IF) of the brain, although it is similar to the IF in composition. The IF of the brain is itself different from the IF in other parts of the body. The neurons in the brain require a highly specialized environment--rich in oxygen and glucose, but poor in many other substances found in IF in other organs--and this environment is maintained by a complex system called the blood-brain barrier. The blood brain-barrier is a combination of membranes, diffusion processes and active-transport processes, all of which work together to control the exchange of substances between the blood and the brain's IF. The main difference between this exchange in the brain and the exchange that takes place in other organs is that in the brain there are few substances that can easily be exchanged. The blood-brain barrier controls the contents of the CSF as well as the contents of the IF in the brain.

In a normal, healthy person, the blood-brain barrier maintains fairly constant concentrations of various substances in the CSF. However, the blood-brain barrier may break down at any point in the brain where there is infection or a tumor, and at such a point it is possible for substances to leak into the CSF which would not normally be found there. In addition, a blood vessel in the brain which is damaged or destroyed may leak red blood cells and other substances into the CSF. So the presence of unusual substances in the CSF is an indicator of disease processes in the brain.

When it is desirable to take a sample of CSF for analysis, the sample is drawn from the lower spinal region by a process called a spinal tap. Because CSF for analysis is normally taken from spaces between the meninges that surround the spine, the CSF is commonly called "spinal fluid." However, the fluid drawn from the spinal region is the same as the fluid that fills the ventricles in the brain and surrounds the space between the middle and inner meninges of the brain.

6-3 Diagnosis by Spinal Tap

How is spinal fluid used in diagnosis?

Abnormalities of the cerebrospinal fluid can often be used as diagnostic clues. When a blood vessel supplying the brain is ruptured by injury the blood-brain barrier is broken. Some of the blood from the ruptured vessel leaks into the cerebrospinal fluid. So the presence of red blood cells in the CSF is common in cases of cerebral hemorrhage.

The fluid may also provide other clues to disease. As we mentioned in Section 5, the appearance of gamma globulin in cerebrospinal fluid may suggest multiple sclerosis. And some brain diseases--including cerebral hemorrhage--may cause an increase in the protein concentration of the cerebrospinal fluid. With cerebral hemorrhage, the cause of the increased protein is obvious: the proteins come from the blood that has leaked through the gap in the blood-brain barrier.

6-4 Cerebral Hemorrhage

What causes cerebral hemorrhage? How does it damage the brain?

A cerebral hemorrhage may happen for any of several reasons. An injury may rupture (burst) a blood vessel of the brain and cause a cerebral hemorrhage. A disease may weaken arterial walls until they are no longer strong enough to contain the blood. Or a person may be born with a weak spot in an artery wall that finally gives way after many years.

But the most common cause of cerebral hemorrhage is hypertension--an abnormally high blood pressure. Recall the concern with high blood pressure in the case history. Most blood vessels can stand rather high pressure for a limited time. But if the pressure remains high for a matter of years, the constant overstressing of the blood vessels is likely to weaken and eventually rupture one or another of them.

A cerebral hemorrhage is one form of stroke. It occurs quickly, often triggered by momentary stress, either physical or emotional. Such a stroke is therefore least likely to happen when a person is relaxed or asleep.

A cerebral hemorrhage usually brings on a coma lasting from several hours to several days and often results in death. The damage comes both from a lack of blood supply to some parts of the brain and from damage to the neurons that come into contact with the leaking blood. Recovery, if it occurs, takes several weeks or more, and may be incomplete.

6-5 Head Injuries

How do head injuries affect the brain?

We have noted that cerebral hemorrhage is sometimes the result of injuries to the head. Such injuries are often fatal. But head injuries can have other effects on the brain and they deserve special emphasis. In an age of high-speed travel, head injuries have become all too common. Fortunately, our skulls and our CSF "suspension systems" protect our brains in many cases of head injury.

Many head injuries are minor and have no lasting effect. They may temporarily stun or daze an individual, but leave no permanent damage. However, injuries to the head leading to unconsciousness that lasts for more than a few minutes are of genuine concern. Such injuries may result in permanent brain damage, causing severe headaches, dizziness or even paralysis. Some forms of epilepsy are caused by head injuries.

In cases of head injury that are more than minor, a physician should be consulted. A complete neurological examination is called for, and may include the EEG, reflex tests, skull X-rays and a spinal tap.

Why are spinal taps used?

What other tests might you request if you had a patient that you suspected had a cerebral hemorrhage? What tests would you request if the patient had just had a severe fall and landed on his head?

What are some functions of cerebrospinal fluid in the body?

What is the major cause of cerebral hemorrhage?

What are some possible effects of head injury?

Vocabulary:

blood-brain barrier--the complex system of membranes, diffusion processes and active-transport processes that controls the exchange of substances between the blood and the brain's interstitial fluid.

cerebral hemorrhage--a rupturing (bursting) of a blood vessel in the brain.

cerebrospinal--pertaining to the brain and spinal cord.

cerebrospinal fluid (CSF)--the fluid that fills the ventricles (cavities) in the brain and the space between the inner and middle meninges. Exchange of substances between the blood and the CSF is controlled by the blood-brain barrier.

meninges (meh-NIN-jeez)--the three membranes that surround the brain and spinal cord. "Meninges" is the plural of "meninx."

spinal tap--removal of a sample of cerebrospinal fluid from the lower part of the spine.

stroke--an event affecting the brain resulting from impairment of circulation to a part of the brain; often referred to as a cerebrovascular accident. Cerebral hemorrhage is one type of stroke.

ventricle--a large cavity in the brain.

PRESENT ILLNESS (as recorded in the patient's chart)

This 61-year-old retired, male appliance salesman was admitted to the hospital because of unconsciousness, possibly of several hours duration.

This patient has been under my care for approximately 10 years. When I first saw him at approximately age 51 he had just moved to this area from another part of the state. He had already been under treatment for hypertension for approximately six or seven years. When I first saw him his blood pressure was in the 160/100 range. He had never had a complete hypertensive workup, so this was carried out. However, no cause for the hypertension could be found, and he was handled as a case of essential hypertension. Following a period of strict weight control, salt restriction, and Thiazide medication, he improved substantially and averaged blood pressure readings of 145/90 over the next few years. His electrocardiogram showed a mild left ventricular hypertrophy pattern. He had no urine abnormalities and no urinary symptoms. However, about four years ago his hypertension became much less easy to control. Blood pressures as high as 180/110 were frequently recorded and were relatively unresponsive to increasing medication. Aldomet was of only slight benefit. He seemed to develop minor mental changes, particularly loss of recent memory, and about a year ago he retired from work.

For the past few years the patient's condition has remained substantially the same. Blood pressures have continued in the 180/110 range in spite of a variety of medications. Weight control has been difficult because he has been so inactive recently. There has also been a general defeatist attitude on the part of his family, and I'm not sure that diet and medication schedules have been closely adhered to.

Shortly before hospital entry, the patient was found totally unconscious in the bathroom. His wife found him upon returning home after an absence of several hours. She called an ambulance and arrangements were made for immediate hospital admission.

PAST HISTORY

His medical history does not appear especially remarkable except as noted above. He had an appendectomy 21 years ago, uncomplicated. Six years ago he had mild pneumonia which cleared promptly on administration of antibiotics.

FAMILY HISTORY

His father died of a heart attack, aged 65, and his mother apparently lived past 80, cause of death unknown. Two brothers and one sister are living and well, although one brother is reported to have moderate hypertension.

PHYSICAL EXAMINATION

The patient is completely comatose, with somewhat irregular noisy breathing, and generally appears older than stated age of 61. Blood pressure 205/120, pulse 84, respiration 20, irregular. The ocular fundi show grade 2 hypertensive changes and there appears to be a slight blurring of the optic discs. He is slightly sweaty. A few scattered tracheal rales are heard. The heart is enlarged about 2 cm to the left and the aortic second sound is definitely accentuated. The abdomen is a little obese but no definite abnormalities are present. The extremities are fairly well muscled. Foot vessel pulsations are diminished bilaterally but present.

NEUROLOGICAL EXAMINATION

He is completely comatose and cannot be roused, even by painful stimuli. It is uncertain whether paralysis is present because, due to coma, neither side moves spontaneously. There are some deep-muscle reflex differences, with all reflexes being slightly more active on the right side than on the left. A right Babinski reflex is present. Sensory exam was not carried out because of coma.

A spinal tap was done on entry, with the spinal fluid slightly increased in pressure and slightly bloody. The specimen was sent to the lab for further study.

IMPRESSIONS

1. Cerebral hemorrhage, massive.
2. Background of long-standing essential hypertension, with known left ventricular hypertrophy.

PLAN

Patient is critically ill, and prognosis appears very guarded. He will remain in intensive care, at least until vital signs stabilize. Routine CVA work-up is planned. The possibility exists that a neurosurgical approach may be helpful, and so a neurosurgical consultation will be obtained as soon as possible.

NOTES

1. Moderate to severe hypertension almost always culminates in critical damage to some vital organ, usually the heart, kidneys or brain.

2. Hypertension is best treated early, when regular medical treatment seems to have the most beneficial effect. Long-standing hypertension is often quite unresponsive to treatment. "Essential hypertension" is hypertension that cannot be traced to a known cause such as kidney disease.

3. It is not unusual for a patient with hypertension to develop still higher blood pressure after a cerebral hemorrhage.

4. Following the initial work-up on a hospital patient, especially when critically ill, there are usually daily follow-up notes indicating the patient's general condition and improvement, if any. Results of key tests are also noted. At the time of discharge, a brief summary is prepared, which consists of an abstract of the entry history along with pertinent physical findings, changes in physical findings, the final outcome and the results of principal laboratory, X-ray and other important tests. Any special medications are also listed. Finally, there is a list of discharge diagnoses in descending order of current importance.

SECTION 7: CEREBRAL THROMBOSIS AND PSYCHOMETRIC TESTING

7-1 Case History: Female, Age 56

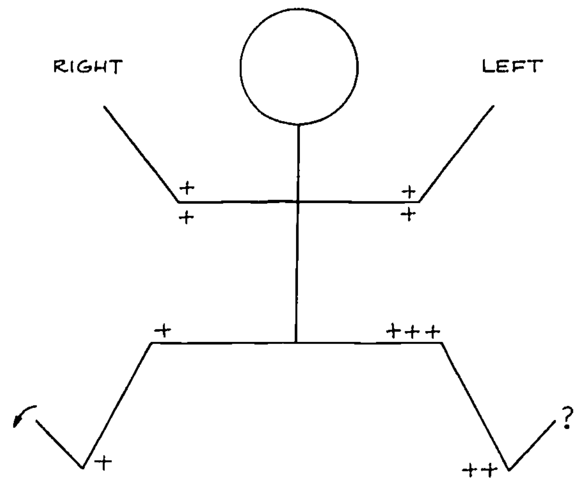
The patient was a 56-year-old accountant complaining that she had trouble walking and that her left arm felt weak.

The history, reconstructed with her husband's help, seemed like this.

About two years ago her memory seemed to fail. Usually sharp with figures, she began to have trouble with complex calculations, and her firm changed her work to doing simpler things. About three months ago, she had "dizzy spells" and began losing time at work because she "didn't feel well." There was even talk of medical retirement.

The present problem started very recently One night, she went to bed early, just saying she "didn't feel well." When she tried to get out of bed the next morning, she fell to the floor. She could barely stand with someone helping her, and it was obvious that the grip in her left hand was almost lacking.

The doctor's examination notes are as follows: blood pressure--150/95 (the doctor had seen the patient three years before and had noted that her "BP" was only 125/85 then). Seems drowsy but knows place and person. There is marked weakness of the entire left side. The reflex stick figure looked like this. (This indicates that the knee and ankle reflexes were more active on the left than on the right, and that the plantar response was normal on the right but uncertain on the left.)



"We need you in a hospital for further testing."

After a week, further data had been obtained. Blood cholesterol and glucose were elevated. The skull X-rays appeared normal. The spinal fluid showed only a "slight increase in protein." The EEG showed "some abnormal activity over the right side, poorly localized." Visual field testing showed slight impairment in both eyes. The tests confirmed a diagnosis of cerebral thrombosis.

After a week, the patient was much improved and could walk unaided. Her left-hand grip was still rather weak but she could use it to hold a fork, etc.

Notes:

1. Most cases of cerebral thrombosis are preceded by symptoms related to reduced blood circulation in the brain. The commonest type of "stroke" involves thrombosis of the middle cerebral artery and causes the findings noted above.

2. Strokes are more common in people with hypertension.

3. Exaggerated reflexes are present in most cases of stroke. It may take days for these changes to develop.

4. Elevated blood glucose indicates that diabetes was also probably present. Strokes before the age of 60 are often related to diabetes, which may cause early atherosclerosis.

5. Recovery in milder cases of cerebral thrombosis is often complete in a few weeks. However, the basic problem remains and recurring strokes are the rule--usually with progressive loss of brain function. Apparently the patient had at least one stroke before this incident.

6. Treatment for stroke of this type is usually "supportive"--that is, a complete cure is not possible. Diabetes, if present, is treated. Physical therapy is often necessary. When paralysis remains, a short leg brace is used to maintain stability at the knee and ankle.

Weight, dietary and blood pressure control are important in reducing the risk of future strokes. These are examples of "preventive" rather than "supportive" treatment.

7-2 Measuring the Mind

What kinds of mental tests are useful in diagnosing brain damage?

Because the patient had been an accountant, some diagnostic "tests" that were useful to the doctor had already been made by accident. Strokes such as the patient had experienced often disrupt the ability to deal with abstract ideas or calculations. Since complex calculations were part of the accountant's job, her ability in that area was tested almost daily.

Just what mental abilities are impaired may often give clues to the location of brain damage. And, of course, the type of impairment may indicate what sort of therapy may be used to help recover the lost functions. Recovery, to one extent or another, is often possible because other parts of the brain take over the functions of the damaged section.

One set of tests used to check for and perhaps locate brain damage is the Halstead-Reitan series. These tests include the following.

1. Category: The patient sorts out objects by size, shape or some other abstract notion.

2. Tactile Performance: (Tactile refers to the sense or touch.) The patient, blindfolded, places blocks of different shapes into corresponding holes on a board. He is timed using each hand separately and then using both together. Finally, he is tested on his memory of the shapes and their location on the board.

3. Rhythm: The patient attempts to distinguish between different rhythmic beats.

4. Speech-Sounds Perception: The patient matches spoken nonsense words with the same words in print.

5. Time-Sense: The patient estimates the length of a period of time.

6. Trail-making: The patient follows a numbered sequence drawn on a page, as in a dot-to-dot picturebook exercise.

7. Aphasia: (Aphasia is a partial or complete loss of the ability to understand and use words to express ideas. It is caused by damage in the cerebral cortex.) This test determines whether the patient has difficulty saying words which are part of his normal vocabulary.

8. The Wechsler Adult Intelligence Scale: This is a test of general intelligence.

9. The Minnesota Multiphasic Personality Inventory: In this personality test, the subject answers some 550 questions about himself, his physical conditions and attitudes. All of these kinds of tests usually go under the name of psychometric tests. They may disclose defects in the brain which might be overlooked in physical tests.

Of course, one problem in interpreting the results of psychometric testing is determining whether a patient has lost an ability or never had it. The non-reader, for example, will fail the speech-sounds perception test even without brain damage.

7-3 What Other Tests Are Used to Diagnose Brain Damage?

The conscious functioning of the mind can be tested in other areas besides abstract thinking. The ability of the mind to direct the motions of various parts of the body may be a clue to brain damage. If a person can no longer move a particular muscle, often it is possible to establish which nerves in the brain or spinal cord are damaged.

Actual paralysis, a common result of a stroke, is easy enough to recognize. An arm or leg that won't function, a facial muscle that has been damaged--such defects are detectible without special tests.

But minor loss of muscle control or coordination may go unnoticed without testing. The traditional test for drunkenness--walking a straight line--may also reveal more lasting brain deficiencies in a sober stroke victim. This is known as a coordination test. Other areas of coordination may be tested by tasks such as bringing the finger to the nose or moving the eyes to the right or the left. As with psychometric tests, a series of coordination tests may be used to uncover various deficiencies in muscle control.

7-4 Cerebral Thrombosis: A Disease of Old Arteries

What is cerebral thrombosis? How is it caused?

The patient's problem, cerebral thrombosis, is caused by the formation of a blood clot--a thrombus--in one or more blood vessels of the brain. Deprived of blood, a portion of the brain then dies. Although some sites are more common than others, a clot may form in a great variety of places, giving a great variety of symptoms.

The usual cause of cerebral thrombosis is atherosclerosis--the build-up of fatty deposits on artery walls. Where build-up is large, the blood flow may be slowed so much that the blood clots, blocking flow completely.

Cerebral thrombosis is usually considered a disease of old age. But some conditions--notably diabetes--may speed the build-up of deposits on the artery walls and give "old" arteries to middle-aged people.

While strokes caused by cerebral hemorrhage are often very severe, strokes caused by cerebral thrombosis may range from quite minor episodes that do no more than incapacitate the patient for a short time, to occasional death-dealing blows. Typically, a cerebral thrombosis victim will survive the experience with some physical or mental deficiency--or both.

Physical therapy, speech therapy and other forms of therapy may do much to return a stroke patient to normal or near-normal functioning. But if the thrombosis resulted from atherosclerosis, the cause can't be removed. Further strokes will probably occur, although they may be long delayed. Careful attention to the diet and lifestyle can contribute to the length and quality of life of stroke survivors.

What is the difference between cerebral thrombosis and cerebral hemorrhage? Which is generally more serious?

What are some symptoms of cerebral thrombosis?

Give some examples of psychometric tests.

How can impaired coordination be tested for?

Vocabulary:

aphasia (uh-FAY-zhuh)--the loss or partial loss in the ability to comprehend and use words to express ideas.

cerebral thrombosis--formation of a blood clot (thrombus) within a blood vessel in the brain.

psychometric (SI-ko-MET-rik)--pertaining to the measurement of mental functions.

tactile (TACK-tull)--referring to the sense of touch.

SECTION 8: BRAIN TUMORS

8-1 Case History: Male, Age 46

The patient was a 46-year-old car salesman who complained of headaches and poor vision for several months. The examining doctor quickly noted several things. The salesman had had ordinary "tension" headaches very frequently, but they usually went away following rest and relaxation. The recent headaches seemed to come on after sleeping; also, two aspirin didn't help much. The visual disturbance was also unusual. "I see well right in front of me but both sides seem dim."

Past history didn't seem pertinent. The patient had had problems with ulcers and obesity, but these were currently under control.

The doctor's exam notes: Seems a little anxious. BP 130/80. No obvious visual deficits, visual fields to be done later. The optic-disk margins may be a little blurred. Cranial nerves all okay. Strength and coordination normal. Sensory exam normal. Reflexes normal.

"We'll need you in the hospital for a few days of testing," the doctor concluded.

Results of the next week:

Skull X-rays: the bones near the pituitary slightly eroded

Spinal fluid: protein definitely increased and the fluid is under increased pressure

EEG: normal

Visual fields: considerable deficits were noted for each eye; visual acuity was 20/25 in each eye

The attending physician quickly arranged for a neurological consultation. It was readily apparent that, with high spinal-fluid pressure and increased protein, along with marked visual-field changes and probable X-ray changes, a brain tumor was present--probably near the pituitary.

Notes:

1. The symptoms for brain tumor vary, depending on the site of the tumor. This case involves a pituitary tumor. Pituitary tumors account for about 10 per cent of all brain tumors and are usually benign (noncancerous). Surgery or X-ray treatment is usually effective if done early enough.

2. The headache, due to increased pressure inside the skull, is usually different from common types of headaches.

3. When extensive, a pituitary tumor causes a loss in both visual fields. (The visual field is the area that can be seen with one eye when it is focused on a particular spot.)

4. The early symptoms of brain tumor are usually very slight and hard to detect. The symptoms tend to develop gradually. Fortunately, about 50 per cent of brain tumors are benign and early recognition results in a successful outcome.

8-2 Diagnosis of Brain Disorders by Eye Examination

What is the purpose of visual-field testing?

The eyes have been described as mirrors of the soul. A doctor looking into their depths with an ophthalmoscope or exploring their performance in an eye test hardly has the soul in mind. But he may often see clues that are reflections of medical problems. We have already seen that observations of the arteries in the eye may be useful in diagnosing cerebral hemorrhage and hypertension.

One clue to brain damage is some change in the visual field of one or both eyes. The patient in the case history, who had a pituitary tumor, lost his vision in the outer portion of the field of vision of each eye. In other words, the area that he could see with either eye at any one time was smaller than normal.

How does this decrease, or deficit, in the patient's visual fields relate to the pituitary tumor? Light enters the eye through a central hole, the pupil (the little black circle in your eye). The light then falls on a layer of tissue on the inside of the back of the eyeball, called the retina (Figure 1). Nerve endings in the retina sense the light and respond to it with nerve impulses. These impulses are carried by neurons in the optic nerve to the region at the back of the brain in which the impulses are interpreted and experienced as "seeing." The optic nerves are long, and they pass through many parts of the brain. An abnormality in any of these parts of the brain--such as a pituitary tumor--may interfere with the transmission of impulses to the back of the brain, with the result that the person who has the tumor does not "see" everything that his retinas sense. In the case history, the patient's tumor interfered with the transmission of impulses in such a way that the outer portion of each field of vision became dim.

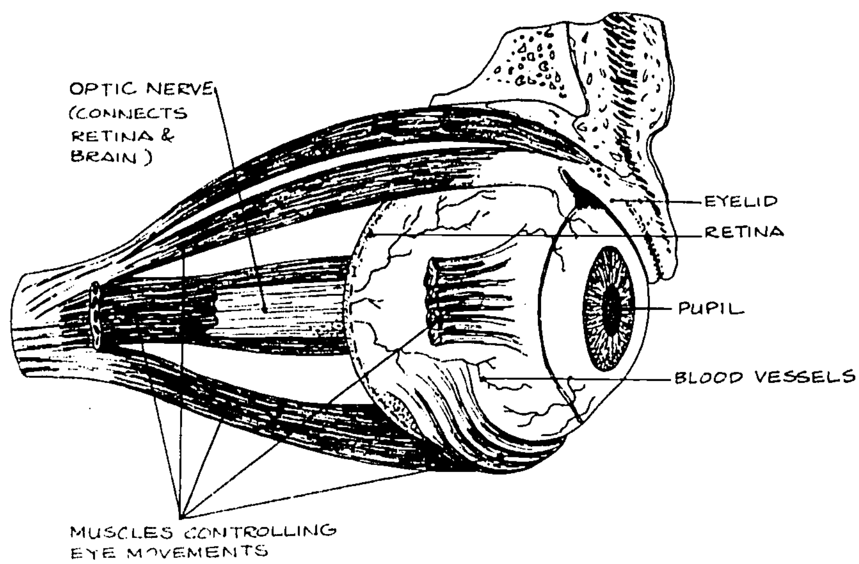


FIGURE 1: Side view of the eye.

Many other visual-field defects may also occur. Various parts of the field of one eye or both eyes may be wiped out. Each defect may point to a different area of the brain, and so may give the doctor great help in deciding where the problem lies.

A defect in the visual fields is not necessarily caused by a tumor. Destruction of a portion of the brain by a stroke or by multiple sclerosis may also affect the visual fields, as may diseases of the eye such as glaucoma.

8-3 The Eye and Intracranial Pressure

How can an eye examination reveal high pressure inside the head?

The eye can also provide clues for the diagnosis of other diseases that occur inside the brain. Normally the optic disk, the region where the optic nerve leaves the back of the eyeball, has a well-defined edge (Figure 2). However, the appearance of the optic disk can be affected by intracranial pressure, the pressure inside the head. When this pressure increases, the optic nerve is squeezed by the tissues and fluids that surround it. One consequence of this squeezing is that the optic nerve pushes forward on the optic disk, which then protrudes into the eyeball. When this has happened, the outer edge of the optic disk no longer appears sharp, but instead looks fuzzy.

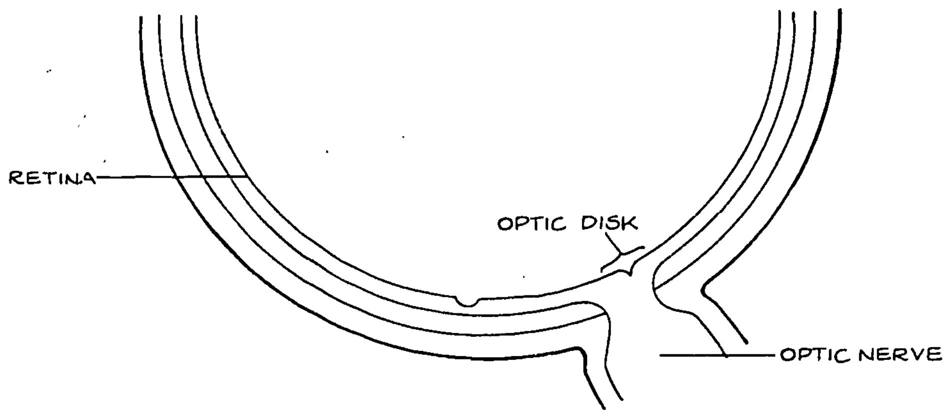


FIGURE 2: Back of the eyeball.

High intracranial pressure may be caused by any of several conditions. Sometimes it is caused by an increase in the pressure of the CSF. Sometimes the pressure of the CSF increases because something obstructs the flow of CSF from the ventricles, to the space between the middle and the inner meninges, and back to the bloodstream. CSF keeps being produced inside the ventricles no matter how high the intracranial pressure. Therefore, if the CSF is not able to flow to the region of the brain where it re-enters the bloodstream, the pressure of the CSF gradually increases. One thing that may obstruct the flow of CSF is a tumor inside the brain. The intracranial pressure may also be increased by a cerebral hemorrhage that leaks blood under high pressure into the brain.

8-4 X-Rays, Ultrasound and Brain Tumors

Why do only some brain tumors show up on X-rays? How else may the presence of brain tumors be demonstrated?

An obvious way to discover a tumor, it might seem, is to take a skull X-ray. But often a good-sized tumor can go undetected in such a test. X-rays are strongly absorbed by bony tissue, but they pass rather easily through soft tissue, whether brain or tumor.

In a skull X-ray, the beams must first penetrate the bony skull, which makes picturing what's inside difficult to start with. About all that can be seen, as a rule, is any change in a few bony structures within the skull, or any tumors that contain calcium deposits.

Since the pituitary gland happens to be located in a bony structure, tumors nearby may often displace or damage that bone, and so be discovered by X-rays.

If a brain tumor is suspected and skull X-rays are normal, other X-ray studies may be done. A common one is a cerebral angiogram, which involves injecting into the arteries serving the brain a fluid that shows up on X-rays. High-speed X-ray photographs are taken of the fluid as it moves through the arteries. This technique may reveal the location of a tumor, since tumors often press against arteries within the brain, thus changing their shape.

Brain scanning is a new X-ray technique (actually a rediscovered method) that is making possible the study of the internal structure of the patient's brain (and other organs). One variation of this technique mathematically combines numerous X-rays of the brain taken from a series of different angles. The combined X-ray that is produced shows more detail than conventional X-rays. As a result, it should be possible to detect some tumors that would go undetected by conventional X-rays.

Another technique that is sometimes useful in diagnosis of brain disorders involves sound that we can't hear. The human ear can sense sounds only in a certain range of pitches. But there are sounds of extemely high pitch that can be produced electronically which we cannot hear. Such sound is known as ultrasound. Ultrasound can be passed through a person. As ultrasound passes through the skull, some of the sound will bounce back as an echo. These echoes can be detected by instruments and recorded in an echoencephalogram. Figure 3 shows an echoencephalogram of a normal head. In this figure, the heights of the three peaks indicate the "loudness" of the three echos. The large peak corresponds to ultrasound being reflected from the skull bone without entering the brain. The echo peak on the right results from ultrasound reflecting from the skull bone on the far side of the head. The cause of the midline peak is not agreed upon by specialists. Yet the position of the midline peak is very significant in diagnosis of brain disorders. Compare Figure 3 and Figure 4. In the latter the midline peak has been significantly displaced. This displacement may indicate that the patient has a brain tumor, cerebral hemorrhage or some other brain disorder. At the same time, the pattern shown in Figure 4 rules out some brain disorders, such as cerebral thrombosis, epilepsy and multiple sclerosis.

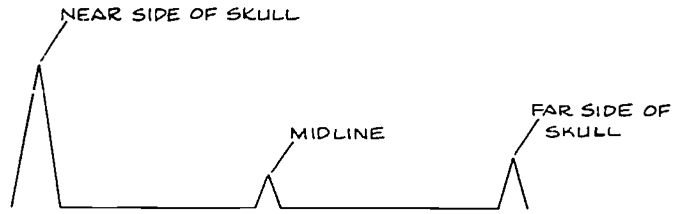


FIGURE 3: Echoencephalogram of normal head.

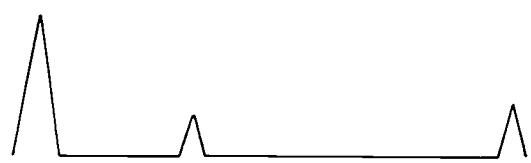


FIGURE 4: Echoencephalogram with midline shift characteristic of some brain disorders.

8-5 Brain Tumor: A Chance for Life or Death

What is the prognosis for brain tumor? What factors affect the outcome?

The tumor of the patient in the case history was benign, as most pituitary tumors are. It was successfully removed by surgery.

Brain tumors may be of various sorts as well as in various locations. Some invade the brain tissue in such a way that a surgeon can't remove them without removing a sizable portion of the brain as well. Others may form distinct pockets of tumorous material that can be removed without much brain destruction.

Although the cause of a tumor is often unknown, in some cases it may have an obvious origin. For example, brain hemorrhage, caused either by atherosclerotic breakdown of a blood vessel or by an injury, may sometimes start a hematoma, a benign tumor consisting of an accumulation of blood, usually clotted.

Which symptoms in the case history led to a diagnosis of brain tumor? How does a tumor produce these symptoms?

What can an eye examination reveal about brain disorders in general?

Trace the progress of a light beam from the time it enters the eyes to the time it has been converted into nerve impulses. What eye structures are involved?

How can high pressure of CSF be demonstrated by use of an ophthalmoscope?

How are X-rays and echoencephalography used in diagnosing brain disorders?

How can brain tumors be treated?

Vocabulary:

echoencephalogram--the data output representing echoes obtained by passing ultrasound through the brain.

hematoma (HEE-muh-TOE-muh)--a tumor consisting of a mass of blood that has collected, usually in a clot.

ophthalmoscope (off-THAL-muh-skope)--a device for examining the interior of the eye; it is especially useful for examining the optic disk and the blood vessels in the back of the eye.

optic disk--a circular area in the eyeball where the retina connects to the optic nerve

retina (RET-uh-nuh)--the layer of tissue in the back of the eyeball that receives light entering the eye.

ultrasound--very high-pitched sound which cannot be heard by the human ear.

visual field--the area that can be seen with one eye when it is focused on a particular point.

REVIEW SET 8:

1. In the first five statements, certain words are underlined. If the statement is true, write "true" on a separate sheet of paper as your answer. If the statement is false, write the word or words that will replace the underlined word(s) to make the statement correct.

EXAMPLE: The junction between two neurons is called an impulse.

ANSWER: synapse

1. The part of the brain that controls important functions such as digestion and the heart rate is the cerebellum.

2. A person partially paralyzed by a stroke probably has severe atherosclerosis in a blood vessel supplying his or her medulla.

3. The central nervous system consists of the brain and spinal cord.

4. For a neuron to produce an impulse, the neuron first takes on an amount of charge greater than a certain minimum value. This value is called the threshold.

5. One neuron can stimulate another to produce a nerve impulse by secreting a chemical called a receptor.

6. Match each type of brain wave with the condition under which it is most likely to appear:

alpha waves	a relaxed state of mind
beta waves	sleep when not dreaming
delta waves	ordinary thinking, sleep during dreaming

7. Choose the phrase in the parentheses to make the statement correct: One theory of epilepsy is that certain neurons in the epileptic brain fire impulses (more easily, less easily) than they should, and these impulses cause convulsions.

8. Briefly describe how biofeedback training could be used to help someone with high blood pressure to lower his or her pressure.

9. Label each of the following activities "sympathetic" or "parasympathetic," according to the branch of the autonomic nervous system that controls the activity.

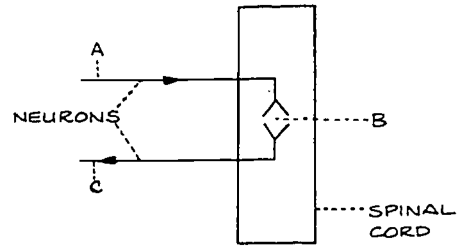
a. an increase in peristalsis after eating.

b. a slowing of the heart rate during rest.

c. an increase in the heart rate during excercise.

d. a widening of the arterioles in muscles during running.

10. Consider the hypothetical reflex arc shown schematically in the diagram. Match each letter in the diagram to the correct term from the following list?



synapse

axon of motor neuron

axon of sensory neuron

11. What is the difference between cerebral hemorrhage and cerebral thrombosis?

12. List at least three tests performed on CSF. What disease might each test indicate?

13. List two or three examples of psychometric tests. How are psychometric tests used in diagnosis of brain diseases?

14. How can an opthalmoscope be used to diagnose a brain disorder? What other devices or instruments might aid in the diagnosis of a brain disorder?

15. Suggest a likely diagnosis based on the hypothetical case histories below.

a. The patient was found unconscious but there was no sign of external damage or bleeding. The optic disks were slightly blurred. A spinal tap revealed blood cells in the CSF.

b. The patient complained of severe headaches that were not relieved by taking aspirin. The CSF showed a high protein concentration and no blood cells. The skull X-ray seemed slightly distorted and echoencephalography revealed a shifted midline.

SECTION 9: DIAGNOSIS OF BRAIN DISEASE

9-1 How Would You Diagnose a Brain Disease?

Suppose you are a physician confronted with a patient who may have one of the brain diseases we have emphasized: epilepsy, multiple sclerosis*, cerebral hemorrhage, cerebral thrombosis or a brain tumor. Which one is it--if any? How would you go about answering this question?

The first thing you would probably do before attempting to make a diagnosis is to collect as much information on the patient's medical history and symptoms as possible.

The term symptom comes up frequently in any discussion of the diagnosis of disease. A sore throat, a headache and nausea are all symptoms. Symptoms involve what the patient *feels* or senses about his or her body and describes to the examining physician. Symptoms often involve discomfort or pain, but they need not. For example, a patient may describe a tingling feeling to an examiner. Even though the sensation is not unpleasant, it is classed as a symptom because it is a subjective feeling of the patient.

*For the purpose of this and the following four sections and activities, we will class multiple sclerosis as a brain disorder, although it might be described more generally as a disease of the nervous system.

There are other kinds of clues besides symptoms that a physician uses in identifying disease. For example, the physician may detect a redness of the throat, an enlarged liver or an abnormal reflex. These clues generally are discovered by the physician rather than by the patient. They involve observations by the examiner rather than feelings. They are called signs. In addition, the physician will often order tests such as an ECG, X-ray or blood-protein analysis. The results of such tests are referred to as findings. Thus, the physician has basically three kinds of information (in addition to the patient's medical history) to use in a diagnosis: symptoms (provided by the patient), signs (provided by the physician) and findings (mostly provided by the laboratory or some other branch of a hospital). The three kinds of information together are classed as clinical findings.

In the rest of this section, we will review how clinical findings are related to the five brain diseases we have been considering.

9-2 Convulsions

What can you infer about brain disease from the clinical finding of convulsions?

Sometimes a convulsion is the first hint of a brain disease, and epilepsy is then the first disease to come to mind. But other brain diseases may also bring on a convulsion. The often-major brain damage caused by a cerebral hemorrhage or thrombosis may at times result in a convulsive seizure. And less often a brain tumor may produce this symptom. Actually, only one of the five diseases is ruled out by this symptom. Because its onset affects rather few neurons at a time, multiple sclerosis would not be expected to trigger a convulsion.

9-3 Brain Dysfunction

Which brain disease is not associated with brain dysfunction?

A more common clinical finding for most of the five brain diseases is a brain dysfunction--an impairment of the brain's normal function.

The epileptic, although often mentally confused and physically abnormal immediately after a seizure, usually survives the event without any lingering impairments. But the sufferer from multiple sclerosis, cerebral hemorrhage, cerebral thrombosis, or a brain tumor is first likely to become aware of a problem by recognizing that his brain is no longer capable of doing what it used to do.

Brain dysfunction may show up in a variety of ways. The patient may lose normal use or coordination of a muscle, or may discover that certain mental tasks are no longer possible to perform.

The list of brain dysfunctions that afflict patients suffering from these four diseases (multiple sclerosis, cerebral hemorrhage, cerebral thrombosis, brain tumor) can often be lengthened by the examining doctor. Additional brain dysfunctions may be detected by visual-field testing, by administration of psychometric and coordination tests and by checking reflexes. Muscle reflexes, in particular, are often less inhibited in cases of brain disease. Thus exaggerated reflex actions are likely to occur.

9-4 Reading the Cerebrospinal Fluid (CSF)

What can you infer about brain disease from studies of CSF?

The CSF reacts to brain disease in ways that aren't entirely understood. However, this fluid sometimes provides clues that are helpful. For example, red blood cells in the cerebrospinal fluid are a sure indication of hemorrhage somewhere in the central nervous system. Of the five diseases we are considering, the most likely candidate in a patient who has red blood cells in his CSF is cerebral hemorrhage. Although it is not common, tumors may also cause hemorrhaging if they infiltrate an area of the brain containing blood vessels.

While red blood cells in the CSF indicate brain disease, it is important to recognize that the absence of this finding does not rule out brain disease, not even cerebral hemorrhage. (It is possible to have a cerebral hemorrhage which remains contained in one area of the brain and does not leak into the CSF.)

A high globulin concentration in the CSF is also significant. Of the five diseases considered, only multiple sclerosis is likely to show this finding. But, again, although the presence of the finding is an important indication of multiple sclerosis, its absence does not rule out the disease.

Since red blood cells contain proteins and globulins are proteins, a high total-protein concentration in the CSF may occur with either cerebral hemorrhage or multiple sclerosis. This finding is not observed in patients with epilepsy or cerebral thrombosis. In the case of brain tumor, however, the total protein level in the CSF is often but not always high.

The pressure of the CSF may also provide a diagnostic clue. Although none of the diseases necessarily involves a significant change in CSF pressure, both cerebral hemorrhage and brain tumor often lead to elevated pressures. In epilepsy, multiple sclerosis and cerebral thrombosis, a normal (or sometimes even low) CSF pressure is the rule.

9-5 A Matter of Time

Why are physicians concerned with how fast symptoms of a brain disease appear?

Sometimes the most distinctive clue to brain disease is how fast the symptoms are shown. Two of the five diseases are quick to make their presence known. Epilepsy is first recognized by some sort of seizure, a sudden and dramatic event. Cerebral hemorrhage is also quick to show its presence. When a blood vessel in the brain ruptures, brain destruction happens rapidly and the victim usually collapses or dies within minutes. Such a rapid onset of effects is also possible, although much less likely, in cerebral thrombosis and brain tumor.

At the other end of the scale is multiple sclerosis, in which a gradual appearance of symptoms and other clinical findings is the rule. This is often the case with a brain tumor as well, where the slowly developing growth impairs the brain bit by bit as it damages the neurons in its vicinity. Even cerebral thrombosis may involve a succession of quite mild strokes, resulting in gradual neural destruction similar to that produced by multiple sclerosis.

In between these two extremes is an intermediate rate of development of symptoms that is quite distinctive when it occurs. Of the five diseases considered, only cerebral thrombosis will show this type of development of symptoms. Although cerebral thrombosis may sometimes come on in minutes and sometimes in days, more often it develops steadily over a matter of hours. Clinical findings start to appear as the clot begins to form and diminish the blood supply, then become more and more severe as the blood vessel is fully shut off. A comparable progressive onset of clinical findings doesn't happen in the other brain diseases being considered. By their nature, the other diseases always show their presence either all in one quick incident or in a leisurely, gradual fashion.

9-6 A Look at the Brain

How do X-rays aid in diagnosis of brain disease?

It would be ideal if there were a way to peer indside the skull and detect brain disease. Unfortunately, a simple X-ray of the brain is not a particularly promising diagnostic tool. Epilepsy, multiple sclerosis, cerebral hemorrhage and cerebral thrombosis do not cause abnormalities in the picture. However, some tumors do affect the bony parts of the skull. Also some tumors contain mineral deposits. Both of these phenomena would show up on a skull X-ray.

9-7 Further Testing in Diagnosis of Brain Disease

What other tests may be used in the diagnosis of brain disease?

When the results of all the foregoing tests are sorted out, the doctor may still be unable to diagnose the disease. Suppose, for example, that a patient has had no convulsion, shows some mental impairment, has a normal cerebrospinal fluid, developed symptoms slowly, and has a normal skull X-ray. Both epilepsy and cerebral hemorrhage may probably be ruled out. But cerebral thrombosis is still a possibility, and multiple sclerosis and brain tumor are both strong candidates.

Obviously the series of tests considered so far may sometimes fall short of distinguishing among the five diseases. Accurate diagnosis may then require further, more sophisticated testing.

These additional tests may be considered "second-round" tests--tests that may be needed if the first round of routine testing is inconclusive. Of course, in many cases they may be needed even if a disease has been correctly diagnosed. A clear case of tumor may still require a more accurate determination of location. An obvious cerebral hemorrhage may need to be pinpointed so that surgery may be performed.

The EEG may be of use in identifying both the type and location of brain disease. Epilepsy, for example, often shows a characteristic pattern. Other brain disorders may also cause the appearance of abnormal brain waves that suggest the cause and may even help localize the problem.

There are also special ways of demonstrating defects in the brain. A regular X-ray may show little because there is little inside the skull that will absorb X-rays. But if a substance that absorbs X-rays strongly is injected into the blood vessels leading to the brain, a picture can be taken. Such an X-ray (an angiogram) will usually reveal any disruption in normal blood flow. A cerebral hemorrhage from which blood still seeps into brain tissue, a cerebral thrombosis that has stopped the flow of blood to one region of the brain, a tumor that has deflected the blood vessels from their usual path--such defects can be discovered by an angiogram.

A number of other ways of peering inside the brain have also been developed such as the brain scan discussed in Section 8. Also radioisotopes may be injected into the bloodstream in another type of angiography. A device measuring the degree of radioactivity in the brain may then disclose a site of brain damage.

Ultrasound--sound with a pitch too high for the human ear to sense--can be used to locate tumors. The principal at work in ultrasound is like that used in radar or sonar--the waves of sound bounce off structures in the brain, and bounce differently for structures of different densities. This information is recorded on a screen and then interpreted by specialists.

9-8 The Computer Diagnosis

How can a computer be used in diagnosis of brain disease?

When a doctor has gathered together all the necessary information from the patient's medical history and test results, the process then is to sift through all the data and make decisions as to which diseases may be ruled out and which are a possibility. This process may take minutes or hours, depending upon the information available. Wouldn't it be convenient if the information could simply be fed into a computer terminal and seconds later receive a printout stating--"diseases x, y and z are definitely ruled out; diseases u and v are distinct possibilities; suggest you perform the following tests to obtain further pertinent information.?" In fact, such an arrangement is now possible.

Computers, which have already made significant contributions to such fields as accounting, scientific research and many more, are now making inroads in the world of medicine. These "electronic wizards" can be programmed to help the medical professional analyze symptoms and test results and arrive at a preliminary diagnosis. Programming the computer involves creating truth tables, such as the ones you have been studying in Biomedical Mathematics. The information from such truth tables can then be fed into a computer to help diagnose diseases.

You will soon be developing truth tables based on the five brain diseases you have been reading about. You will use the tables to design circuitry to attach to a BIP and thus create a "mini" diagnostic computer.

Why is it difficult to diagnose brain disease?

Consider the following five diseases: brain tumor, cerebral hemorrhage, cerebral thrombosis, epilepsy and multiple sclerosis. Which (if any) of these diseases may be eliminated by each of the following clinical findings? Why?

Clinical Finding: convulsions
brain dysfunctions
red blood cells in CSF
high globulin concentration in CSF
abnormal skull X-rays
abnormal EEG

Which of the above clinical findings are symptoms, signs and findings?

How may computers be used in diagnosis of brain diseases?

VOCABULARY:

clinical findings--symptoms, signs and findings.

finding--the results of clinical tests such as EEG, blood sugar, urinalysis, etc.

sign--an observation made by an examining physician regarding abnormalities of a patient. Examples of signs include poor coordination, a lump under the skin, unbalanced reflexes, etc. Signs are objective rather than subjective.

symptom--a feeling or sensation that a patient describes to the examining physican, often involving pain or discomfort. Examples of symptoms are sore back, pain in the ear, double vision.

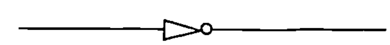
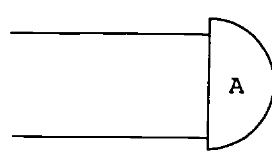
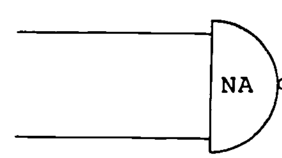
SECTION 10: THE USE OF LOGIC GATES IN A COMPUTER:

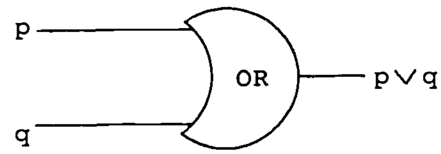
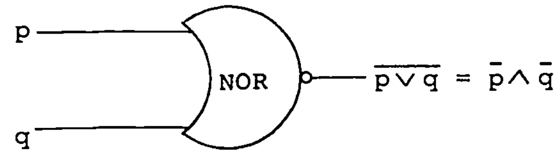
10-1 Review of Logic Gates

What are the switching functions of the common logic gates?

In Activity 9 you began to prepare a truth table that you will use to design the circuitry for your diagnostic computer. The next step in the process is to decide which logic gates correspond to the outputs shown in your truth tables. To do this, you will need to remember the switching functions of the various logic gates. This information was presented in Section 5 of the Mathematics Text, where AND, NAND, OR, NOR and INVERT gates were discussed. For convenience it is summarized again, in the table below.

COMMON LOGIC GATES

Name	Meaning	Symbol and Switching Function
INVERT (or INV)	not	 p → $\bar{p}$
AND	and	 p, q → $p \wedge q$
NAND	not and	 p, q → $\overline{p \wedge q} = \bar{p} \vee \bar{q}$ (De Morgan's Law)

OR	or	
NOR	not or	

10-2 <u>Logic Gates and the Computer</u>

How are gates used in a computer?

A computer is a device which processes large amounts of information very rapidly. The circuits necessary to do the processing are already built into the computer; how the circuits will be used in a particular problem is determined by the particular program used. When information is fed into a computer it is always in terms of truth values: 1's and 0's. These two numbers can be coded to describe such things as words, and--as you've already discovered--sets of findings. The immediate output of a computer is also in terms of 1's and 0's, which are then decoded to give words or diagnoses.

Between the input and the output of a computer there is an assortment of logic gates. These accept inputs of 1's and 0's and respond with some output of 1's and 0's, depending on their switching functions. In the typical computer, various groups of gates are interconnected so that they can perform complicated tasks in a matter of seconds.

The individual gates themselves perform very simple functions. For example, an AND gate with two inputs accepts a 1 or a 0 at each of the inputs. The gate then responds with a 1 if both inputs are 1, and a 0 if they are not. The OR gate with two inputs responds with a 1 if either input (or both) is 1 and a 0 if both are 0. But with combinations of these simple gates, remarkably complex computer tasks can be performed.

10-3 <u>How Do Logic Gates Work?</u>

The gates that make up a computer are tiny electrical circuits that respond to voltages. A truth value of 1 corresponds to a specific voltage level while a value of 0 corresponds to a <u>different</u> voltage level. The arrangement of inputs to a gate determines the output. Thus, for each type of gate, certain combinations of inputs trigger a "switch" that produces a voltage corresponding to an output of 1; a different combination of inputs trigger a "switch" that produces an output of 0. The switching function of a gate describes the combination of inputs that trigger a "switch" producing a voltage corresponding to a truth level of 1.

You will soon have an opportunity to apply information on logic gates to the design of a diagnostic computer. In Laboratory Activity 10, you will begin to work directly with logic gates.

PROBLEM SET 11:

PART I:

In Laboratory Activity 10 you determined that different arrangements of gates had identical switching functions. For example, you determined that a 2-AND gate with output inverted has the same switching function as a 2-NAND gate. It is not necessary to go through the complex process you used (i.e., connecting gates, determining truth tables) to determine the switching functions. Instead you could apply the symbolic logic that you have been studying in Biomedical Mathematics to find the switching functions of various gate combinations.

Consider the above example: a 2-AND gate with the output inverted. The switching function for a 2-AND gate is $p \wedge q$, where p and q are the inputs and $p \wedge q$ is the output. Inverting the output of the 2-AND gate is the equivalent of negating the statement p q, i.e. $\overline{p \wedge q}$. But De Morgan's law states that $\overline{p \wedge q} = \bar{p} \vee \bar{q}$ which is the switching function of the 2-NAND gate.

On a separate sheet of paper, make a table similar to the one at the end of this part of the problem set. See whether you can fill in the boxes in your table by using symbolic logic. For each box, determine the switching function and the gate. For convenience, De Morgan's laws are restated below. Two sample problems are also included for you to refer to, if necessary.

DE MORGAN'S LAWS
$\overline{p \wedge q} = \bar{p} \vee \bar{q}$
$\overline{p \vee q} = \bar{p} \wedge \bar{q}$

Sample Problem #1:

Suppose you have a circuit with a switching function of $\bar{p} \wedge r$. What would be the resultant switching function if the output were inverted?

Solution: The output is $\bar{p} \wedge r$. Inverting this we get $\overline{\bar{p} \wedge r}$. According to De Morgan's law

$$\overline{\bar{p} \wedge r} = \bar{\bar{p}} \vee \bar{r}$$

But since $\bar{\bar{p}} = p$, $\bar{\bar{p}} \vee \bar{r} = p \vee \bar{r}$.

Therefore, the new switching function is $p \vee \bar{r}$.

Sample Problem #2:

What would be the resultant switching function of the circuit in Sample Problem #1, if both inputs and the output were inverted?

Solution: We start with the switching function $\bar{p} \wedge r$ of Problem #1. The inputs are p and r. Inverting the inputs is the same as substituting $\bar{p}$ for p and $\bar{r}$ for r. This gives $\bar{\bar{p}} \wedge \bar{r}$ which simplifies to $p \wedge \bar{r}$. Inverting the output is equivalent to inverting the entire expression $\overline{p \wedge \bar{r}}$. By De Morgan's law,

$$\overline{p \wedge \bar{r}} = \bar{p} \vee r$$

The new switching function is $\bar{p} \vee r$.

2-INPUT GATES AND SWITCHING FUNCTIONS

OUTPUT	$p \wedge q$ AND	$\overline{p \wedge q}$ NAND	$p \vee q$ OR	$\overline{p \vee q}$ NOR
WITH OUTPUT INVERTED		$\overline{\overline{p \wedge q}} = p \wedge q$ AND		
WITH BOTH INPUTS INVERTED	$\bar{p} \wedge \bar{q}$ $= \overline{p \vee q}$ NOR			
WITH BOTH INPUTS INVERTED AND OUTPUT INVERTED				$\overline{\overline{\bar{p} \vee \bar{q}}}$ $= \bar{p} \vee \bar{q}$ $= \overline{p \wedge q}$ NAND

PART II:

In Activity 9 you developed a diagnostic truth table for five brain diseases and constructed a logical statement representing each disease. The next step in designing the diagnostic computer wil be to design the electrical circuits having those logical statements as their switching functions. This step involves applying the principles you have studied in Biomedical Mathematics. This portion of Problem Set 11 is designed to review those principles.

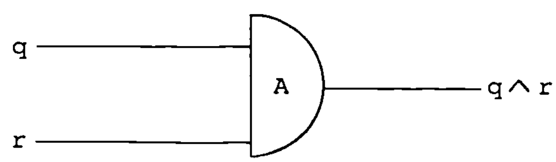
First we will give you a few examples of the operations involved in designing circuitry that corresponds to a given logic statement, and then you will be asked to solve a number of similar problems. It is important for you to be able to solve such problems if you are to be successful in designing the circuitry for your diagnostic computer. If you have trouble with this material, we suggest you review Sections 7 and 8 of your Mathematics Text.

<u>Example 1:</u> Below is the simplified truth table for bacterial pneumonia, where p = cough, q = fever and r = bacteria in sputum.

FINDINGS			DISEASE
p	q	r	
1/0	1	1	bacterial pneumonia

What is the logic statement for bacterial pneumonia? Since p either may or may not be present, it is not included in the statement. Thus, the logic statement for bacterial pneumonia is $q \wedge r$.

In Mathematics class you saw how to design a circuit with switching function $q \wedge r$. You simply combine inputs q and r by an AND gate.

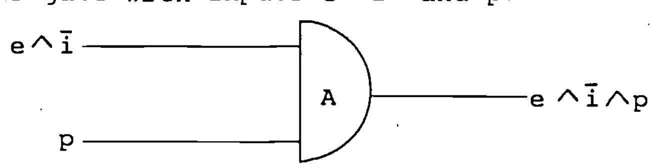


This is the diagnostic circuit for bacterial pneumonia.

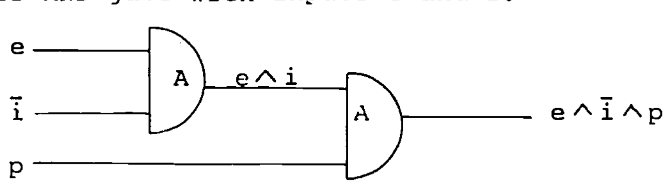
<u>Example 2</u>: Design a circuit for the following logic statement:

$$e \wedge \bar{i} \wedge p$$

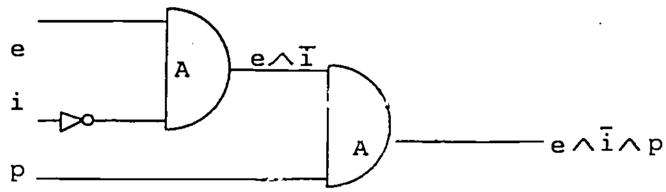
Since the gates we are using so far have only two inputs, we may arbitrarily divide the above statement so that it reads $(e \wedge \bar{i}) \wedge p$. We can now consider this statement as the output of an AND gate with inputs $e \wedge \bar{i}$ and p.



We now include another AND gate with inputs e and $\bar{i}$.

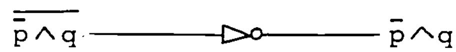


We now note that $\bar{i}$ is the output of an INVERT gate with input i. The completed circuit diagram is shown below.

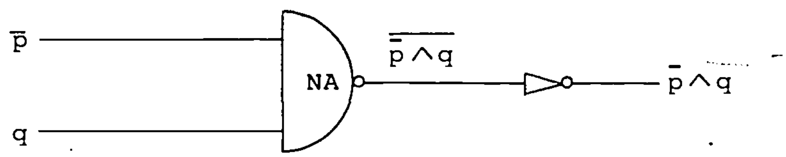


Example 3: As you will see in Laboratory Activity 11, many of your circuit designs will end with a final INVERT gate. As an example of this type of design, suppose you want to complete the circuit diagram shown below.

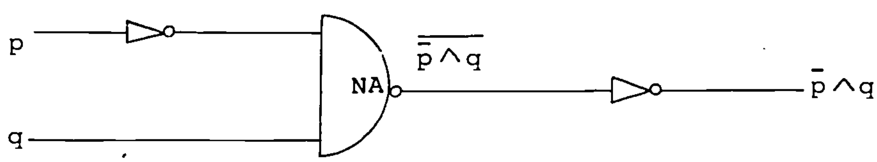
Since the input to an INVERT gate is the negative of the output, the input must be $\overline{\bar{p} \wedge q}$.



The switching function $\overline{\bar{p} \wedge q}$ is the output of a NAND gate with inputs $\bar{p}$ and q



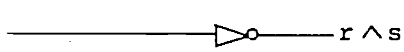
Finally $\bar{p}$ is the output of an INVERT gate with input p. The complete diagram is shown below.



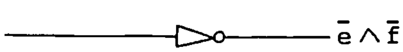
PROBLEMS 1 to 5: Write a possible circuit for each logic statement. If you have any difficulty, refer to the examples given above or to those given in Section 8 of your Mathematics Text. (Note: more than one answer is possible for each of these problems. You need give only one.)

1. $(p \wedge q) \vee r$
2. $(e \vee \bar{i}) \wedge q$
3. $(p \wedge q) \vee (r \wedge t)$
4. $(\overline{p \wedge q}) \vee s$
5. $(p \vee \bar{q}) \wedge (s \vee \bar{t})$

PROBLEMS 6 to 8: Complete the following circuits by using only 2-NAND and INVERT gates as needed. (See Example 3 above.)

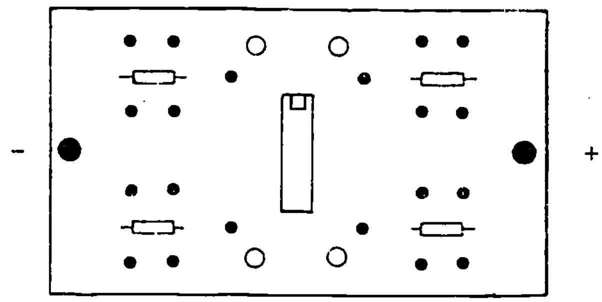
6. 

7. 

8. 

REVIEW SET 13:

Questions 1 through 6 refer to the following diagram of a PC card.



1. How many logic gates are on this card?

2. How many input sockets are there for each gate?

3. How many inputs are needed for each gate?

4. How many output sockets are there for each gate?

5. Based on the cards you have worked with, what kinds of gates might be on this card?

6. When the diode light for a gate is on, what is the logic level of the output?

7. Use the information given in the truth table below to:

    a. write the logic statement for each disease,

    b. draw a circuit diagram that will give an output of 1 when all inputs are 1. (Note: Remember to include a final diagnostic invert gate.)

TRUTH TABLE

Findings				Diseases
g	p	q	r	
1	0	1/0	1	X
0	1	1	1	Y

SECTION 14: NATURAL SOURCES OF DRUGS

14-1 Introduction to the Study of Medical Drugs

What do drugs have to do with the nervous system?

This section is the first in a sequence on medical drugs. The drugs used in medicine act on many different systems of the body and have a great variety of effects on body functions. Many of these drugs act directly on the nervous system. They may affect any part of the nervous system, from the brain and spinal cord to the ends of sensory and motor neurons. Some affect functions we control consciously, some affect functions controlled by the autonomic nervous system and some affect our perceptions of events either in our bodies or in the environment.

In this sequence you will learn something about the sources of medical drugs, about health-career opportunities in fields that involve drugs and about the classes into which medical drugs are divided by scientists who study drugs and their effects. Finally, you will study several classes of drugs in more detail. With the exception of antibiotics, the classes of drugs you will study act on the nervous system.

14-2 Medical Drugs in Other Cultures

Where do drugs come from? How are their medical uses discovered?

In any part of the world, health and medicine are greatly affected by the relationship between people and the environment they live in. A particular environment may make people very likely to get some diseases and very unlikely to get others. For example, consider people who live in a warm, damp region rich in many forms of plant and animal life. These people may be likely to get diseases carried by mosquitos and other insects that breed in ponds. However, they are not likely to get frostbite or to suffer from starvation.

The environment doesn't only contribute to the diseases that people get. In many instances it also contributes the cures for those diseases. Throughout the world and throughout history, people have discovered in their natural environments substances that they could use in dealing with their health problems. Some of these substances are plants or juices derived from plants; some are substances taken from the bodies of animals; some are clays or other mineral substances taken directly from the earth. In some parts of the world, even the water--water from underground sources that contains large amounts of minerals--has been found useful in medicine.

There has been much speculation and much research about the ways in which people have discovered the medical uses of substances in their environments. Today, scientists called ethnobiologists study the relationships between people and the plants and animals in their environments. Usually ethnobiologists study cultures that are much different from our own--perhaps much less complex in such fields as government, economy and technology. Often, however, the people in these cultures are much more sophisticated in their knowledge of, and ability to use, the things they find in their natural environments.

The work of ethnobiologists suggests that the development of medical drugs in most cultures is mainly a matter of trial and error or simple accidental discovery. Even in our own, highly scientific and rational system of medicine, there are many drugs that work in ways we do not understand. Aspirin, for example, kills pain and reduces fever. Nobody knows how it does either of those things, but that does not prevent us from taking aspirin to kill pain or reduce a fever.

14-3 Drugs Derived from Plants

How many of our drugs come from plants?

A person looking at the medical drugs used in our society might find it hard to believe that any of them is made out of a plant. They are colorful, neat-looking and certified pure, and they have very impressive names. It would be easy to believe that all of them were synthesized in the laboratory. The fact is, however, that over 37 percent of drug prescriptions in this country contain one or more substances derived from plants. The average physician in the U.S. writes at least eight prescriptions a day for drugs made out of plants.

Many of the most useful medical drugs in our society were first discovered not by chemists working with test tubes and centrifuges, but by the medical practitioners of cultures that had never heard of chemistry. Some of these drugs have been used in European medicine for centuries; some have recently been brought to the attention of modern medical science by ethnobiologists. In some countries, great effort is put into scientific analysis of the plant, animal and mineral substances used by practitioners of "primitive," "traditional" or "folk" medicine.

The following list includes a few of the drugs used in medicine in this country which were first used by "primitive" or "folk" healers. Reserpine, derived from Indian snakeroot, was first used by healers in ancient India; it is now considered a useful drug for lowering blood pressure. Digitoxin, derived from foxglove (digitalis), is a powerful heart stimulant and diuretic used in treatment of heart patients. Quinine is made from the bark of cinchona trees, which grow in South America; it is a specific cure for malaria. Morphine, one of the most powerful pain killers available to modern medicine, is made from the opium poppy. Cocaine, made from coca leaves, is used as a local anesthetic. Atropine is made from the plant known as deadly nightshade, and is used to relax the muscles of the heart and other internal organs. Finally, curare, derived from certain vines, is used by South American Indians in making poisoned arrows with which to hunt game; in modern medicine it is useful in very small doses as a powerful muscle relaxant.

14-4 Drugs Derived from Animals

What types of drugs come from animals?

About 71 percent of the earth's surface is covered with water, and four-fifths of the animal life on the planet is found in or near the water. Only relatively few medically useful drugs have been derived from the animals of the sea. However, the sea and ocean life have been much less studied than life on dry land, and scientists expect that the sea will eventually yield many more medically useful drugs.

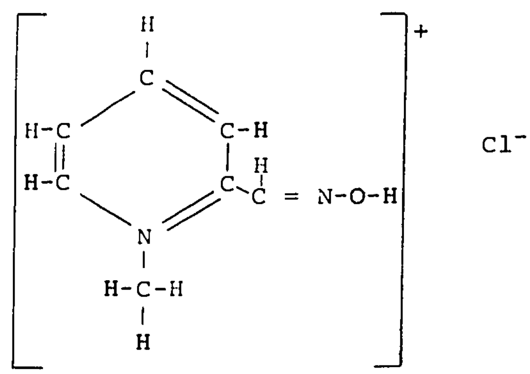


FIGURE 1: Pralidoxime chloride, a useful drug from the sea.

One drug that comes from the sea is pralidoxime (Figure 1), which comes from the electric eel. This substance is used as an antidote for poisoning by the insecticide parathion. Parathion poisons people by inhibiting cholinesterase, an enzyme important in the functioning of the nervous system. Pralidoxime counteracts the insecticide by reactivating cholinesterase.

Tetrodotoxin is another useful drug that comes from the sea. It is the poision of the porcupine fish, the puffer fish (Figure 2), salamanders and the California newt. This drug acts on the membranes of neurons and prevents them from transmitting nerve impulses. Small doses of this substance are used in Japan to relieve muscular convulsions and to ease the pain of terminal cancer.

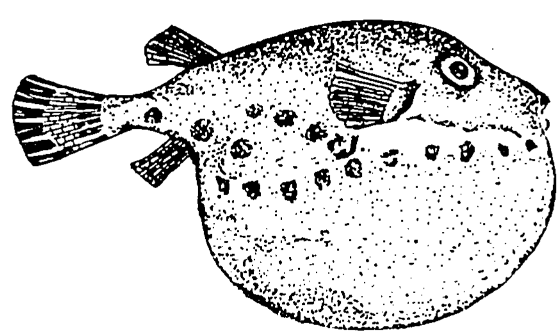


FIGURE 2: The puffer fish, source of a powerful muscle relaxant.

Cod-liver oil is perhaps the best known of all drugs from the sea animals. The oil is derived from fresh codfish livers. It is rich in vitamin A and also contains vitamin D. Halibut-liver oil and shark-liver oil are also useful for their high vitamin A and vitamin D content.

Many other important medical drugs are derived from animals that live on dry land. Nearly two thirds of all prescriptions for animal-derived drugs are for natural hormones. The hormone most often prescribed is thyroxin, or thyroid hormone. Thyroxin is obtained from the dried and powdered thyroid glands of sheep and hogs. It is used to treat thyroid insufficiency.

Estrogens are a group of hormones used in treating many disorders of the female reproductive system. The estrogens used in medicine are derived from the urine of pregnant mares and from other sources. They are used in controlling some of the symptoms that follow menopause (the production of estrogens by the ovaries of the human female declines after a woman stops menstruating, with a variety of upsetting consequences) and in a number of other disorders.

The table on the following page summarizes the sources and uses of these and some other medical drugs derived from land-dwelling animals.

SOME ANIMAL-DERIVED DRUGS.

DRUG	ANIMAL SOURCE	USED TO TREAT
Thyroxin	Thyroid gland of sheep and hogs	Thyroid insufficiency
Estrogen	Urine of pregnant mares	Female reproductive disorders
Insulin	Pancreas of cattle and hogs	Diabetes mellitus
Epinephrin	Adrenals of domesticated animals	Acute asthma
Oxytocin	Pituitary of cattle and hogs	Bleeding of the uterus after birth; also used to increase uterine contractions in childbirth
Vasopressin	Pituitary of domesticated animals	Intestinal paralysis, diabetes insipidus (a form of diabetes caused by insufficient antidiuretic hormone)
Digestive enzymes (pepsin, pancreatin, trypsin, chymotrypsin)	Stomach (pepsin) and pancreas of hogs and other domesticated animals	Digestive insufficiency

14-5 The Frequency of Drug Use in American Families

Do Americans consume more drugs than they used to?

An immense variety of drugs, some derived from natural sources and some synthesized in the laboratory, is currently available in our society. A recent national survey found that the average family keeps 30 medical drugs in the house. Other studies have shown that Americans are using increasing amounts, as well as an increasing variety, of drugs for all kinds of purposes, medical and otherwise.

Several explanations have been suggested for the increase in our consumption of nonmedical drugs. Perhaps the increasing use of prescription drugs in medicine has influenced people to use more drugs for other purposes as well. Perhaps the advertising of nonprescription medical drugs and of other drugs, such as alcohol and tobacco, has influenced people to believe that drugs can solve any problem quickly and simply. Perhaps the stresses of living in a large, complex and competitive society have led people to use drugs as a source of relief from everyday life.

The following six sections will deal with pharmacology (the study of the sources, chemistry, actions and medical uses of drugs), the classes into which medical drugs are divided and some of the drugs commonly used (and abused) by Americans for nonmedical purposes.

In cultures without chemistry, how do people discover the medical uses of drugs?

What value is there in studying the medical practices of cultures that are in some ways more "primitive" than ours?

Name three important drugs derived from plants and describe their medical uses.

Name three important drugs derived from animals and describe their medical uses.

Why do you think the consumption of drugs is increasing in the U.S.?

Vocabulary:

antidote (AN-tih-dote)--a drug or other treatment for counteracting a poison.

ethnobiology--the study of relationships between people and the plants and animals in their environments; the people studied are usually in cultures having less sophisticated technology than our own culture has.

SECTION 15: PHARMACOLOGY

15-1 Science and Drugs

What is a drug?

The word "drug" is not a technical, scientific term with a meaning that all scientists agree on. Many different definitions of the word are in use among scientists, government officials, health-care providers and other people. The most accurate answer to the question, "What is a drug?" is, "It depends on whom you ask."

When we discuss drugs in Biomedical Science and Social Science, we will have in mind two categories of substances. We will sometimes use the term "drugs" to include all those substances that people in this country use to prevent, diagnose, treat or cure disease. This category includes prescription drugs, such as morphine and penicillin, as well as nonprescription drugs such as aspirin and medicated soaps.

We will also use the term "drugs" to include substances which people use for other purposes, which affect the structure or functioning of their bodies and which may increase the user's chances of getting a disease. This category includes substances used legally, such as tobacco and alcohol. It also includes substances used illegally, such as marijuana, heroin and cocaine.

In Biomedical Science we will mainly be concerned with the ways in which various drugs act in the body and the effects their actions have on the structure or functioning of the body. In Biomedical Social Science you will investigate some of the things in our society that influence people's decisions about which drugs to use and how to use them.

15-2 Getting Information About Drugs

Where can you learn about drugs and their effects?

Many different kinds of scientists do research on drugs and the effects they have on people. For example, psychologists study the effects of various substances on the mental and emotional processes of people who use them. Sociologists study the characteristics of people who use particular drugs in order to learn why people use those drugs.

In this course, however, we will be mainly concerned with the work of pharmacologists. Pharmacology is sometimes called "the science of drugs." Pharmacologists study the sources of drugs, their chemistry, ways of preparing them, their actions in and effects on the body, their ability to harm the body and their uses in health care. For the purposes of this course, the best sources of information about drugs are books on pharmacology. The next section describes in more detail the many things you can learn about a drug by looking it up in a pharmacology book.

15-3 What Pharmacology Is About

What kinds of information do pharmacology books contain?

If you looked up a drug in a pharmocology reference book, among the first things you would find would be a history of its medical use, a description of its source and some information about its chemical nature.

The history of the drug usually includes a description of how the drug was discovered and what medical uses it has been put to in the past. For example, cocaine, a product of the leaves of the coca tree, was discovered many centuries ago by the natives of Peru and Bolivia, who used it to increase their physical endurance. Near the turn of the century, it was used in cola drinks. Today it is used in medicine primarily as a local anesthetic.

A drug may be derived from a plant, an animal or a mineral ore, or it may be synthesized in the laboratory. Quinine, a compound used to treat malaria, comes from the bark of the cichona tree. Insulin, sometimes used in treating diabetes mellitus, comes from the pancreas of domestic animals. Kaolin, which is used to control diarrhea, is a clay taken from the earth. Aspirin is synthesized in the laboratory.

The chemical description of a drug usually includes the name of the chemical group to which the drug belongs and the drug's structural formula.

The bulk of the information contained in a pharmacology book concerns the way a drug acts in the body and the effects of this action on the body. For example, we may consider penicillin. This drug is an antibiotic, a substance produced by one organism (usually a mold) that kills or prevents growth of other organisms, usually bacteria. The mechanism of action of penicillin is now well understood and involves the bacterial cell wall (Figure 1).

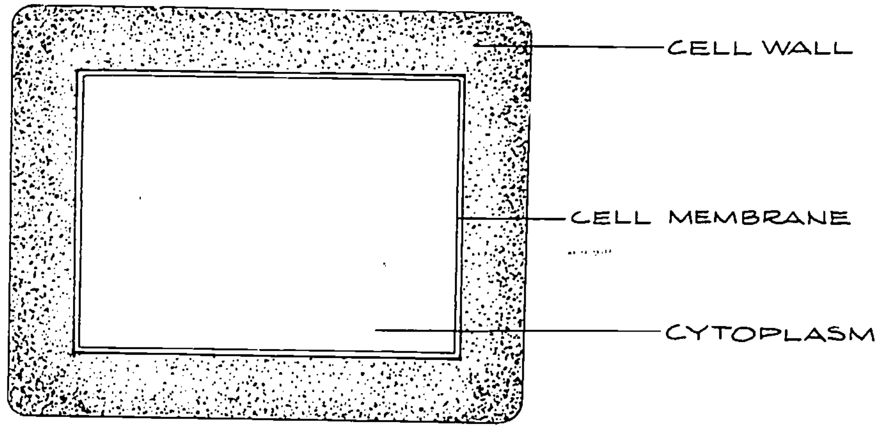


FIGURE 1: Some components of a bacterial cell (schematic).

The cytoplasm of a bacterium is contained within a cell membrane that is chemically and physically much like our cell membranes. But the bacterium also has a thick and very strong coat, a cell wall (Figure 1). The cell wall prevents the bacterium from exploding when the pressure inside the cell is greater than the pressure outside the cell. A bacterium reproduces by stretching and dividing into two cells. To accomplish this, the bacterium must synthesize a partition, or septum, between the two halves (Figure 2). The septum will form a part of the cell walls of the daughter cells after the division process is completed.

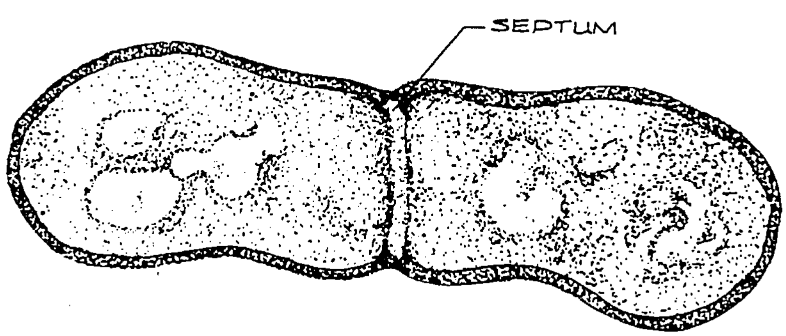


Figure 2: Dividing bacterial cell, showing newly formed septum.

Penicillin prevents the dividing bacterium from constructing a normal septum. When a bacterium divides in the presence of penicillin, each wall formed from the septum is structurally imperfect and weak. The imperfect cell walls burst very easily, usually before the process of division is even complete. When the cell walls burst, the bacteria die. The action of penicillin, then, is to kill bacteria during division; the effect of this action is to rid the body of a bacterial infection.

A pharmacology book also lists the possible ill effects of a drug. These include the effects of overdose as well as the side effects of a normal dose. Again, consider the example of penicillin. Allergic reactions are a common side effect of penicillin. These reactions include asthmatic attacks, nausea, severe abdominal pain, sudden falls in blood pressure and skin rashes; in an extreme case the patient may go into shock and even die of respiratory failure. Thus, information about the ill effects of a drug is useful to people who prescribe the drug and to people who use it.

A pharmacology book also describes the way a drug is absorbed by the body, the way it is distributed through the body once it has been absorbed and the dosages required to obtain the desired effects. It is important that doctors have this information on hand so that they can prescribe drugs correctly. For instance, suppose a doctor wants to administer a muscle relaxant. If the drug is given orally, some of it will be excreted or changed by enzymes before it reaches the target organ. If it is injected into a muscle or vein it will reach the target organ more quickly, but a smaller dose must be used because very little of the drug will be lost along the way. A pharmacology book will help the doctor decide how to administer the drug and how much of it to use in order to obtain the desired effect.

What are the two ways in which we use the term "drug?"

Give some examples of the kind of information about drugs that you can obtain from a pharmacology book.

How does penicillin work as an antibiotic?

Why is penicillin sometimes not used in treating bacterial infections?

Vocabulary:

antibiotic (AN-tee-by-AHT-ik)-- a substance produced by one organism, usually a mold, that destroys or slows down the growth of bacteria and other microorganisms.

cell wall--the outer "shell" of a cell, found in plant and bacterial cells, but not in animal cells.

pharmacology (FAR-muh-KAHL-uh-jee)--the science of the sources, chemistry, preparation, actions, ill effects and medical uses of drugs.

septum (SEP-tum)--a partition separating two cavities or two masses of tissue.

SECTION 16: CATEGORIES OF DRUGS

16-1 How Pharmacology Books Are Organized

Why are pharmacology books organized the way they are?

In Section 15 we talked about the various kinds of information available in pharmacology books. The information in these books is arranged in such a way as to be useful to the people who make the most use of such books: health-care providers. In general, these people use pharmacology books to determine or evaluate drug therapies for particular patients. For these readers, the most effective way to organize pharmacological information is according to systems of the body, such as the nervous system and the gastrointestinal system. Consequently, most pharmacology books are organized in this way.

Consider the following example. A man visits his physician for an annual checkup. During the checkup the doctor discovers that the patient has symptoms of a peptic ulcer. The doctor wishes to prescribe a drug to treat this disorder. Since peptic ulcers occur in the gastrointestinal system, the doctor refers to the chapter in the pharmacology book entitled, "Drugs Acting on the Gastrointestinal System."

That chapter may even include a section on antacids, which provides the information the doctor needs to choose and prescribe a drug for the patient.

16-2 Pharmacological Categories of Drugs

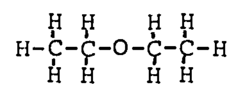
What are the major classifications of drugs? How do the drugs in each category affect the body?

DRUGS ACTING ON THE CENTRAL NERVOUS SYSTEM

This category includes two main classes of drugs: depressants ("downers"), which decrease the activity of neurons, and stimulants ("uppers"), which increase neural activity.

Depressants

General anesthetics: These drugs are used when major surgery is performed. They produce general anesthesia, which is the loss of sensation combined with the loss of consciousness. Different general anesthetics produce different levels of anesthesia, beginning with loss of consciousness and proceeding through relaxation of the muscles, the loss of sensation and reflexes and (in overdose) depression of first the respiratory and then the cardiac control centers of the nervous system. Two examples of such drugs are ether (specifically diethyl ether), which is inhaled and can produce any level of anesthesia, depending on dosage, and Pentothal sodium (trade name for sodium thiopental), which is injected and can produce either hypnosis (which resembles sleep without complete loss of consciousness) or anesthesia.



Local anesthetics: These drugs produce loss of sensation in a small area of the body without producing loss of consciousness. They are either injected or applied externally, and their effect is localized. Two examples are procaine, which dentists inject before drilling or pulling teeth, and Xylocaine, which a doctor might apply externally to the area around a deep cut before sewing it up.

Hypnotics and sedatives: A hypnotic is a drug that causes sleep; a sedative is one that has a quieting effect on the central nervous system but does not produce sleep or kill pain. You may recall that sedatives are sometimes prescribed to prevent epileptic seizures. Some drugs are both sedatives and hypnotics. The most common of these sedative-hypnotic drugs are barbiturates. Two examples of non-barbiturates sedative-hypnotics are Valium and Librium, the most frequently prescribed drugs in the United States.

Narcotic analgesics: An analgesic is a drug that kills pain. The word "narcotic" is not so easy to define, because it is used in different ways. It means (1) a drug that in moderate doses reduces sensation, kills pain and produces sleep, but in large doses produces stupor, coma or convulsions; (2) a drug derived from opium or having morphine-like properties (morphine is derived from opium); or (3) a drug defined as a narcotic by Federal law. We shall use the second meaning: a narcotic is a drug derived from opium or having morphine-like properties. Narcotic analgesics include morphine and codeine, two drugs derived from opium. Such drugs are very powerful; they are used for severe pain such as that following surgery, the breaking of a bone or severe burns of the skin. (These drugs also slow the peristaltic motion of the bowel and depress the cough reflex.)

Stimulants

Probably the most commonly used stimulant is caffeine. It is found in coffee, tea and cola drinks and in nonprescription stimulants such as No Doz. It is also added to nonprescription analgesics, such as Empirin and Vanquish, because it increases the effectiveness of aspirin in relieving certain types of headache.

Amphetamines are a group of powerful central nervous system stimulants that were once very popular as diet pills and, on the black market, as "pep" pills and injectable "speed." In the early 1970's the Food and Drug Administration (FDA) concluded (1) that amphetamines were effective in making people lose weight, but (2) that patients on amphetamines lost only a fraction of a pound per week more than other patients who were simply on restricted diets, (3) that amphetamines were effective for weight loss only during the first few weeks of use, (4) that amphetamines were capable of producing physical dependence (see "Drug Abuse" below) and (5) that the risk of abuse of injectable amphetamines was considerable. As a result, the FDA reduced the amount of amphetamines legally manufactured in the United States by 92% between 1971 and 1973, banned manufacture of injectable amphetamines and required that the labels on all amphetamines warn doctors that the drugs should be used with extreme care and only for a few weeks along with diet restrictions in weight-reduction treatment.

Some deadly poisons, such as strychnine and tetanus toxin, are also central nervous system stimulants. By increasing the excitability of neurons and by blocking inhibitory mechanisms, these substances are capable of producing strong convulsions. Death results from sustained contraction of the diaphragm and suffocation.

DRUGS ACTING ON THE AUTONOMIC NERVOUS SYSTEM

You may recall that the autonomic nervous system is that part of the nervous system which controls the actions of the digestive organs, heart, blood vessels and glands. It regulates such things as respiration, heart rate and the flow of blood through the vessels. We have seen that this system is divided into two branches, called the sympathetic nervous system and the parasympathetic nervous system. Most organs controlled by the autonomic nervous system is connected to both the sympathetic and the parasympathetic branches, and the nerves of these two branches produce opposite effects on the organs. For example, one branch makes the heart rate faster, the other slows it down. This arrangement enables the autonomic nervous system to maintain a fine homeostatic balance in each of the organs it controls. It also permits this system to produce rapid changes in these organs in emergency situations.

A drug acting on the autonomic nervous system may stimulate or depress either the sympathetic or the parasympathetic branch. One drug that has a variety of effects on the body through the autonomic nervous system is epinephrin, a sympathetic nervous system stimulant. This is a hormone produced naturally by the body, but it can be prepared synthetically or extracted from the adrenal glands of animals. Some of the effects of this drug are familiar to you if you have had "stage fright" or an acute attack of "butterflies" just before an important test. Some of the therapeutic uses of epinephrin include increasing the heart rate and the strength of the heartbeat; constricting blood vessels (useful for slowing bleeding or for slowing the flow of an injected local anesthetic such as procaine away from the area under anesthesia); and relaxing the bronchial muscle (useful for relief from symptoms of asthma and other allergic reactions--Tom was given epinephrin when he had his asthma attack).

DRUGS ACTING ON THE CARDIOVASCULAR SYSTEM

The main medical effect of a drug in this category is to alter some function of the circulatory system. It is useful to keep in mind that several drugs that affect the circulatory system have been included above in other categories connected with their other pharmacological functions. Epinephrin is such a drug.

Digitalis

This drug (and its active ingredient digitoxin) is one of the most valued medicines in the treatment of <u>congestive heart failure</u>, which is abnormal accumulation of fluid in the blood vessels caused by heart disease. Digitalis increases the force with which the heart contracts, thus increasing the flow of blood. Digitalis is also useful in treating certain irregularities in the heartbeat.

Antihypertensives

These are the drugs used to treat hypertension. The causes of hypertension are often obscure, and several types of drugs that act in different ways have the effect of reducing hypertension. One such type of drug is a diuretic. A diuretic acts to speed the formation of urine and thus to decrease the amount of water in the body. Diuretics may decrease blood pressure by decreasing the volume of blood in the blood vessels. You may be familiar with diuretics sold on a nonprescription basis. They are used to decrease the amount of water in the body and thus to get rid of the extra weight a woman gains due to water retention around the time of her menstrual period. Other familiar substances that are pharmacologically classed as diuretics include alcohol, caffeine and water.

Vasodilators

Vasodilators dilate (increase the diameter of) the blood vessels. One of their most common uses in medicine is in the treatment of angina pectoris, a condition characterized by acute pain arising from a lack of oxygen in the heart tissue. Nitroglycerine is a vasodilator commonly used to relieve the symptoms of angina pectoris. By dilating the blood vessels it decreases the work the heart must do to push blood through them, thus lowering the heart's requirement for oxygen. The result is that the heart muscle gets enough oxygen and the pain is eased.

DRUGS ACTING ON THE GASTROINTESTINAL TRACT

The disorders of the gastrointestinal tract most commonly treated with drugs are peptic ulcer, constipation and diarrhea.

Antacids

As you may recall, the treatment of peptic ulcer involves administration of drugs known as antacids. The most popular antacids are aluminum and magnesium salts. Their function is to raise the pH of the stomach contents by neutralizing the acid, which is an irritant to ulcers.

Laxatives and cathartics

Both laxatives and cathartics promote defecation; the action of cathartics is more intense than that of laxatives. Laxatives promote formation of soft feces. Some laxatives act by adding one or another kind of nondigestible bulk, such as a cellulose derivative, to the contents of the intestine; this bulk absorbs water and thus keeps the feces soft. Other laxatives act by adding a softening agent other than water, such as mineral oil, directly to the feces. Some cathartics act by stimulating the muscles that move the feces through the intestine; one such stimulant cathartic is castor oil, which stimulates the small intestine. Another is cascara sagrada, which you prepared in Laboratory Activity 14, and which stimulates the colon. Other cathartics act by adding to the digestive tract certain salts which are incompletely digested and which draw water into the intestine; among these are certain magnesium salts, sulfates and tartrates.

Laxatives and cathartics were at one time widely prescribed because it was believed that persistent constipation could result in the absorption of poisonous waste products into the blood. This is no longer held to be true, and the prescription of laxatives and cathartics has decreased accordingly. However, these drugs still have some therapeutic uses. For example, after surgery for the removal of hemorrhoids (dilated blood vessels in the colon or rectum) it is desirable to have soft stools in order to avoid straining or stretching the tissues.

Antidiarrhetics

These drugs combat diarrhea in either of two ways. Some add to the feces a substance which absorbs water. One such substance is kaolin, a clay, which is available in nonprescription drugs. Antidiarrhetics of the other class act by slowing the activity of the muscles that move the feces through the intestines; the slower the feces move, the more water is absorbed from them through the intestinal wall. The most effective antidiarrhetics of this class are opium preparations such as paregoric.

DRUGS ACTING ON THE BLOOD

A great number of drugs act on the blood and the blood-forming organs. Among the most important are the drugs used in treating the many forms of anemia. Because minerals and vitamins play important roles in the formation of blood one would expect them to be prominent agents in the treatment of blood disorders. In fact, iron, copper, vitamin B_{12}, folic acid, riboflavin and many other vitamins and minerals are useful in the treatment of anemias.

Among the most important drugs that act on the blood are chemicals that inhibit the clotting function of the blood. These drugs are called anticoagulants, and the most popular among them is heparin, a drug obtained from animal livers and lungs. In recent years heparin has been widely used to treat cardiovascular conditions involving the formation of unwanted clots in the blood vessels.

DRUGS ACTING ON THE ENDOCRINE SYSTEM

The endocrine system releases hormones that regulate a multitude of physiological processes (growth, sexual development, blood-sugar levels, etc.). Many hormones can be extracted from the glands of animals or synthesized in the laboratory. They can be used to treat endocrine disorders involving the presence of too little or too much of a hormone in the body. For example, insulin is a hormone sometimes used to treat diabetics.

Hormones may also be used to regulate certain processes in the body when there is no medical disorder. Birth-control pills are a good example. They contain quantities of two hormones which normally regulate the ovulatory cycle in the female.

DRUGS ACTING ON MICROBES

This category of drugs is subdivided according to the types of microbes the drugs attack. There are three basic groups.

Antibacterial and antifungal drugs

As their names imply, the targets of these drugs are bacteria and fungi. We have already seen an example of an antibiotic (penicillin) and explained how it destroys bacteria. Most antibacterial and antifungal drugs are antibiotics. Which of these drugs a doctor prescribes depends on which kind of bacterium or fungus is present; different drugs attack different kinds of bacteria and fungi.

Antiprotozoal drugs

These drugs attack protozoa, which are one-celled animals. Some kinds of protozoa are found in the digestive tract of man. Some of them cause disease. For example, amebic dysentery is a disease caused by an ameba, and drugs used in its treatment fall into this subcategory.

Topical antiseptics

These agents are applied to the skin to stop or inhibit the growth of microorganisms. They are used to prepare the skin for surgical procedures and to sterilize instruments. One commonly used antiseptic is tincture of iodine.

ANTICANCER DRUGS

These are many in number, yet there is no effective drug therapy for many kinds of cancer. Many anticancer drugs work by inhibiting cell division or destroying dividing cells. In recent years a great deal of effort has gone into research on anticancer drugs.

VITAMINS AND MINERALS

Vitamins and minerals are used in medicine to correct nutritional deficiencies. Vitamins have also at times been given as therapy for disorders that are not nutritional. Some people take large doses of vitamin C for a cold, for example.

Various claims have been made for the use of vitamins in non-nutritional disorders, but many of these claims are unsubstantiated.

TOXICOLOGY

Toxicology is the branch of pharmacology that deals with the nature and effects of poisons and with means of detecting and treating toxic (poisoned) states. This is an important part of pharmacology because many medical drugs have toxic effects in addition to their medically useful effects. A pharmacology book indicates the possible toxic effects of these drugs and the means of detecting and treating them. It may also include a section on the detection and treatment of toxic states caused by chemical poisons other than medical drugs, such as household cleansers, industrial chemicals and insecticides. This information is important because there are well over a million accidental poisonings in the United States each year, about half of them involving small children and several thousand of them being fatal. The treatment depends on the nature of the poison, and may consist of such things as the use of drugs to cause vomiting; the use of a "stomach pump"; feeding of materials that absorb the poison, such as milk, egg white, flour, starch or powdered activated charcoal; use of diuretics with other drugs to promote elimination of the poison; and use of antidotes, which prevent or counteract the effects of some poisons.

DRUG ABUSE

The term "drug abuse" like the term "narcotic," has more than one meaning. Just as one meaning of "narcotic" is "a drug defined by law as a narcotic," so one meaning of "drug abuse" is "an act defined by law as a drug abuse." Drug abuse may also be defined as the misuse of a medical drug, such as using an antacid to treat a headache or prescribing an antibiotic for a condition that cannot be cured with antibiotics; such misuses may not fall within the legal definition of "drug abuse," but from the point of view of the medical professions they are abuses of drugs.

In recent years many pharmacology books have included sections on drug abuse, chiefly because of the increasing incidence of abuse of drugs that alter mood or behavior, including narcotics, barbiturates and other sedative-hypnotics, alcohol, amphetamines and cocaine. All these drugs are capable of producing drug dependence, which may be of two kinds. One is habituation, which is a craving for a drug in order to produce pleasure or abolish discomfort. The other is addiction, which is characterized by the appearance of physical symptoms when the drug is withdrawn; these symptoms are called a withdrawal syndrome. All of the types of drugs mentioned above are capable of producing habituation, but not all of them are capable of producing addiction.

Some of the types of drugs listed above are capable of producing tolerance, which is the need for increasingly large doses of the drug in order to produce the same effect. A chapter on drug abuse in a pharmacology text is likely to contain information on the potential of various drugs to produce tolerance, habituation and addiction, the incidence of addiction, the effects of addiction and the symptoms of withdrawal.

What kinds of information about drugs are contained in a pharmacology textbook?

How are such books organized?

Name one narcotic drug. One stimulant. One heart drug.

Why are amphetamines no longer commonly used in dieting?

Define toxicology. Of what value are pharmacology and toxicology to the average person?

Vocabulary

addiction (uh-DIK-shun)--need for a drug, such that withdrawal of the drug produces physical symptoms; sometimes called physical dependence.

analgesic (AN-ul-JEE-zik)--a drug that kills pain.

anesthesia (AN-ess-THEE-zhuh)--a loss of sensation.

cathartic--a drug used to cause a bowel movement by stimulating the muscles of the intestine or by drawing water into the intestine.

congestive heart failure--an abnormally high concentration of fluid in the blood vessels caused by heart disease.

depressant--a drug that decreases the activity of neurons; a "downer."

general anesthetic--a drug that produces loss of sensation and loss of consciousness (compare "local anesthetic").

habituation (huh-BIT-chew-A-shun)--craving for periodic or chronic use of a drug in order to produce pleasure or abolish discomfort; sometimes called psychic dependence.

hypnotic (hip-NOT-ik)--a drug that produces sleep (compare "sedative").

laxative--a drug used to cause a bowel movement by softening the feces. Laxatives are more gentle than cathartics.

local anesthetic--a drug that produces loss of sensation in a localized area without loss of consciousness (compare "general anesthetic").

narcotic--a drug derived from opium or having morphine-like properties. (There are other definitions.)

sedative--a drug that quiets the central nervous system without producing sleep or killing pain (compare "hypnotic").

stimulant--a drug that stimulates the activity of neurons; an "upper."

tolerance--need for increasingly large doses of a drug in order to produce the same effect.

toxicology--the science dealing with detection, evaluation and treatment of poisons.

vasodilator (VAY-zo-DIE-lay-tur)--a drug that causes an increase in the diameter of blood vessels.

withdrawal syndrome--physical symptoms that appear when a drug is withdrawn during physical dependence.

SECTION 17: ANTIBACTERIAL AGENTS

17-1 Case History

"Any appointments, Calamity?"

"Yes, Dr. Holliday. The Earp boy will be in at ten. He called and made the appointment just this morning."

"Hmm. What's Wyatt doing these days? Wasn't he the one that was interested in going into physical therapy?"

"That's right. I believe he said he had a summer job at the Ike Clanton Memorial Pediatric Clinic."

"Oh, yes. Well, I wonder what's bothering him."

"Maybe he's sick of children. There's the bell, that's probably him."

The nurse padded off, and soon she returned with the patient and his file.

"Good morning, Wyatt. How are things down at the corral?"

"O.K.," said Wyatt, hoarsely.

"What can we do for you?" asked the doctor.

Wyatt pointed at his throat and grimaced.

"Sore throat?" asked the doctor.

Wyatt started to nod "yes," but stopped suddenly. He touched his fingertips to the glands under his jaw and grimaced. Then, doing his best to talk without moving any part of his mouth, he said, "Sore throat."

"Glands a little sore?" said the doctor.

"Very sore," said Wyatt, very carefully.

"Any other symptoms?"

"Headache," said Wyatt, pointing at his head. "Nausea," holding his stomach. "Fever."

"I see," said the doctor. "Well, let's have a look at your throat."

Wyatt opened wide and the doctor looked in. Wyatt's throat was badly inflamed, very red with a lot of tiny, white pus pockets. The doctor nodded, put a thermometer in Wyatt's mouth, and told him to close it.

While waiting for the thermometer, the doctor looked over Wyatt's record. Nothing much had happened to him during his eighteen years, just a couple of allergies, a sprained ankle and an infection from an arrow in his right buttock. He took the thermometer out of Wyatt's mouth and checked the temperature. It was 103.5 °F.

"Bad sore throat, all right," said the doctor. "Tell me, now, about this summer job of yours. Pediatric clinic, right?"

"Right."

"Any sore throats in there lately?"

"Some," said Wyatt.

"Strep?"

"One a couple of days ago."

"You help on the case?"

"Yes," said Wyatt.

"Well, then, that's probably what it is. I'll take a culture from your throat to make sure--it might be some other kind of bacteria--but in the meantime I'll start you on an antibiotic for streptococci."

"What if it's not strep?" asked Wyatt.

"Well, we'll know within a couple of days, and if it's not strep then we'll adjust the treatment accordingly. But it probably is strep, and you've got more to lose by letting those things multiply in your throat than by taking an unnecessary antibiotic for two days."

"O.K.," said Wyatt.

"Now," said the doctor, "the best drug for strep is penicillin. Even if it doesn't kill the little beasties in your throat it'll do you relatively little harm --unless you're allergic to it. Are you?"

"Don't know," said Wyatt. "Never took it."

"Well, we'd better check, then," said the doctor. "A lot of people have allergic reactions to it. About one in ten. More than one in ten in the case of people who're allergic to other things, and I see in your record that you've had some troubles with cats and pollen."

"Sure have," said Wyatt.

"What we'll do is a scratch test. I'm going to dip this little needle into a dilute solution of penicillin and just nick your arm with it. If that starts a rebellion--swelling and redness--we'll have to find another antibiotic. Roll up your sleeve."

Doctor Holliday dipped the needle into the penicillin solution and made a tiny scratch on Wyatt's arm with it. After 10 or 15 minutes there was no reaction.

"Well, that's one thing you're probably not allergic to," said the doctor. "I'll write out a prescription for you."

"Thanks," said Wyatt.

"Now, there's one or two things I have to tell you about this stuff," said the doctor. "One is that you are to take one 250-mg tablet four times a day for ten days. Another is that when I say ten days, what I mean is ten days. If the symptoms disappear before ten days are up, I still mean ten days. Just because you can't feel anything doesn't mean those bacteria aren't still in there. Got it?"

"Got it," said Wyatt.

"All right, that's it. The nurse will take the culture from your throat. It'll take about thirty hours to find out just what's living in there, so be sure you call me in two days."

"Sure will," said Wyatt. "Thanks."

17-2 Antibacterial Agents

How can the growth of bacteria be controlled in our environment?

Strep throat is one of the many diseases caused by bacteria. Since bacteria can cause many serious diseases, controlling the bacteria in our environment and in our bodies has become one of the most important tasks of the health scientist. Many antibacterial agents are currently used for combating harmful bacteria. An antibacterial agent is any substance or condition which prevents normal growth of bacteria.

Antibacterial agents work in a variety of ways. The agent may inhibit bacterial reproduction without killing the bacteria directly. This prevents continued bacterial growth and allows the body's immune system to eliminate the remaining bacteria. Other agents are capable of directly killing the bacteria. These agents are not always the best choice for treatment of a disease. In many cases, the agent may be as harmful to human tissue as it is to the bacteria.

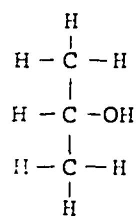
Although certain antibacterial agents may not be suitable for disease treatment, they can often be used for disease prevention. Most of us use antibacterial agents every day to destroy bacteria in our food, water and environment. There are far too many substances used for this purpose to be discussed here. However, a partial list of some common antibacterial agents is provided so that you may get some idea of the many ways in which these agents can be used.

Oxidizing agents: Chlorine, when added to water, produces hypochlorite ion, which is a strong oxidizing agent. Hypochlorite kills bacteria by inactivating enzymes that are needed for bacterial metabolism. Chlorine is used in very small

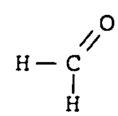
$$Cl_2 + H_2O \longrightarrow OCl^- + 2H^+ + Cl^-$$

concentrations to purify drinking water. Sodium hypochlorite is the principal active ingredient of many bleaches and cleansers, and is also used to purify the water in swimming pools.

Alcohols: If you have used a blood lancet to provide blood for a laboratory activity, you probably remember swabbing your finger with alcohol before puncturing your finger. Physicians also use alcohol to clean the skin before giving injections with a hypodermic syringe. The alcohol kills bacteria on the skin surface by coagulating bacterial proteins.



isopropyl alcohol.



formaldehyde.

Formaldehyde: This chemical is a gas which is quite soluble in water. The water solution is commonly used to preserve laboratory specimens. The formaldehyde prevents bacterial growth without damaging the tissues of the specimen.

Salt and Sugar: These two substances are commonly used to protect foods from bacterial decomposition. Most bacteria cannot grow and reproduce in an environment with either a high sugar or a high salt concentration. Meat, fish and olives are often cured with salt in order to prevent spoilage. Fruits are often preserved by combining them with large amounts of sugar (as in jellies and jams).

Detergents and Soaps: These substances act by dissolving the bacterial cell membrane, thereby killing the bacteria. Soaps may be made by combining sodium hydroxide with fats, thus producing the sodium salts of the various long-chain fatty acids.

$$[CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}\text{-}O^-]Na^+$$

A soap.

Fluoride: As used in toothpaste, this antibacterial agent does not directly kill or inhibit the growth of bacteria. Instead, fluoride is incorporated into the enamel of the teeth, making the enamel harder and more resistant to bacterial attack.

Heat: Heat is probably the most commonly used of all antibacterial agents. It is used for killing bacteria in our food and water, on laboratory equipment and home utensils, and anyplace else where dangerous bacteria may be present. Heat is also used for pasteurizing milk.

Most of these agents, when used correctly, can be effective in preventing disease. However, since they can also be injurious to human tissue, these agents have only limited usefulness for treating disease. For example, one of the best treatments for a simple cut is to wash the wound with soap and water. However, this treatment is clearly not suitable for the strep throat infection described in the case history.

Another important consideration when using antibacterial agents is that most of the bacteria in our body are not harmful, and many are necessary for normal body function. For example, bacteria are needed for normal digestion in the large intestine. Yet, the antibacterial agents discussed thus far are effective against almost all bacteria. In treating a bacterial disease, what is needed is an agent that attacks only pathogenic bacteria and, at the same time, has little effect on the normal bacteria of the body. Unfortunately, no antibacterial agent is that specific. All antibacterial agents damage some harmless and some useful bacteria.

The best defense against bacterial infection is the body's own immune system. As you may remember from Unit III, the body eliminates bacteria by producing antibodies, which bind with antigens on the surface of bacterial cells. White blood cells also attack and eliminate bacteria. Unfortunately, the body's immune system is not always effective in fighting off pathogenic bacteria. In such cases, another antibacterial agent (besides the body's immune system) is needed to eliminate the pathogenic bacteria.

17-3 Chemotherapy

How do antibacterial agents work when taken internally?

Around the turn of the century, a German chemist named Paul Ehrlich began searching for antibacterial agents that specifically attacked pathogenic bacteria without harming human tissue. Ehrlich was a medical doctor, who wrote that he was looking for "charmed bullets which strike only those objects for whose destruction they have been produced." This statement expresses the essence of chemotherapy and the challenge that still exists today.

Ehrlich was searching for compounds that could be used to treat bacterial diseases. He would test literally hundreds of compounds before finding one that worked. In fact, the first 605 chemicals tested were ineffective for disease treatment; the 606th chemical worked against syphilis and the first chemotherapeutic drug came to be called "606." This trial-and-error approach is typical of chemotherapeutic research; for each antibacterial drug that has proved to be safe and effective, hundreds have been discarded.

Few useful advances occurred in the field of chemotherapy until 1935, when the sulfonamides were discovered. These substances, commonly called "sulfa" drugs, proved to be very effective against certain types of bacterial infection, producing "miracle" cures when no other treatment would work. Sulfonamides worked so well because they attacked bacteria in a very special way.

Sulfonamides are effective because they interfere with the metabolism of many bacteria, thus preventing their growth. Certain bacteria require para-aminobenzoic acid (PABA) in order to synthesize folic acid, a substance that is essential for bacterial growth. Sulfonamides are very similar in structure to PABA (see Figure 1), and also react in much the same way. Consequently, in the presence of a sulfonamide drug, the bacteria produce a compound that is similar to folic acid, but does not function like folic acid. As long as the bacteria produce

FIGURE 1: A. para-aminobenzoic acid. B. a sulfonamide drug.

these non-functional compounds, the bacteria cannot grow. Sulfa drugs are not harmful to humans because we do not manufacture folic acid from PABA. We obtain folic acid by eating plants which already contain the vitamin. Consequently, sulfa drugs can be extremely effective in destroying certain types of harmful bacteria in our bodies.

Unfortunately, sulfonamides do not work on all pathogenic bacteria. The development of other chemotherapeutic agents did not occur until the beginning of World War II, when there was a large demand for drugs that would combat bacterial infection in battlefield wounds. In 1940, it was demonstrated that penicillin could be used as an effective antibacterial agent. This discovery was one of the most important events of modern medicine, since it provided a means for treating simple bacterial infections that previously had often been fatal. (Actually, the ability of penicillin to inhibit bacterial growth had been demonstrated in 1929. At that time, however, no one believed that it might be used to treat disease.) Since 1940, many other antibiotics have been developed that are capable of destroying harmful bacteria without doing damage to the body.

How do antibiotics work? Like sulfonamides, antibiotics generally take advantage of metabolic differences which exist between bacteria and man. Antibiotics usually disrupt either the synthesis or the structure of one of four components of bacterial cells. These components are listed below (Figure 2).

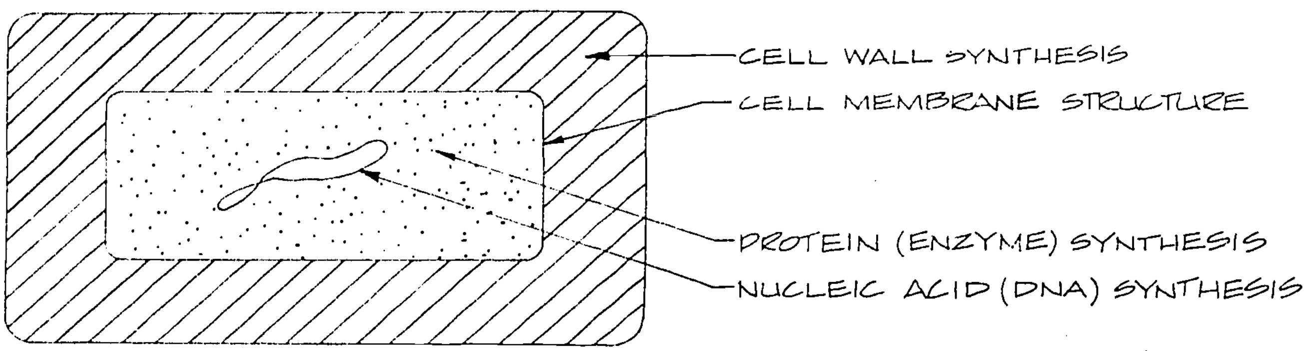


FIGURE 2: The four principal sites of antibiotic attack on a bacterial cell.

<u>Cell-wall synthesis</u>: Penicillin is an antibiotic that prevents the normal synthesis of the bacterial cell wall. Human cells do not have cell walls, so penicillin is not harmful to us (unless we are allergic to penicillin).

<u>Cell-membrane structure</u>: Normally, an intact cell membrane is needed to maintain the proper composition of any cell. If the cell membrane is disrupted, essential constituents of the bacterial cytoplasm can leak out of the cell, causing death or severe damage to the bacterium. Animal cell membranes are much more resistant to disruption by antibiotics than are bacterial cell membranes.

<u>Protein synthesis</u>: All living cells need proteins for both cell structure and cell metabolism. (Remember that all enzymes are proteins.) Fortunately, there are significant differences between protein synthesis in man and in bacteria. Antibiotics have been developed that selectively prevent protein synthesis in bacteria, but not in human cells.

<u>Nucleic-acid synthesis</u>: Nucleic acids (such as DNA) carry the coded instructions for the chemical organization of all life on earth. (This topic will be discussed more thoroughly in Unit V, Genetics.) If the nucleic acids of bacteria are synthesized incorrectly, the bacteria die. Some antibiotics interfere with nucleic-acid synthesis. These antibiotics are toxic to animal cells as well as bacteria and are not widely used in chemotherapy. However, they are suitable for treating certain skin diseases.

One of the biggest advantages of some antibiotics is that they can be used to kill only certain types of bacteria without killing all of the useful bacteria in the body. For example, penicillin is very effective against the streptococci bacteria which cause strep throat; yet penicillin has little effect on the bacteria normally found in the large intestine. Since there are many types of pathogenic bacteria, many antibiotics have been developed. Each antibiotic works best against certain types of bacteria.

When treating a patient, a physician needs to know which antibiotic will strike the pathogenic bacteria most directly. Usually, a sample of bacteria is taken from the patient, and the sample is sent to a laboratory where the bacteria are grown on agar Petri dishes. The task of the lab worker is to identify the bacteria or to find an antibiotic that is effective against the bacteria. The bacteria may be treated with special stains and then examined under the microscope. Often, antibiotics are applied directly to the growing bacterial cultures. The antibiotic that most effectively inhibits the growth of the pathogenic bacteria may then be used to treat the patient.

17-4 Which Drug?

How does a doctor decide which drug to prescribe?

The case history illustrates the stepwise method a doctor uses to determine what drug therapy, if any, should be used to treat a patient's illness. The first step is to find out what is wrong with the patient, to establish a diagnosis. When Wyatt went to see Dr. Holliday, the doctor asked him why he was there. What specifically was bothering him? Wyatt told the doctor of his problems (sore throat, swollen glands, headache, fever and nausea).

After Dr. Holliday had listened to Wyatt's complaints he performed a physical examination, paying particular attention to Wyatt's throat. Taking into consideration the inflamed condition of his throat, the pus pockets and the fact that Wyatt had a fever of 103.5 °F, Dr. Holliday tentatively diagnosed the condition as strep throat. To confirm the diagnosis the doctor did two things. First, he asked questions to find out whether Wyatt had been exposed to strep throat in the preceding week. Then he took a scraping from Wyatt's throat to culture it for the presence of streptococci, the bacteria that cause strep throat.

Although Dr. Holliday would have to wait about thirty hours to get the results of the bacterial culture, he was almost sure that Wyatt had strep throat because of the symptoms, the findings of the physical examination and the fact that Wyatt had indeed been exposed to strep throat only three days earlier.

The doctor's next step was to determine which drug was indicated in Wyatt's case--that is , which drug should be prescribed. Wyatt's symptoms, his high temperature and the fact that he had just been exposed to strep throat were all indications that the drug prescribed should be penicillin.

The doctor's next step was to determine whether penicillin was contraindicated in Wyatt's case--that is, whether there was any reason penicillin should not be used. A contraindication is a symptom or other circumstance that makes a particular method of treatment (including a particular drug) inadvisable. An important contraindication for any drug is an allergic reaction to the drug. A drug is also contraindicated if the patient is already taking another drug that reacts with the one being prescribed and thereby produces undesirable side-effects. Another kind of contraindication is the presence in the patient of some pathological condition that might be aggravated by the drug. For example, patients with kidney disease cannot take certain antibiotics. Since antibiotics are eliminated almost entirely by the kidneys, normal therapeutic dosages of certain antibiotics given to a patient with kidney disease could result in the accumulation of dangerously high levels of the antibiotic in the patient's body.

Dr. Holliday wanted to find out whether Wyatt would have an allergic reaction to penicillin. The doctor noted that Wyatt did have other allergies, and that Wyatt had not taken penicillin previously; so the doctor decided to do a scratch test. He applied a small amount of dilute penicillin solution to a needle and scratched Wyatt's skin with the needle. After 10 to 15 minutes there was no marked swelling or redness at the site of the scratch. This meant there was a good chance Wyatt would not have an allergic reaction to the penicillin. Just to play it safe, Dr. Holliday prescribed the drug in tablet form because he knew that the chances of allergic reaction are lower when the drug is administered orally than when it is injected.

The last thing Dr. Holliday did was to give Wyatt instructions on how to use the drug. He emphasized that Wyatt must take the drug for a full ten days even if his sore throat went away sooner. The reason for this is that when the bacterial population is small enough to produce no symptoms, it is still large enough to recover from the drug. If the drug is discontinued after a few days most bacteria will have died, but enough will remain to enable the infection to re-establish itself, and the symptoms will soon return.

Last, Dr. Holliday instructed Wyatt to check back in a few days for results of the culture. If the culture revealed streptococci as expected, Wyatt could simply continue the therapy. If it revealed some other bacteria that were resistant to penicillin, the drug therapy would have to be adjusted.

It should be mentioned that if Wyatt had turned out to be allergic to penicillin, Dr. Holliday could have chosen another drug to combat the infection. He tested penicillin first because penicillin is the "treatment of choice" for strep throat; of all the drugs known to be effective against streptococcal bacteria it is the safest, the most effective, and the one with which doctors and researchers have had the most experience.

Why is it desirable to be able to control bacteria in our environment?

Why are many antibacterial agents unsuitable for treatment of disease?

Is it necessary to rid the body of all bacteria? Why or why not?

List four ways in which antibiotics work to prevent bacterial growth.

What steps does a doctor go through in deciding which drug to prescribe?

Vocabulary:

antibacterial agent--any substance or condition which prevents normal growth of bacteria.

chemotherapy (KEY-mo-THAIR-uh-pee)--the prevention or treatment of disease by chemical agents.

contraindication (KON-truh-IN-di-KAY-shun)--any symptom or other circumstance that makes a particular method of treatment inadvisable.

SECTION 18: PLACEBOS

18-1 The Placebo Effect

What is a placebo? How does it work?

Medical drugs are useful for preventing, diagnosing or curing disease. Most of them are medically useful because of their chemical or physical actions in the body. For example, kaolin clay is useful as an antidiarrhetic because it has the physical property of absorbing water; heparin is useful as an anticoagulant because it has the biochemical property of inhibiting a certain chemical reaction that is necessary for clotting. These and almost all other drugs act directly on some part of the body (or on some organism living in the body, as penicillin acts on bacteria) to bring about some change within the body.

There is one kind of drug, however, that does not work in this way. This kind of drug does not require any particular chemical or physical properties in order to work, because it works without directly affecting any part of the body or any organism living in the body. The important thing about this kind of drug is not what is in it, but who gives it to the patient and under what conditions; for the effects of treatment with this kind of drug are not chemical or physical, but psychological. This kind of drug is called a placebo.

Medical researchers have found that many patients--people with a variety of disorders--get better simply because they have been treated, even if the treatment did not have any direct effect on their illness. For example, sometimes a patient goes into surgery but does not get the operation expected: the surgeon cuts open the patient but then decides, for one reason or another, that the operation should not be performed. In such cases, some patients get better anyway! Their illness responds to the fact that someone has operated on them, even though the operation was not completed. This phenomenon--improvement in a patient even though the treatment given has brought about no physical change--is called the placebo effect.

The placebo effect occurs in response to several kinds of treatment. One is ineffective surgery. Another is drug therapy with pharmacologically ineffective drugs: the use of placebos in place of real drugs. Researchers have found placebos effective in relieving a variety of complaints, including several kinds of pain. Placebos relieve some people of pains ranging in intensity from mild headaches to angina pectoris and postoperative pain (pain following surgery).

How do placebos work? An important clue is the fact that they don't work on everybody, although most people get relief with them some of the time. Researchers have suggested that placebos may work on some people because of certain personality traits.

There have been few attempts to identify the personality traits that make a person responsive to placebos, but the few studies that have been done indicate that one important factor might be suggestibility. Suggestibility is simply the tendency to be influenced by various kinds of suggestions. Some people are more suggestible than others. A very suggestible person who has felt fine all day might begin to feel terrible the moment someone walks up to him and says, "You look terrible." Some experts believe that highly suggestible patients might be the ones most likely to respond to placebos.

One study conducted in the 1950's sought personality differences between patients who responded well and patients who did not respond at all to placebos, when placebos were given for postoperative pain. The researchers found no difference in the average age or IQ of the two groups, and no higher proportion of members of either sex in either group. They did find that, as a group, the patients who responded well to placebos had less education, liked hospitals more, tended to develop physical symptoms under stress, and were more cooperative, more concerned about themselves, more talkative, more religious, more anxious, less hostile and more concerned with their pelvic and abdominal regions. These findings do not explain why some people respond better to placebos than others, but they do indicate that personality differences might be involved.

Of course, we cannot conclude from these differences between groups that every person who responds well to a placebo has all these personality characteristics, or even some of them. Nor can we predict with any certainty that a person who has some or all of these characteristics will respond well to placebos. All we can conclude is that the patient's personality is one thing that might affect the way in which the patient's body responds to a placebo.

Some other things that appear to affect the way a patient responds to a placebo include the type and severity of illness, the attitude of the doctor who administers or prescribes the placebo and the environment in which the placebo is taken.

18-2 Clinical Use of Placebos

What are placebos used for in clinical medicine?

Doctors sometimes administer or prescribe placebos for patients whom they are treating for real disorders. Placebos are useful in medicine because in many cases they do have a beneficial effect on the patient, even though the reason for this effect is not known. A doctor might prescribe a placebo while awaiting the results of diagnostic tests which may identify the nature of the patient's disorder. A placebo may also be used by a physician for an unidentified condition that does not appear serious enough to warrant extensive testing or for an identified condition that cannot be cured by drugs.

In any of these situations it is pointless to give the patient a pharmacologically active drug. But it may be necessary to give the patient something, if only because the patient requires proof that the doctor is doing all he can. And when the patient begins to take the placebo--who knows?--the patient may get better. Some people do: the mere fact of receiving attention from the doctor brings about a psychological change that somehow enables the patient's body to recover, partially or completely, from the disorder. We do not understand how the placebo effect works, but presumably the brain, through its neural control of the body, is involved in this effect. The placebo often reduces the seriousness of the patient's symptoms. The patient senses that he or she feels better.

Some of the placebos used in clinical medicine are pharmacologically inactive substances, such as sugar pills and shots of saline solution. In most cases, however, doctors prescribe drugs that really are pharmacologically active, but only minimally so. In either case, the doctor is depending not so much on the pharmacological effects of the drug but more on the psychological effects of the treatment. Some doctors have found in practice that these psychological effects are heightened by the use of bitter flavorings added to pills, bright colors in pills or fluids, or pills that are either very large and impressive or very small and therefore potent-looking.

The placebo effect has something in common with psychosomatic illness and with biofeedback training: in all three, events in the brain ("mental" or "psychological" events) influence the health of the rest of the body. In a psychosomatic illness, the mind appears to cause body functions to change for the worse. For example, peptic ulcers and indigestion, which we considered in the Nutrition Unit, can be caused or aggravated by mental stress. In biofeedback training, the opposite happens: the mind can sometimes make the body well instead of making it sick. For example, a person can learn to alter the blood flow in one hand and thus prevent or cure migraine headaches. The placebo effect and the effects of biofeedback training are similar in that both can be used to heal the body; they are different, however, in that the placebo effect works only if the patient does not know it is the placebo effect that is working. Nobody knows for sure just how any of these things--psychosomatic illness, biofeedback training and the placebo effect--take place. We do know that they all involve the central nervous system and probably the sympathetic nervous system. As more is learned about the nervous system, it is likely that the mechanisms of these three mental-and-bodily processes will become more clearly understood.

18-3 Experimental Use of Placebos

How else are placebos used?

Placebos are often used as controls in the testing of new drugs before they are put on the market. The FDA requires both that a new drug be effective and that its desirable effects outweigh its undesirable ones. But how effective should a new drug be? Even placebos are effective, in many patients, against a variety of disorders. But placebos are effective psychologically, not pharmacologically. The FDA wants new drugs to be pharmacologically more effective than a placebo. A new drug that "works" only because it is a pill prescribed by a doctor should not be on the market.

After a new drug is tested on animals to ensure that it is not grossly unsafe, the FDA requires three phases of testing on human subjects. In Phase I, the new drug is given to a small number of volunteers, usually healthy, in order to determine how it is absorbed into the body, what chemical actions it has in the body, how it should be administered (orally, by injection, etc.) and what the safe dosage range is. There is some danger to the subjects in this phase of testing. After all, they are the first humans to use the drug, and nobody really knows what will happen to them. But the FDA has guidelines to protect the subjects, and during the first twelve years of testing drugs under these guidelines no subject was permanently damaged. Some subjects got sick, but they later got better. Phase I is intended to show that the drug does do something in the body and that it does not have unacceptable side effects. If the drug passes Phase I, it is tested on patients in the next phase.

In Phase II, the new drug is given to a small number of patients who have the disorder that the drug is supposed to be effective against. During this phase, researchers attempt to determine whether the drug actually has any effect on the disorder and, if so, what effect it has. If the drug is successful in this phase of the testing, then the FDA allows that the drug might be effective, and research proceeds to Phase III.

In Phase III the drug is tested on a large number of patients for the purpose of determining how safe the drug is, how effective it is and what dosages are best for producing desired effects. During this phase, the researchers must show that any desirable effects they observe really are effects of the drug they are testing. One way of doing this is to test the drug against a placebo and show that the new drug is more effective than the placebo.

Such a test is conducted as follows. The researchers assemble two groups of patients who are suffering from the disorder in question. The two groups are matched for such things as age, sex and any other variables that might influence the patients' responses to the drug. Then one group is treated with the new drug, and the other group is treated with the placebo. The group that gets the new drug is called the experimental group; the group that gets the placebo is called the control group. This is a blind experiment: the subjects are not aware whether they are getting the drug or the placebo (in fact, they do not know that any of them is getting a placebo). In most cases it is also a double-blind experiment: the physicians and other researchers who deal with the patients also do not know who is getting the drug and who is getting the placebo. (Records are kept so that the results in the two groups can be compared when the experiment is over, but the researchers themselves do not know which patients are in which group.) This arrangement ensures that the researchers will not treat the two groups differently; without this arrangement, the behavior of the researchers might influence the patients' responses.

After Phase III is completed, the drug company must submit to the FDA the results of Phase III along with a variety of other kinds of information about the new drug, and the FDA then decides whether to allow the drug to go on the market. Many drugs do not survive Phase III. Some are found to be no more effective than a placebo. Some are even found to be worse than a placebo: their side effects make patients sicker, whereas the placebo at least does not hurt the patients. Whatever the outcome, placebos are useful in drug research because they enable researchers to distinguish between the pharmacological effects of a drug and the psychological effects of being treated.

What is the difference between the way placebos work and the ways other drugs work?

In what sort of situation might a doctor prescribe a placebo to a patient who has come to him with a complaint?

How are placebos used in research on new drugs?

What is the advantage of a double-blind experiment over a blind experiment?

How can a drug be worse than a placebo?

Vocabulary:

blind experiment--an experiment in which the subject does not know which of several kinds of treatment he is receiving. (Also called a single-blind experiment.)

control group--in an experiment to test the effects of some procedure (such as taking a new drug), the group that does not receive the procedure being tested.

double-blind experiment--an experiment in which neither the subjects nor the experimenters know which of several kinds of treatment any subject is receiving.

experimental group--in an experiment to test the effects of some procedure, the group that receives the procedure being tested.

placebo (pluh-SEE-bo)--a drug that works because of the psychological effects of the situation in which it is given, not because of the physical or chemical effects of the drug itself.

placebo effect--improvement in a patient who has received treatment (such as drug therapy with a placebo) which is not really chemically or physically effective.

SECTION 19: ALCOHOL

19-1 Nonmedical Drug Use and Health Care

Why are drugs that have little or no use in medicine important to health-care providers?

In the last several sections we have discussed drugs that are important to medicine because they can be used in treating diseases. Many such drugs are derived from natural sources and have been used in crude forms for centuries, often by people who had no idea why they worked or who explained their healing powers in terms of supernatural powers.

Today all these drugs are synthesized in the laboratory or, if derived from natural sources, they are highly purified. Moreover, most of the drugs we have discussed are used only in medicine, for the purpose of preventing or treating disease.

In this section and the next one we shall discuss four drugs that are important to medicine in a different way. These are drugs that are often used for nonmedical purposes: alcohol, opiates, cocaine and marijuana. Such drugs are medically important because their use sometimes results in health problems that health-care providers have to treat. Some of these substances also have medical uses and some of them do not. We shall describe their medical uses, but we shall concentrate on their nonmedical uses.

All of these drugs act directly on the central nervous system (CNS); three of them are depressants and one is a stimulant. In each case, some of the possible ill effects of using the drug are the result of the drug's action on the CNS. But in each case, as we shall see, the ill effects depend on the circumstances in which the drug is used, as well as on the pharmacological properties of the drug itself. This is why we speak of the ill effects of the use of drugs, as opposed to ill effects of drugs. Some of these drugs have pharmacological properties that are dangerous, but many of the possible ill effects of their use have nothing to do with their pharmacological properties.

19-2 Alcohol and the Central Nervous System

What are the immediate effects of alcohol on the body?

Alcohol* once had several medical uses. It was used as a sedative-hypnotic, to calm jangled nerves or induce sleep. It was used as a general anesthetic, to cause loss of sensation and loss of consciousness during surgery. And it was used as a disinfectant on open wounds. Today, however, most of the medical uses of alcohol have been taken over by other drugs that are safer or more effective.

Alcohol is rapidly absorbed from the stomach and small intestine. Once alcohol enters the bloodstream, it is rapidly distributed to all parts of the body except the fat and bones. Alcohol is metabolized (broken down) in the liver and excreted through the kidneys. The products of alcohol metabolism are carbon dioxide (CO_2) and water.

The use of alcohol has several kinds of consequences, all due to the nature of the drug itself. First we shall describe the immediate effects on the user.

Alcohol is a CNS depressant. The intensity of the depressant effect depends in part on the dose consumed, but it can range from mild sedation through all the levels

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*The term "alcohol" is used by the organic chemist to mean "any organic compound with an -OH group attached to a carbon atom." The same term is generally used in medical literature (and here) to mean a specific alcohol, ethyl alcohol $(H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH)$ or beverage alcohol.

of anesthesia to respiratory failure and death. Death occasionally occurs in drinkers who are showing off how well they can hold their liquor. Chronic use of increasing amounts of alcohol results in an increasing level of tolerance, or ability to drink more without getting drunk but it does not make a drinker immune to respiratory failure.

In moderate doses, one depressant effect of alcohol is reduction of the speed and accuracy of motor performance of all kinds, whether in simple tasks such as standing up or in complex activities such as typing. Another effect is impairment of mental functions such as learning, concentration and discrimination.

In small doses, alcohol may not act as a depressant on the brain at all. Rather, it may stimulate the brain by increasing the flow of blood to the brain.

In addition to these effects, the chronic use of large doses of alcohol has some other consequences, as the following case history illustrates.

19-3 Case History Female, Age 50

Mary Smith was 50, but she looked a lot older. Her legs and arms were thin, and she had a paunch. Her skin was pale, wrinkled and blotchy. Her hair was dry and thin. When she talked to people--if she talked to them at all--she seemed nervous and insecure. She was a loser, a wreck, shot to pieces.

People who had known her ten or fifteen years ago couldn't believe how she had changed. They noticed, said "Tsk," and shook their heads. Mary used to be healthy. And so attractive. She certainly had gone to pieces. She certainly had gone downhill.

Fifteen years ago--back when she was healthy and attractive and 35--Mary Smith and her husband had been on the way up. Finally. Henry had got himself a foothold on a career ladder, and they climbed. They "entertained a lot." They had parties where Henry's business associates and Mary's social connections came together and got acquainted. The more they drank, it seemed, the better acquainted they became. And the better acquainted they became, the brighter Henry's future looked. So they drank.

Bourbon, vodka, gin, scotch. Straight up or on the rocks? Extra dry, and make it a triple. It was all rather new to Mary. So many different kinds of booze. She remembered a few sorority functions where everybody drank beer out of big paper cups and got high, but that sort of thing had always seemed rather childish. This, of course, was different. This entertaining was serious business. It was what really important people did. All the time.

Many didn't do it all the time, of course. Only at parties. Oh, an occasional cocktail with lunch, and then of course one or two--three?--before dinner, but that was different. Only occasionally with lunch. Right at first. Then more often. Well--all the time.

By the time she was 40, a little "pick-me-up" with breakfast wasn't unusual. Her friends didn't need to know about that, of course. She knew about the remarks one or two of them had made. That Mary sure can put it away. Drinks her lunch. That sort of thing. But she also knew she hadn't lost her looks. And they knew it too. They were jealous. Weren't they? Sure they were. Think I'll have a little vodka in my orange juice this morning.

But then she began to lose interest in food. She developed a "sensitive stomach." Didn't eat that much, and what she did eat was milk and ice cream, cream soups, broth--things that "set well with her stomach." Apples and wheat bread just didn't make it. By the time she was 45 she was getting more calories from the sauce than she was getting from food.

Henry was bound to notice, after a while. No matter how engaged a man is in ladder climbing, he is sure to take a glance at his family now and then. And one morning Henry just happened to be glancing when Mary poured the vodka in her orange juice. Needless to say, he was surprised. Here he was on the way up, and his wife was a bottle baby. That sort of thing only happened in stories. He told her she'd better cut it out. He threatened to take her to a doctor. He wasn't going to have a lush around the house, drinking up his liquor.

But he was all talk. It didn't make any difference. Mary just went along. Sometimes she would lose interest in food altogether. A few weeks ago she had practically stopped eating--ate almost nothing for several days. She hadn't felt good, and she had been depressed. But she still had the sauce, and so everything had gone along pretty smoothly.

Until now. Now, all of a sudden, she was in the bathroom on her knees, vomiting blood into the toilet. Lots of it. Bright red, fresh blood. Her own blood. And dark brown blood along with it. She saw it all.

Her husband was horrified. He called an ambulance and then he paced up and down. He was frightened. He felt helpless. It was repulsive. She might actually bleed to death and die right there on the floor. He could see it. It was awful. He didn't know what to do.

* * *

Mary Smith was in shock, but she remained conscious. She received emergency treatment at the hospital, including three blood transfusions, and was then transferred to general medical care for a complete evaluation. Findings included anemia and elevation of certain serum enzymes. An X-ray of the lower esophagus showed varices--varicose veins. The physical exam showed a liver that felt quite hard and somewhat irregular in shape--normally the liver is firm and smooth, if it can be felt at all--as well as an abdomen slightly distended with fluid, thin arms and legs, pale, wrinkled, blotchy skin and thin, dry hair.

* * *

"Mary, do you drink?"

"Sure, doctor. I have a drink now and then."

"What do you mean?"

"Oh--sometimes one a day."

"And what do you drink?"

"Wine, sometimes."

"Is that all?"

"Actually, sometimes, a highball."

"Mary, how many drinks do you have before six o'clock every evening?"

"Oh, I don't know. A few, I guess."

* * *

"Mr. Smith, your wife has severe liver damage. It has affected her liver circulation so badly that varicose veins have appeared in the lower esophagus. That's where she bled from. The chance that this will happen again is very great. And it can be fatal."

The doctor saw Henry's eyes go blank. Henry saw again what he had seen before, what he had imagined. Fatal. What a way to die.

"But, Doc, what if she stops drinking? Won't it be all right?"

"I'm afraid not," said the doctor. "It's essential that she stop, of course. But the liver damage will not reverse, even if she never has another drink in her life."

"Well," said Henry, "what do we do?"

"A good medical program will help some," said the doctor. "We'll get that started right away."

* * *

Mary went on the wagon. It was not an easy thing to do. From the first day she quit she had a craving, a need for alcohol. She was nervous, worried, anxious. Her hands shook. For the first few days it got worse and worse, but she stuck with it. She put up with the craving, the tremors and the anxiety because she was scared.

She didn't drink for two years. She improved some, but most of the ravages of ten years' alcoholism remained with her. Most of the damage was irreversible. Most of the harm she had done to herself, and to her relationships with others, was permanent.

After two years on the wagon, Mary started drinking. She quickly forgot why, and kept drinking. For several months she drank heavily. Then she had a massive hemorrhage. She died on the bathroom floor.

19-4 Medical Consequences of Chronic Use of Alcohol

What are the long-term effects of alcohol on the body?

Your initial reaction to the case history may be that we have chosen an extreme example of what alcohol can do. In a sense, we have. Mary does not represent the average drinker. However, she is fairly typical of alcohol addicts. There are over 5,000,000 alcohol addicts in the United States today, and many of them drink more than Mary did.

When Mary was examined at the hospital the clinical findings included a firm and enlarged liver, distended abdomen, thin arms and legs, pale, wrinkled, blotchy skin and thin, dry hair. Esophageal varices were found on X-ray examination. All of these findings are associated with malnutrition and with a condition known as cirrhosis of the liver.

Mary's thin arms and legs and the poor condition of her skin and hair were all symptoms of malnutrition, which is common among chronic alcohol users for two reasons. One reason is that alcohol, taken in large doses, irritates the digestive tract and thus lessens the user's desire for food. The other reason is that alcohol provides calories, and thus further lessens the desire for food.

Mary was no exception--she was badly malnourished. She had chronic gastritis (inflammation of the stomach lining). Because of that and the calories she got from alcohol, she ate only bland foods, consisting mainly of fat and carbohydrate, or she ate nothing at all. If you were to conduct a nutritional analysis of Mary's diet, using the methods described in the Nutrition Unit, you would certainly find her diet deficient in protein, vitamins and minerals.

Mary's malnutrition lowered her tissues' resistance to the stresses they were subjected to. Her liver cells, in particular, could not continue to process the large amounts of alcohol that Mary was drinking regularly. Her liver cells broke down faster than they could be replaced with new ones. The dead cells were replaced instead by scar tissue. The result was cirrhosis of the liver, which is a hardening of the liver due to the accumulation of scar tissue within the organ.

Cirrhosis, in turn, contributed to Mary's other medical problems. Large deposits of scar tissue in the liver interfere with the flow of blood through that organ. The blockage may become so severe that it causes the blood to back up into other vessels. These vessels then become distended, or stretched, and are called varicose veins. Esophageal varices are varicose veins in the esophagus. It was from these veins that Mary bled.

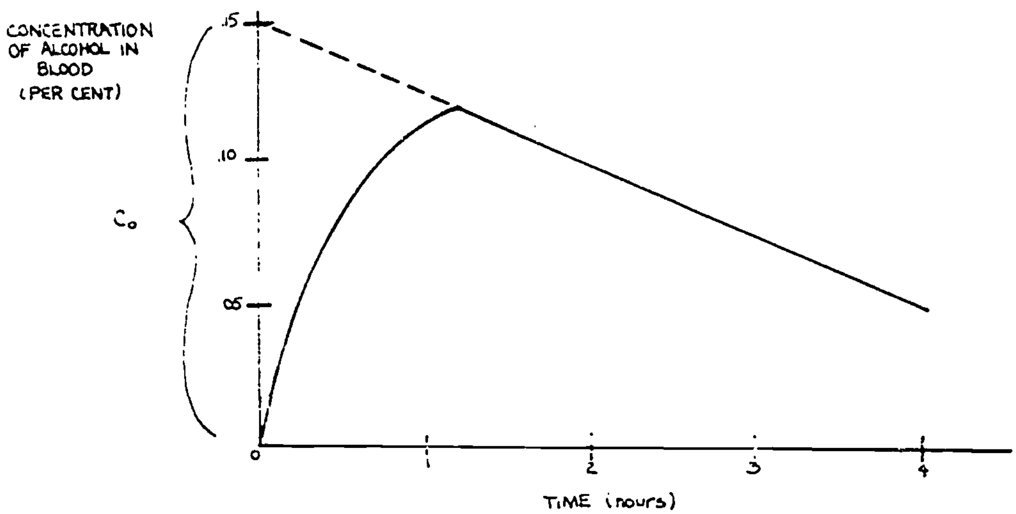
Another way in which the body tries to compensate for the blockage of the flow of blood through the liver is to allow fluids to diffuse out of the vessels and into the abdomen. These fluids accumulate in the abdomen, which thus becomes distended.

A note on dosage and effect: The pharmacological effects of a drug always depend on the dose of the drug used. Generally, the larger the dose, the more intense the effect. It was noted above that the immediate effects of alcohol consumption range from mild sedation to death due to respiratory failure, and that the intensity of the effects depends partly on the dosage. Similarly, the effects of chronic use of alcohol may include malnutrition, cirrhosis and even brain damage, but the intensity of the effects depends on the dosage, and if the dosage is small enough there may be no irreversible effects at all. The use of moderate amounts of alcohol over long periods of time has been found to produce such effects in some people but not in others.

19-5 Tolerance, Withdrawal and Addiction

How quickly is alcohol removed from the blood?

The graph below appeared in Mathematics Unit I. It is a graph of blood-alcohol concentration (per cent) as a function of time. After an individual drinks an alcoholic beverage, the concentration of blood alcohol rises rapidly for a short time;



then it reaches a peak, and after that it decreases as a linear function of time. When the linear portion of the graph is extended to the vertical axis, the straight line is described by the equation

$$c \approx \beta t + c_o$$

where c is the concentration, t is time elapsed since the alcohol was consumed and c_o is what the initial concentration would be if the alcohol diffused through the body immediately when it was consumed. β is the slope of the line; it indicates the rate at which the concentration decreases.

The value of c_o is related to the amount of alcohol consumed and the mass of the consumer by the equation

$$\frac{A}{m} \approx rc_o$$

where A is the amount consumed, m is the mass of the consumer and r is a constant of proportionality. This equation means that as the amount consumed goes up, the initial concentration goes up; as the mass of the consumer goes up, the initial concentration goes down.

There are two constants involved in all this: β, the slope of the line on the graph, which corresponds to the rate at which the blood-alcohol concentration decreases; and r, the constant of proportionality that relates the initial concentration to the amount consumed and to the mass of the consumer. The value of these constants have been calculated from observations of people who are not chronic drinkers of large amounts of alcohol. For these people,

$$\beta = -.01338 \pm .00184 \frac{\text{g alcohol}}{\text{100 g blood}} \text{ per hour}$$

and, if A is given in ml and m is given in kg,

$$r = 9.04 \pm 0.71$$

Both of these constants are different for chronic users of large doses of alcohol. For these people, r is larger, which means that the initial concentration is smaller after drinking the same amount of alcohol. And β is a larger negative number, which means that the blood-alcohol concentration decreases faster. In fact, if a person drinks a certain amount of alcohol every day for a period of several weeks, the initial concentration steadily decreases to near zero over that time, and the speed with which alcohol is removed from the bloodstream steadily increases. Why is that?

We have seen that alcohol acts immediately on the body as a CNS depressant, and that chronic use of large doses of alcohol leads to malnutrition and permanent liver damage. In addition to these direct effects of alcohol on the body, there are changes that occur as the body tries to adjust to the steady consumption of large amounts of alcohol.

The body of a chronic drinker attempts to maintain internal homeostasis by making a variety of changes in its biochemical processes. One such change is an increase in the speed with which alcohol is metabolized. As a consequence, after consuming a given amount of alcohol, the chronic drinker has a relatively low initial blood-alcohol concentration and the concentration decreases relatively quickly. In addition, the chronic drinker requires a higher blood-alcohol concentration than a non-drinker would require to feel the same effects. The result is that the chronic drinker becomes able to consume more alcohol per hour without feeling stronger effects of the drug. In medical terms, the body's attempt to maintain homeostasis produces a tolerance for the drug.

An individual's level of tolerance for alcohol depends on many things, including diet, the general state of health and perhaps some genetic factors. However, one of the most important determinants of the level of tolerance is the rate at which the body is accustomed to consuming alcohol. In a person who seldom drinks or who drinks only small amounts, alcohol is metabolized relatively slowly. In a person who chronically drinks large amounts, alcohol is metabolized much more quickly.

If a particular person consumes just slightly less alcohol per hour than his body metabolizes in an hour, then that person's blood-alcohol level will rise insignificantly and then remain stable, and the drug will have few if any noticeable effects on the drinker. However, if that same person drinks alcohol just a little bit faster than his body can metabolize it, then the excess alcohol consumed will steadily increase the blood-alcohol level and the person will rapidly get drunk. The difference in dosage for any particular person may be as little as a quarter of an ounce of whiskey per hour.

A person's level of tolerance for alcohol determines how fast that person must drink in order to feel the effects of the drug. If a chronic user of alcohol wants to feel slightly "high" day after day, then that person will have to drink gradually increasing amounts of alcohol each day in order to obtain that effect. As his level of tolerance increases, his dosage must increase to produce the same effects on his central nervous system.

We have seen that certain changes in the body produce tolerance in a person who keeps drinking the same amount or an increasing amount of alcohol per day. These same changes in the body also produce a withdrawal syndrome in a person who suddenly reduces the amount he drinks each day or stops drinking altogether. This person's body has gradually adjusted its biochemical processes so that homeostasis will be maintained when the customary dosage of alcohol is consumed each day. When the dosage drops suddenly, the homeostasis is drastically upset. The body cannot immediately adjust to the "shortage" of alcohol. The body's "overcompensation" in this situation produces a variety of predictable physical and psychological symptoms: the alcohol-withdrawal syndrome.

Note that the chronic user of alcohol does not have to stop drinking altogether in order to feel withdrawal symptoms. A person may drink heavily and still suffer withdrawal symptoms, if he is consuming alcohol more slowly than his body is metabolizing it.

We have defined addiction to a drug as the condition in which withdrawal of the drug produces symptoms. According to this definition, a person is addicted to alcohol if he or she suffers any of the symptoms of the alcohol withdrawal syndrome when the amount of alcohol consumed is reduced.

The alcohol withdrawal syndrome includes five different stages, which are summarized in the table below. The nature and severity of symptoms depend on how long and how much the patient has been drinking. The higher the level of tolerance has become, the worse the symptoms of withdrawal will be. The mildest stage may occur after only a few days of drinking followed by a few hours of abstinence. The most severe stage occurs only after months of heavy drinking followed by several days of abstinence.

A given patient may pass through one or all of these stages. If several occur, they occur in a predictable sequence (with some overlap), beginning with the symptoms at the top of the table and progressing toward the bottom of the table.

STAGES OF THE ALCOHOL WITHDRAWAL SYNDROME
(Listed in order of increasing severity)

STAGE	POPULAR NAMES	SYMPTOMS AND PROGNOSIS
1	the shakes, the jitters	tremor, irritability, nausea, vomiting; major symptoms subside in a few days
2	--	disturbed sleep, bad dreams, distorted perceptions, visual hallucinations; occurs in one fourth of cases of Stage 1
3	--	sound hallucinations, usually voices of familiar people; usually subsides within a few days, but persists in some cases and becomes chronic in a few
4	rum fits	major generalized convulsion with loss of consciousness; one or several seizures within two days after withdrawal; many patients enter Stage 5 within days after seizures stop
5	D.T.'s	confusion, delusions, hallucinations, tremor, agitation, sleeplessness, dilated pupils, fever, increased heart rate, perspiration; subsides after a few days in most cases, but fatal in about 15% of cases

19-6 <u>Habituation and Alcoholism</u>:

What is alcoholism? Is it different from addiction to alcohol?

We have seen that alcohol can cause tolerance and a withdrawal syndrome; that is, drinking alcohol produces addiction, or physical dependence. Alcohol can also cause habituation, or psychological dependence. A person can become habituated to alcohol without becoming addicted to it. A person in this condition does not suffer any physical symptoms when the drug is withdrawn, but does feel a desire or a need for the drug.

Ordinarily, people who <u>are</u> addicted to alcohol are also habituated to it. A person who is both addicted <u>and</u> habituated can abolish the addiction by going through withdrawal and letting his body reestablish homeostasis without alcohol. However, this person is likely to remain habituated to the drug. Even though the drug is no longer needed physically (to prevent withdrawal symptoms), it still is needed psychologically. For this reason it is very difficult for an alcohol addict to swear off the drug permanently.

The term "alcoholism," like the terms "drug," "narcotic" and "drug abuse," is used in different ways by different people. Some people use the term to mean addiction to alcohol. Others use the term "alcoholism" to mean psychological dependence, or habituation. Still other definitions refer to the effects of the drug on the user's ability to do his work, its effect on his health or its effects on his relationships with others, incl his family.

The fact that habituation contin after addiction is abolished helps to explain why there are several definitio the word "alcoholism." One solution to the problem of definition is to apply the term "alcoholic" only to the alcohol addict; another is to apply it to anyone who is habituated to the drug. A third solution, used by Alcoholics Anonymous, is to refer to a person who was formerly addicted and is now habituated as a "recovering alcoholic." This term emphasizes the fact that ituation remains after addiction has been abolished by withdrawal.

For our p ses it is not necessary to use the term "alcoholism," as long as it is understood that chronic consumption of large doses of alcohol can produce both permanent damage, such as cirrhosis of the liver and esophageal varices, and also habituation, tolerance and addiction. Among the other disorders that may be associated with alcohol use are chronic gastritis, malnutrition and brain damage. Disorders related to alcohol rank above all other diagnoses in admissions to mental hospitals.

All these are consequences of alcohol use which proceed directly from the nature of the drug itself and its pharmacological effects on the body. In addition, all these are consequences that directly affect the user of the drug.

It is generally recognized that the use of nonmedical drugs such as alcohol (or the nonmedical use of medical drugs such as black-market amphetamines and morphine) can have undesirable consequences for people other than the user. For example, a person who suffers chronic ill health because of alcohol does not suffer alone: the family and friends suffer too. Furthermore, when large numbers of people in a society are chronic users of large doses of the drug, there are consequences for the society at large. For example, disorders associated with alcohol account for a large proportion of admissions to mental hospitals. This fact suggests that alcohol use is causing an unnecessary drain on our society's health-care resources. Adverse effects of alcohol use on society are also suggested by the statistical correlations between alcohol use and such things as fatal car accidents, homicides, child beatings and suicides.

Why is malnutrition common in chronic users of large doses of alcohol?

Which of Mary's symptoms were the direct consequences of malnutrition?

How does malnutrition contribute to cirrhosis of the liver?

How does cirrhosis of the liver develop?

How does cirrhosis of the liver contribute to the formation of esophageal varices?

How does edema develop in a chronic user of large doses of alcohol?

Why may a person be considered an "alcoholic" even though he or she has passed through withdrawal and is no longer physically dependent on the drug?

Name one effect of large doses of alcohol for which tolerance <u>does not</u> develop with chronic use.

Vocabulary:

varices (VAIR-uh-seez)--dilated veins (also called "varicose veins").

SECTION 20: OPIATES, COCAINE AND MARIJUANA

20-1 Introduction

What do opiates, cocaine and marijuana have in common with alcohol? How are they different from alcohol?

In this section we will discuss three drugs: the opiates, derived from the opium poppy; cocaine, derived from the coca leaf; and marijuana, derived from the hemp plant.

Like alcohol, all these drugs either have or used to have certain uses in medicine. In addition, like alcohol, all these drugs have long had nonmedical uses. And like alcohol, all these drugs are important to medicine because their use sometimes causes diseases.

We have seen that alcohol can cause habituation and addiction. In this way some of the drugs discussed in this section are similar to alcohol and some are different. Opiates cause habituation and addiction. Cocaine causes habituation, but scientists disagree as to whether it causes addiction. Marijuana is not addictive, and scientists disagree as to whether it causes habituation.

In one other way, however, all the drugs discussed in this section are different from alcohol. Alcohol is readily available, without prescription, in pure preparations of known concentration, to anyone in this country who is above a certain age. (The age is set by state law. In some states it is illegal to sell alcohol, but residents can, and many regularly do, buy alcohol in other states.)

On the other hand, opiates, cocaine and marijuana are not readily available to the public through legal channels. Opiates and cocaine are legally available only by prescription. Marijuana is not legally available. Since some people use these drugs, but cannot readily get them through legal channels, they buy them on the black market. Black-market drugs (including illegally produced "moonshine" beverages) are often associated with disease, for two reasons. First, the drugs are often "cut" (diluted) or unintentionally contaminated with other substances, which may be poisonous. Second, because these drugs are often cut, the user does not know how strong the drug is and may accidentally take too much. A large-enough dose of an opiate or cocaine will kill the user. (This is not true of marijuana; a lethal dose of marijuana is so large that, so far as is known to science, nobody has ever managed to ingest one.)

20-2 Opiates

What drugs are obtained from the opium poppy? What are their pharmacological properties?

The opiates are drugs derived from opium. Opium comes from the resin of the immature seed pod of the opium poppy. The resin is dried to produce gum opium, which can be further dried to produce powdered opium. Both forms are official medical drugs in the United States. About 25% of opium by weight consists of pharmacologically active organic compounds. Only about 10% of opium by weight is morphine. About 0.5% by weight is codeine, and other compounds are present in small proportions.

Morphine, either in its pure form or in the form of morphine sulfate or morphine hydrochloride, is an official drug, and the pharmacological properties of this compound account for most of the properties of the opium from which it is derived. Codeine, pure or in the form of salts, is also an official drug. It is about one twelfth as potent (strong) per unit mass as morphine, but its pharmacological properties are otherwise similar to those of morphine.

Heroin is synthesized (manufactured) from morphine. Its pharmacological properties are very similar to those of morphine, but it is about two and one half times as potent per unit mass as morphine. Heroin is not an official drug in the United States; it is against the law to manufacture the drug in this country or to import it. There are many other opiates obtained from opium. However, we shall concentrate on morphine, which is the most important of the opiates used in medical treatment and has pharmacological properties similar to those of heroin.

Morphine is readily absorbed from the gastrointestinal tract. It is also absorbed from the mucous membranes in the nasal passages (as when heroin is "snorted") and from the lungs (as when opium is smoked). It can also be administered by injection under the skin, into the muscle or into a vein.

The earliest medical use of opium was for its ability to stop diarrhea. Morphine, in the proper dosage, can almost completely stop peristalsis in both the small and the large intestines.

The immediate effects of morphine on the body are many and varied, and central nervous system (CNS) depressant effects are medically of most importance. The best-known medical effect of morphine is analgesia: morphine reduces pain. It does not abolish other sensations (touch, vision, hearing, etc.), and some of its analgesic effect may be due to the fact that it makes the patient better able to stand pain when the sensation of pain is not entirely abolished.

In addition to analgesia, morphine produces a sense of euphoria (a feeling of unrealistic well-being or elation) in some persons and a feeling of anxiety [illegible]r in others, particularly those who have not used the drug before and were not [illegible] in when they took it. The drug also produces drowsiness and mental clouding: [illegible]ity to concentrate, apathy and lessened physical activity.

Morphine depresses the respiratory center in the brain. As with alcohol, death due to overdose is usually caused by respiratory failure.

20-3 Habituation, Tolerance, Addiction and Withdrawal

What are the consequences of continued use of opiates in large amounts?

The chronic use of large doses of morphine or heroin does not produce any irreversible change in the physiology or anatomy of the body. There is no evidence of damage to the brain, liver, kidneys or other organs. On the contrary, there are documented cases of persons who have used morphine for decades without physical or mental deterioration.

However, morphine does cause habituation, tolerance and addiction. Tolerance develops for the depressant effects of the drug, including the analgesia, the euphoria and the depression of the respiratory center. Tolerance greatly increases the lethal dose: a dose that would kill a person who does not ordinarily use the drug might produce little or no depressant effect on an addict who has worked up to a massive dosage. The lethal blood concentration of alcohol, in contrast, remains about the same for a given individual no matter how long or how much he drinks.

The length of time required to produce addiction to morphine depends on the dosage. The intensity of the withdrawal syndrome increases with the dosage, up to 500 mg of morphine per day. Dosages up to ten times that large (5 g per day) have been recorded for addicts under treatment, but beyond 500 mg per day the withdrawal symptoms do not get worse.

Two parts of the withdrawal syndrome have been identified: behavior directed toward getting more of the drug, and physical symptoms. The craving for heroin begins shortly before the time of the next scheduled dose, peaks in two or three days after the last dose and then gradually subsides. Physical symptoms begin to appear within [illegible] hours of the last dose and peak in two or three days. Most of the observable symptoms are gone in less than two weeks after consumption of the last dose, but physiological adjustments continue beyond that time. As with alcohol, habituation remains after addiction has been abolished by withdrawal. The former addict is still subject of a craving for the drug.

The physical symptoms of withdrawal include irritability, loss of appetite, inability to sleep, yawning, irritation of the upper respiratory tract, weakness, depression, gastrointestinal distress, elevated heart rate and blood pressure, chills alternating with flushing and sweating, pains in the bones and muscles, and muscle spasms. Withdrawal is seldom fatal, but death due to complications (not directly due to effects of the drug on the body) does occur occasionally. The symptoms can be abolished at any time during the withdrawal period by administration of a narcotic similar to the one the patient used. For example, methadone, a synthetic drug that is not derived from morphine, but closely mimics its pharmacological effects, can be used to abolish withdrawal symptoms in heroin addicts. However, methadone is more addictive than heroin.

20-4 Other Consequences of Heroin Use

In what other ways does heroin affect health?

There are two significant differences between the pharmacological effects of alcohol and opiates. One is that opiates produce analgesia and, in some people, euphoria; alcohol produces these effects with much less intensity. This is important both because the strong analgesic effects of opiates make them valuable in medicine, and because the euphoric effects make them popular on the black market.

The other important difference is that chronic use of large doses of alcohol leads to malnutrition, chronic gastritis, cirrhosis of the liver and sometimes brain damage, whereas chronic use of large doses of opiates is not known to cause any physical or mental deterioration.

This is not a complete description of the consequences of the use of these two drugs. It is incomplete because it ignores the consequences of the conditions under which these two drugs are used. Alcohol, unlike opiates, is readily available, pure, cheap, socially acceptable and heavily advertised. These conditions may account for the fact that there are 80 times as many alcohol addicts as opiate addicts, even though it is much easier to become addicted to opiates than to alcohol.

Heroin addicts are highly likely to contract two dangerous diseases, both of which are transmitted by contaminated blood: bacterial endocarditis, which is an infection of the heart valves or the lining of the heart cavities and is fatal unless treated; and serum hepatitis, which is an acute inflammatory disease of the liver. Note: the pharmacological properties of opiates do not contribute to the development of either of these two diseases, but the conditions under which heroin is used contribute to both. Both diseases are transmitted among heroin addicts by way of contaminated hypodermic needles.

In addition to contacting these diseases, a heroin addict is in danger of dying in any of three ways. First, the addict may purposely increase his dose in order to obtain a more intense "high," and the dose consumed may be sufficient to cause death due to respiratory failure (i.e., heroin overdose). Second, the addict may accidentally take an overdose. This is possible because black-market heroin is usually cut to very low percentages of heroin, but an occasional sample contains a high percentage. An addict who unknowingly uses a mixture that is very potent, thinking it is highly diluted, may easily consume an overdose. Third, the addict may be poisoned by other substances mixed with the drug. It appears that many deaths that have been attributed to heroin overdose are actually caused by poisoning with quinine or with other substances that have been used to cut the heroin.

20-5 Cocaine

Where does cocaine come from? How does it affect the body?

Cocaine is an organic compound found in the leaves of the coca tree, which grows in the Andes mountains in Peru and Bolivia. Its first and best-known use was as a central nervous system (CNS) stimulant. Before the arrival of the Spanish in South America, coca leaves were used as a ritual drug by the highest class of the Inca Indian society. The chewing of coca leaves became widespread among the Indians of the area when the Spanish destroyed their social system, and it remains so today. When the drug is taken by chewing coca leaves, its effects are much like those of drinking coffee. In addition to its stimulant effect, the drug prevents the user from feeling fatigue.

Cocaine was first isolated in a German laboratory in 1860. Some twenty years later Sigmund Freud (Austrian neurologist and founder of psychoanalysis) used it as a euphoriant; Freud also prescribed the drug for patients, both as a euphoriant and as a cure for addiction to morphine. Freud's co-worker Carl Koller, an ophthalmologist, discovered that cocaine is a local anesthetic. For some time the drug was used to anesthetize the eyeball for medical treatment, but it tends to damage the surface of the eyeball and has been replaced by safer drugs for this purpose.

After the Civil War, cocaine was prescribed in the United States as a cure for morphine addiction, and it was also used as an ingredient in the original version of Coca-Cola. Coca leaves are still used in the preparation of cola drinks, but the cocaine is no longer included in the final product.

Cocaine has a variety of actions in the body. As we have seen, it is a CNS stimulant, making the user talkative, restless and excited and producing a feeling of euphoria. Second, cocaine increases responses in organs controlled by the sympathetic nervous system, apparently by altering the flow of chemicals at synapses in this system. Two effects of the drug's action on the sympathetic nervous system are narrowing of blood vessels and dilation of the pupils. A third action of cocaine is to block the conduction of nerve impulses in neurons directly in contact with the drug. This action accounts for cocaine's effect as a local anesthetic. A combination of actions produces another effect of cocaine, the elevation of body temperature. This effect is apparently due to (1) increased muscular activity brought on by CNS stimulation; (2) constriction of blood vessels, which reduces heat loss from the surface of the body; and (3) direct action on the temperature-regulating centers in the brain.

Cocaine is now used in medicine as a local anesthetic on the mucous membranes of the nose and throat. It is used for this purpose because it is the only known local anesthetic that also constricts blood vessels--thus it not only anesthetizes the tissue but also minimizes bleeding. Cocaine is no longer used in medicine for any other purpose.

Cocaine is absorbed into the body slowly, because it constricts the blood vessels that transport it. It is absorbed from all parts of the body, including the mucous membranes. However, if taken orally it is broken down in the gastrointestinal tract and is therefore ineffective. Cocaine absorbed through any route is broken down rapidly--at the rate of about one gram per hour--in the liver.

Despite the fact that cocaine is absorbed slowly, it is relatively easy to administer or take a lethal dose, because a lethal dose is small--a little over one gram. In addition, individuals vary widely in their sensitivity to the drug: some individuals may be killed by a dose that would not harm other individuals.

A large dose of cocaine taken intravenously causes death almost immediately by stopping the heart muscle. In other cases, cocaine poisoning is largely due to the effects of the drug on the nervous system. The symptoms of cocaine poisoning are numerous. They include rapid pulse and irregular breathing, chill followed by a rise in temperature, vomiting and abdominal pain and the feeling that live things are crawling around on the skin.

20-6 Habituation and Addiction

What are the consequences of continued use of cocaine?

Black-market cocaine is increasingly used in the US and Europe for its stimulating and euphoric effects. The drug causes habituation (psychological dependence). Scientists disagree as to whether it also causes tolerance, withdrawal symptoms and addiction (physical dependence).

After a period of several weeks to several months of steady use of cocaine, some users develop what has been called a toxic psychosis, apparently due to the toxic effects of the drug on the CNS. The symptoms of this condition include vivid hallucinations, the feeling of things crawling on the skin, paranoia (unreasonable fear, suspicion or distrustfulness of other people), a decline in the ability to think clearly, and emotional changes. This condition usually goes away within seven days if the drug is withdrawn.

A chronic user of cocaine can work up to a daily intake of the drug that is several times the lethal dose. However, this does not necessarily mean that tolerance develops with chronic cocaine use, because of the fact that the drug is broken down so rapidly in the liver.

The cocaine user feels depressed and "not normal" when deprived of the drug, and EEG changes and altered sleep patterns persist for days after withdrawal of the drug. However, these facts do not necessarily mean that the drug causes withdrawal symptoms. The symptoms that appear are not nearly as dramatic or intense as the withdrawal symptoms of either alcohol or opiates. Furthermore, it has been suggested that the apparent withdrawal symptoms are actually the result of sleeplessness associated with heavy use of cocaine.

The effects of black-market cocaine, like the effects of black-market opiates, are unpredictable. The user of black-market cocaine does not know how much cocaine is in the substance taken, nor does he know what else is in it. In addition to the danger of poisoning by other substances mixed with the cocaine, there is considerable danger of cocaine poisoning and death because the lethal dose is so small.

20-7 Marijuana

What are the pharmacological properties of marijuana?

Marijuana is defined by law in the US as any part, or any pharmacologically active derivative, of the plant known as Cannabis sativa, or hemp. The active ingredients of the plant are several isomers of tetrahydrocannabinol (THC), which are found in the leaves of the plant and in a resin that covers the ripe flower clusters and top leaves of the plant.

Hemp has long been used in many parts of the world as a source of fiber, a ritual drug and a medicine. The earliest known reference to its use in medicine occurs in a Chinese herbal (a book about the medicinal properties of plants) written some 4,700 years ago. During the 19th century, marijuana was used in European and American medicine in treating a variety of disorders, including cough, fatigue, rheumatism, asthma, migraine headache and painful menstruation. It was an official medical drug in the U.S. until 1937.

In recent decades marijuana has been used successfully in small-scale experimental programs to cure addiction to opiates, barbiturates and alcohol. Addicts have been put on marijuana as a substitute for their drug of addiction, then marijuana has been withdrawn gradually without withdrawal symptoms.

Marijuana is a CNS depressant, specifically a sedative-hypnotic. In large doses it is a general anesthetic. It is thus in the same pharmacological category as alcohol, phenobarbital, Valium and Librium. The mechanisms of action of marijuana are not well understood, but the only observable physiological changes consistently produced by the drug are an increase in pulse rate and reddening of the eyes. Occasional changes, especially with large doses, include dizziness, nausea and vomiting. An increase in appetite is sometimes reported, but there is no change in blood-sugar level, respiratory rate, blood pressure or reflexes. In addition to these effects, marijuana usually (but not always) produces a feeling of excitement and euphoria.

Marijuana may be either smoked or eaten. When it is smoked, the feelings of excitement and euphoria (if they are experienced at all) begin within minutes and pass relatively soon. Such feelings are replaced by the sedative effects of the drug, sometimes including depressed moods. The sedative effects decline gradually and disappear in an hour or so. When the drug is eaten, about three times as much marijuana is required to produce effects of the same intensity. It is absorbed more slowly; effects may not become apparent until 30 to 60 minutes after ingestion. The effects also last longer--usually for three to five hours--and are experienced as more similar to the effects of alcohol.

The consequences of chronic marijuana use are the subject of considerable research and debate, largely because what happens to THC in the body is not fully known. The overwhelming weight of evidence currently is that marijuana does not cause either tolerance or withdrawal symptoms. On the question of whether marijuana causes habituation, the evidence is more evenly divided. It appears that some individuals may become dependent on the drug for psychological comfort. It also appears that a reduction in motivation to perform mental and physical tasks occurs in many chronic users of the drug.

Recent research suggests that THC, after it enters the bloodstream, may become bound to certain tissues in the central nervous system and may remain there for a long period to time. This phenomenon may be related to the apparent mild tolerance and loss of motivation that have been observed in some chronic users of marijuana. However, the consequences of this phenomenon for the mental and physical health of the marijuana user, particularly the chronic user of large doses of the drug, are not well known.

Other consequences of marijuana use for the health of the user are unpredictable. It has not been established that marijuana causes any permanent changes in the body such as those brought about by chronic use of large doses of alcohol. However, chronic heavy smoking of marijuana (like chronic heavy smoking of anything else) may increase the risk of bronchial and lung disease. Furthermore, there are unknown health risks associated with the use of marijuana, particularly if it is purchased on the black market. First, as with any other drug, the body's response to a given dose varies with the individual; some people, after taking only a small dose of marijuana, suffer consequences such as hallucinations which are normally associated only with large doses. Second, marijuana varies greatly in THC content and therefore in strength. Third, black-market marijuana may contain any number of other substances, including both poisons that are included accidentally and potent drugs that are mixed with the marijuana to intensify its effects on the user.

There has been no known case of death of a human due to ingestion of marijuana. Experimental animals given huge doses of THC die of respiratory failure.

20-8 Recent Studies of the Effects of Marijuana

What other effects does marijuana have?

The effects of marijuana use are widely misunderstood. Of the three drugs discussed in this section--opiates, cocaine and marijuana--marijuana is by far the most commonly used and the least thoroughly studied.

Marijuana is sometimes described or classified as a "mild hallucinogen," because with heavy doses, some users hallucinate. However, the same effect is also reported with large doses of alcohol, nitrous oxide ("laughing gas," used as a general anesthetic in dental procedures), and Librium--none of which is considered a hallucinogen. The hallucinations that sometimes follow large doses of marijuana vary widely in content; they appear to depend more on the personality of the user than on the actions of the drug.

Marijuana has also been described as a "stepping stone" to the use of opiates. This conclusion is drawn from the fact that large percentages of opiate addicts have in the past used marijuana. It is also true, however, that the percentages of opiate addicts who have used alcohol and tobacco are about as large as the percentage who have used marijuana. From the available information, it cannot be concluded that marijuana use increases one's likelihood of using opiates. It has been suggested, however, that because marijuana use is illegal, people who use it associate with people who sell illegal drugs--opiates as well as marijuana--and are therefore in a position to be influenced by those people.

Some studies conducted in the 60's and 70's have yielded fairly reliable information about the immediate effects of marijuana use. One study compared the performance of subjects who had smoked marijuana of known strength with the performance of the same subjects when they had smoked a placebo (a marijuana cigarette from which the active ingredients had been extracted). The marijuana used in the study was from Asia. It was much higher in THC content than most marijuana available in the U.S. This study showed that subjects did worse on two tests after smoking marijuana than after smoking the placebo. One test required following a moving dot on an oscilloscope screen, using a hand-held pointer. The other required speaking aloud while listening to earphones that played back the subject's voice about a third of a second after he had spoken.

Another study involved questioning 100 experienced marijuana users about the "usual" effects of the drug on them during the "high." A majority of these subjects reported that they usually experienced euphoria, relaxation, keener sound sense, a "peaceful" feeling, increased sensitivity, increased hunger, "time slowed down," increased thirst and dry mouth and throat. Fewer than 10% reported that they usually experienced poorer memory, "time speeded up," anxiety, confusion and bewilderment, and flushing.

What is the difference between opium and morphine?

What is the difference between morphine and codeine?

What is the difference between morphine and heroin?

What is the difference between morphine and methadone?

What pharmacological properties do opium, morphine, codeine, heroin and methadone have in common?

What is the difference between the effects of cocaine and the opiates on the CNS

What other properties of cocaine make it useful in modern medicine?

Why is it possible to ingest several times the lethal dose of cocaine over a period of a day or two without dying?

Why is it possible to use marijuana to cure addiciton to opiates, barbiturates and alcohol?

Which of the following drugs--alcohol, opiates, cocaine--is most different from marijuana in its effect on the CNS? What is the difference?

Vocabulary

cocaine (ko-KANE)--an organic compound found in coca leaves that acts as a CNS stimulant and a local anesthetic.

heroin (HAIR-uh-win)--a drug manufactured from morphine, with pharmacological properties very similar to those of morphine, but about two and one half times as potent as morphine; cannot be legally manufactured in or imported into the United States.

marijuana (MAIR-uh-WAH-nuh)--any part or pharmacologically active derivative of Cannabis sativa (legal definition in U.S.); dried and chopped leaves and flower clusters of this plant.

morphine (MORE-feen)--a naturally organic compound occuring in opium; a CNS depressant useful in medicine as an analgesic and antidiarrhetic; causes habituation, tolerance and addiction.

opiates (OH-pee-uts)--opium and the drugs derived from opium, including naturally occuring alkaloids such as morphine and synthetic derivatives such as heroin.

opium (OH-pee-um)--the dried resin from the immature seed pod of the opium poppy, containing about 25% pharmacologically active drugs.

psychosis (si-KO-sus)--severe mental disturbance usually including loss of contact with reality.

REVIEW SET 20:

1. Give at least one example of a drug derived from a plant and at least one example of a drug derived from an animal.

2. How does penicillin function as an antibiotic?

3. In the following table, match the drug classification and function columns.

DRUG	FUNCTION
analgesic	A. stimulates the muscles of the intestine or draws water into the intestine; causes a bowel movement
cathartic	B. quiets the central nervous system without causing sleep
depressant	C. kills pain
sedative	D. causes an increase in diameter of blood vessels
stimulant	E. decreases the activity of neurons; a "downer"
vasodilator	F. increases the activity of neurons; an "upper"

4. List at least three antibacterial agents other than antibiotics and state how each functions.

5. List the kinds of information that a physician typically uses to determine whether or not a drug is indicated.

6. a. Describe the placebo effect.

b. Describe at least one use of placebos in medicine.

7. Give an example of each of the following:

a. control group and experimental group

b. blind experiment and double-blind experiment.

8. a. List at least two immediate effects of alcohol on the body.

b. List at least two possible permanent effects on the body of chronic use of large doses of alcohol.

9. Compare habituation, addiction, tolerance and withdrawal for alcohol, opiates, cocaine and marijuana.

SECTION 21: WAVES

21-1 Waves and the Senses

How are waves important?

Life would be impossible without waves. Without sound waves there would be nothing to hear. Without light waves there would be nothing to see. On a much more fundamental level, the findings of relativistic physics tell us that the very atoms that make up our bodies could not even exist without waves. So if there were no waves, there would be no atoms, no matter and no life.

Traveling waves carry energy over a distance. Sound waves carry the energy of your instructor's speech to your ears. If you fall asleep in class, the sound energy transmitted by your instructor and received by you is likely to increase. The sun transmits vast amounts of energy to the earth by means of light waves. The programs you watch on television also reach your television set by means of light waves, although they aren't in the visible frequencies. The energy of the wind blowing over the sea is transmitted to the beach by means of water waves.

Our eyes and ears function to detect the energy in waves. Our eyes sense the energy transmitted by means of light waves. Our ears respond to the energy carried by sound waves.

Not all waves travel from one place to another. As air moves past your vocal cords (larynx) they vibrate, setting up standing waves in the cords. In turn, the standing waves in your vocal cords set up traveling sound waves--your voice. The strings of a guitar or piano vibrate in the form of standing waves to produce music. In wind instruments such as trumpets, tubas and trombones standing waves are generated in the air column inside the instrument and give rise to traveling waves of music.

In a laser, light waves bounce back and forth between mirrors setting up standing waves, which generate traveling light waves of a very specific frequency. One of the uses of lasers is in eye surgery.

The use of lasers is only one of the many applications of knowledge about waves to medicine. We have already considered how X-rays and ultrasound are used to diagnose brain disorders. Diseases or defects that involve perception of sound (hearing) or light (vision) are among the most common in medicine. Such diseases are typically not killers like heart disease and stroke. But any disease that damages our sight or hearing ability takes something away from the quality of life and, especially in the very young, may interfere with learning. There are tens of thousands of health professionals involved in the prevention, diagnosis and treatment of disorders related to vision or hearing.

In this sequence we will concentrate first on sound, hearing and speech, then on light and vision. Finally, we will consider some of our other senses--smell, taste and touch.

21-2 Transverse and Longitudinal Waves

What are the different patterns of movement in waves?

A convenient model for light and sound waves is a coiled spring. By attaching one end of a spring to a wall and flipping the other end back and forth at right angles to the length of the spring, an impulse may be made to travel along the spring that looks something like this (Figure 1). Remember that λ is wavelength, or the length of one cycle.

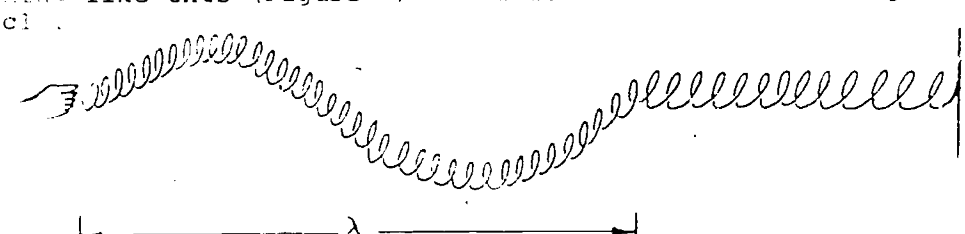


FIGURE 1: A coiled-spring model of a wave.

At one instant the spring may look like Figure 1 and at the next instant like Figure 2.

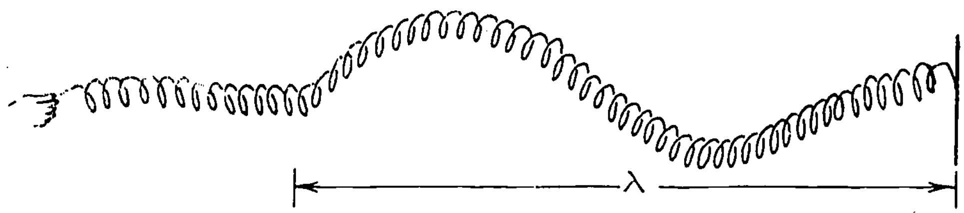


FIGURE 2: The impulse has moved to the right.

The impulse has moved along the spring from left to right. But note that the individual coils have not moved from left to right; they have only moved up and down.

A wave such as the one in Figure 2 in which the displacement is at right angles to the direction in which the wave travels is called a transverse wave.

It is possible to create a second kind of wave in a coiled spring by attaching one end and pulling back a few coils at the other end. When the coils are released, an impulse travels along the spring (Figure 3).

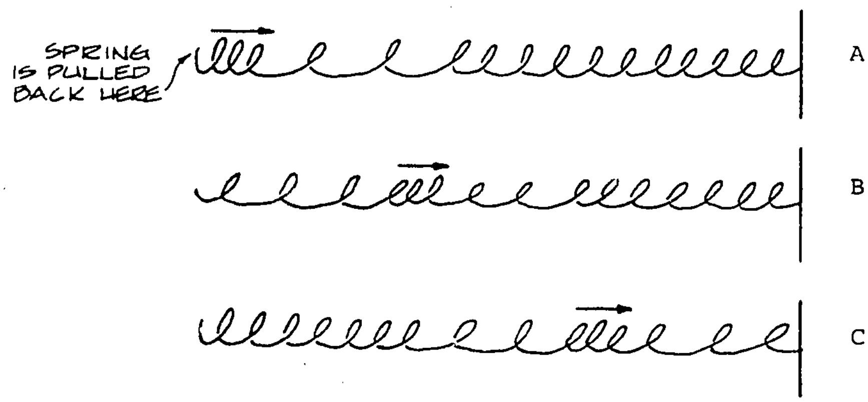


FIGURE 3: A longitudinal wave. A. Impulse on far left. B. Impulse has moved toward middle. C. Impulse near point of attachment.

The impulse consists of a section in which the coils are closer together (denser) than normal, and sections in which the coils are farther apart (less dense) than normal.

The impulse travels from one end of the spring to the other, but do the coils travel along the spring? No, each coil moves back and forth but ends up approximately where it began.

This second kind of wave is transmitted by coils vibrating back and forth in the direction of motion, and is called a longitudinal wave. Longitudinal waves are distinguished from transverse waves by the direction of motion of individual particles. Transverse waves are transmitted by movement at right angles to the direction of the wave, longitudinal waves by movement in the direction of the wave (Figure 4). It is possible for waves to have both longitudinal and transverse motion.

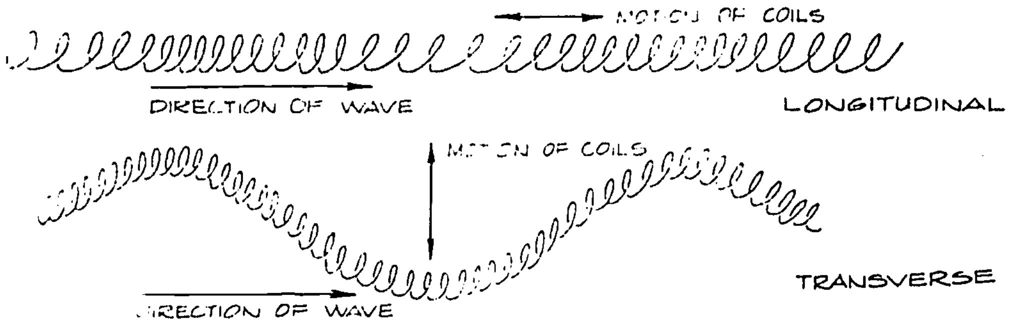


FIGURE 4: The difference between longitudinal and transverse waves.

Figure 5 represents a tuning fork setting up traveling sound waves in air. As the tines of the tuning fork vibrate back and forth, they alternately push air molecules closer together and pull them farther apart, creating alternating regions of higher and lower pressure. These spherical regions or "shells" of higher and lower pressure radiate outward from the tuning fork although individual air molecules only vibrate back and forth about their rest positions.

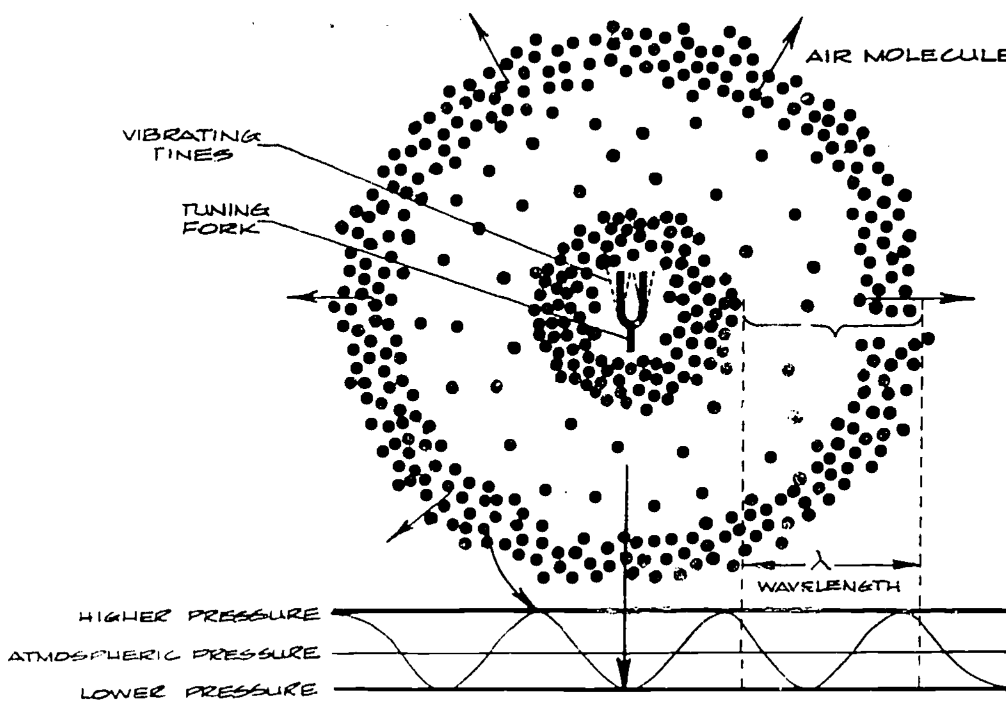


FIGURE 5: Sound waves produced by a tuning fork.

If we draw a line from the tuning fork outward, we find that air molecules move back and forth along the line instead of perpendicular to it. Therefore, sound waves are longitudinal rather than transverse.

21-3 Sound Waves and Hearing

How is hearing loss detected?

In Mathematics you have learned a variety of terms to describe waves, i.e., amplitude, wavelength, frequency and period. For example, a soprano voice generates sound waves of higher frequency, shorter wavelength and shorter period in general than a bass voice. A loud sound is characterized by waves of greater amplitude than a soft one.

You may be acquainted with people who are "hard of hearing." You know that you generally have to speak more loudly (generate waves with greater amplitude) to such people (unless they are wearing a hearing aid). What you may not know is that you might be able to make yourself understood by simply changing the frequency of your voice. Our ears are more sensitive to sound waves of certain frequencies than others. For example, waves of 10,000 cps must be of greater amplitude to be heard than waves of 2,000 cps.

Starting in Laboratory Activity 21, you will use an audiometer to generate tones of different frequencies and amplitudes. One student will operate the audiometer while another listens through earphones. The person operating the audiometer will be acting as an audiologist determining the hearing loss of the patient.

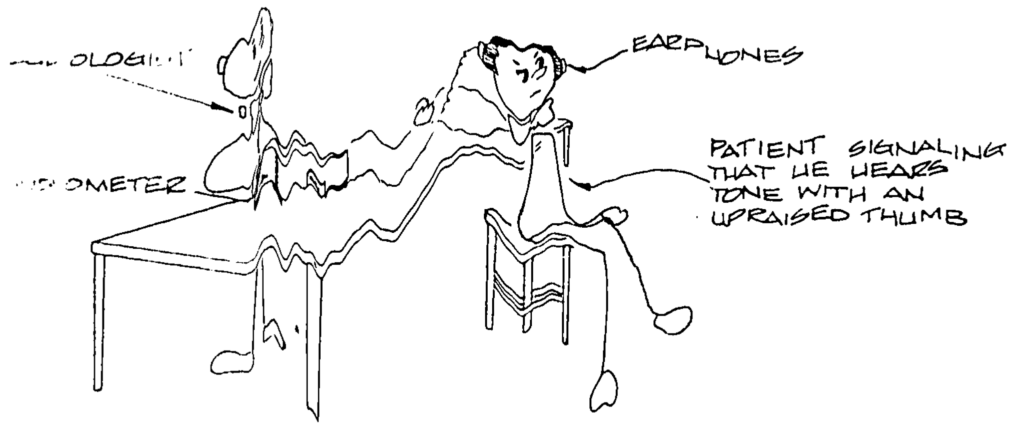


FIGURE 6: An audiologist administering a hearing test.

The process of determining the hearing loss of a patient in such a manner is known as pure-tone audiometry. The audiologist first sets the frequency of the tone and then varies the amplitude. The patient signals the audiologist when she/he can just barely hear the tone. In this way, hearing thresholds are established for each frequency. The information gathered is used to construct an audiogram, an example of which is shown in Figure 7.

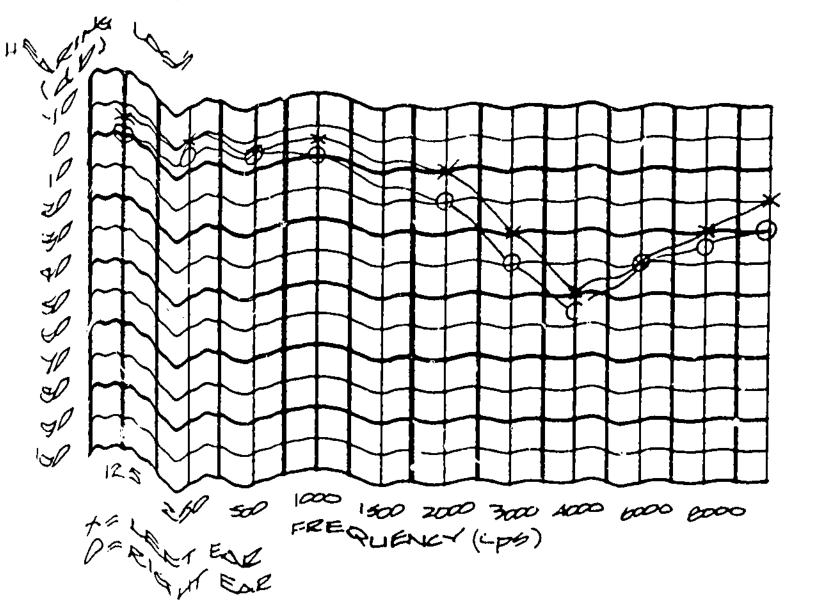


FIGURE 7: An audiogram showing maximum hearing loss in both ears in the neighborhood of 4,000 cps.

Notice that the units of hearing loss are given in "db" which is an abbreviation for decibels.

The unit is related to the amplitude (loudness) of sound waves. A person with no hearing loss would have hearing thresholds of 0 db or less for all of the tested frequencies.

Suppose an audiologist determined that Agnes could just barely hear a 2000-cps tone when the amplitude dial was set at 15 db. Agnes' hearing threshold would be 15 db. Hearing loss is numerically equivalent--the same 15 db. Clinically, hearing losses of 20 db or less are generally considered to be insignificant.

Describe the difference between traveling and standing waves. Between transverse and longitudinal waves.

Classify sound waves in the following terms: traveling, standing, transverse, longitudinal.

Describe the process of pure-tone audiometry.

Vocabulary:

audiogram (AW-dee-oh-GRAM)--a graph that shows a subject's hearing loss as a function of frequency.

decibel (DESS-ul-BELL)--the units used for loudness in pure-tone audiometry.

hearing threshold or hearing loss--the loudness (in decibels) of a pure tone of a given frequency that a subject can barely hear.

laser (LAY-zur)--a device that generates standing waves of light, which in turn generate traveling light waves of specific frequencies.

longitudinal wave--a wave in which the direction of vibration is parallel to the direction of movement.

pure-tone audiometry--the process of determining hearing thresholds at different frequencies.

transverse wave--a wave in which the direction of vibration is perpendicular to the direction of movement.

SECTION 22: THE EARS

22-1 Introduction

Most of us consider our eyes to be our most important sensory organs, and the eyes perhaps evoke our greatest sense of wonder about how our bodies work. Yet our ears are scarcely less remarkable in their complexity and accomplishments than our eyes. Furthermore, our ears contribute greatly to the quality of our lives. Think of what life would be like without being able to hear speech, music, the sounds of nature or traffic noise. It is the task of our ears to transform the small oscillations of air molecules that we call sound into impulses that can be interpreted by our brains. At the same time, the ear can avoid certain sounds that would tend to distract us. To understand how our ears accomplish these tasks, we must understand the anatomy of the ear.

22-2 The Outer Ear

What is the most easily correctable cause of hearing loss?

Hearing begins with the outer ear, which gathers and funnels sound into the auditory canal (Figure 1 on the following page). The auditory canal amplifies sound waves of certain frequencies. In Laboratory Activity 21 you found that standing waves were set up in the slinky at certain frequencies. These frequencies are called resonant frequencies. Air-filled tubes like the auditory canal also have resonant frequencies. At these frequencies standing sound waves are set up in the tube and the sound is amplified. Resonance of the auditory canal occurs in the neighborhood of 3,000 to 4,000 cps. In Laboratory Activity 23 you will investigate further the behavior of resonating columns of air.

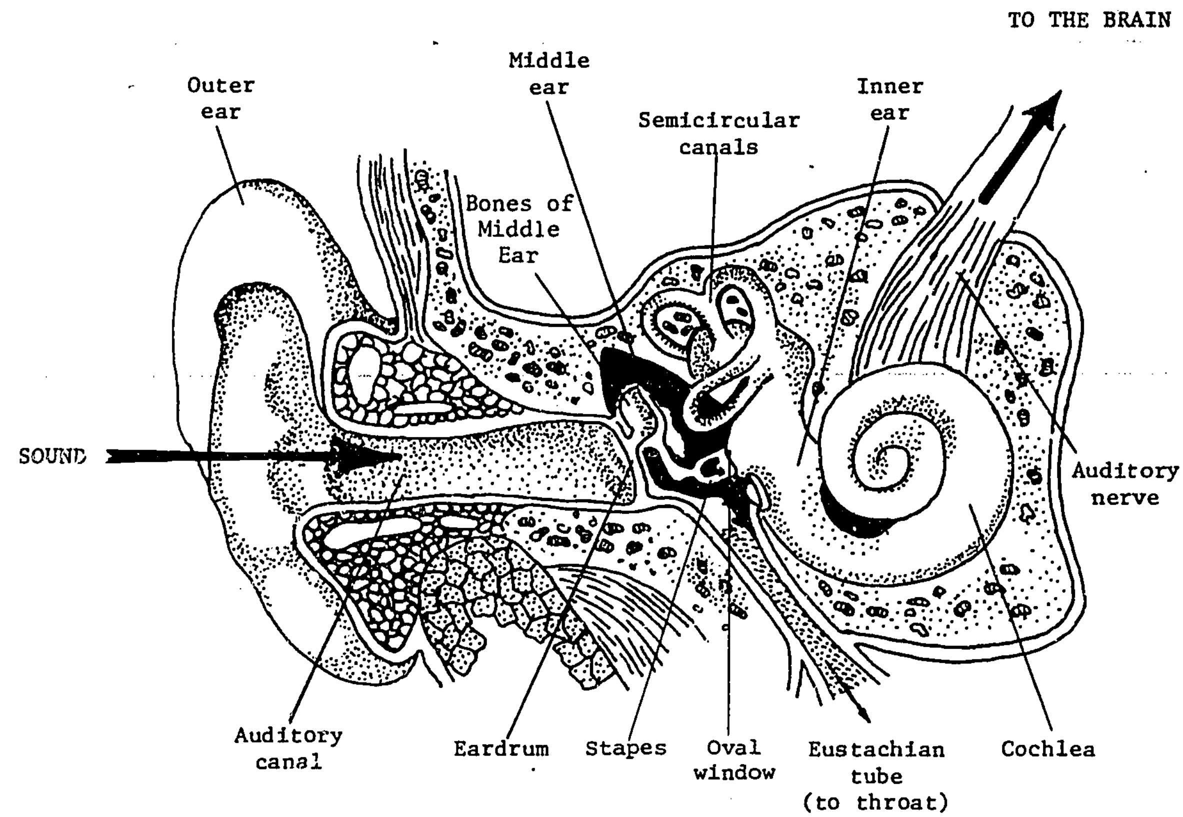


FIGURE 1: The ear.

At the end of the auditory canal is the organ known as the eardrum. Sound waves cause the eardrum to vibrate.

Ear wax impacted in the auditory canal is the most easily correctable cause of hearing loss. Figure 2 illustrates some of the more common problems associated with the auditory canal.

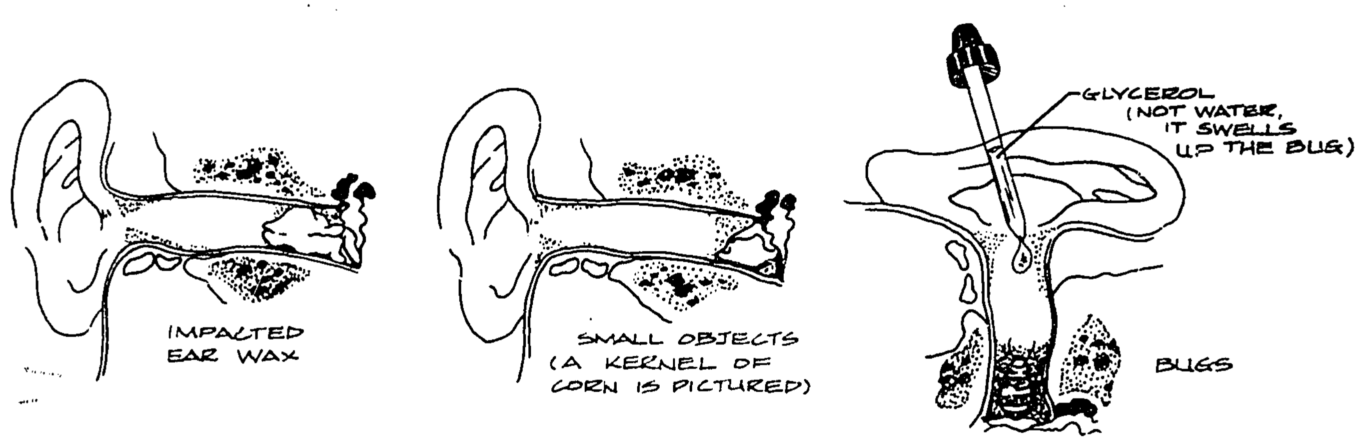


FIGURE 2: Common auditory canal problems.

Most of you have had your ears examined during the course of a physical examination. Figure 3 represents what may be seen by looking down the auditory canal by means of a device known as an otoscope ("oto" is the medical prefix for "ear"). In Laboratory Activity 22 you will construct an otoscope and visually examine the eardrums of some of your classmates. You should be able to see one of the bones of the middle ear resting against the eardrum.

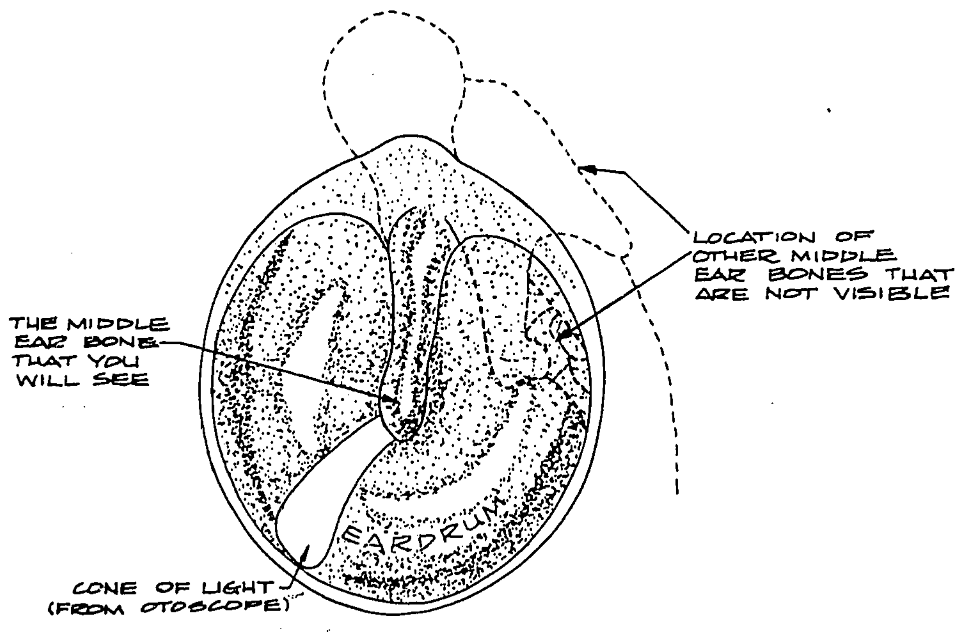


FIGURE 3: A view of the eardrum as seen with an otoscope.

22-3 The Middle Ear

What happens to sound waves after they hit the eardrum?

Beyond the eardrum lie the bones of the middle ear (Figure 4). These bones mechanically conduct the vibrations of the eardrum to the oval window, the input of the sensory mechanism of the inner ear. Like the eardrum, the oval window is a membrane which vibrates in response to sound waves.

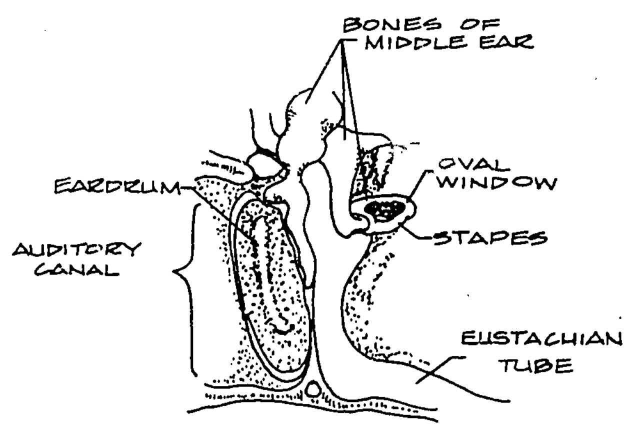


FIGURE 4: The bones of the middle ear.

Vibrations of the oval window set up sound waves in the fluid of the inner ear. The neurons and synapses of the hearing mechanism are bathed in this fluid. The function of the middle ear bones is to relay the vibrations of the eardrum to the oval window and either to amplify them or deaden them. How they transmit and amplify sound waves will be dealt with here. How they may deaden them will be covered later.

The middle ear bones are tiny, occupying about as much space as a carpet tack. They must be small and lightweight to perform their function. If they were heavier, they would not vibrate as easily in response to the tiny forces generated by sound waves.

The area of the eardrum is about 25 times the area of the oval window. This difference in area is one of the ways in which our ears amplify sound. Sound waves are rapid variations of pressure. When these pressure waves strike your eardrum, they generate forces which move the eardrum in and out in response. These forces are picked up by the middle ear bone resting against the eardrum (Figure 4) and transferred to the stapes--the middle ear bone which rests against the oval window. The forces picked up at the eardrum are applied to the much smaller surface of the oval window. When the same force is applied to a smaller area, the pressure increases. (Remember that pressure = $\frac{\text{force}}{\text{area}}$.) Since sound waves are pressure waves, this increase in pressure results in an increase of the amplitude of sound waves generated in the fluid of the inner ear (Figure 1).

The chain of bones in the middle ear amplifies sound pressures in yet another way. By means of lever action, the forces picked up at the eardrum are multiplied as they are transferred to the oval window. This increase in force also results in an increase in pressure at the oval window. As mentioned earlier, an increase in pressure at the oval window results in an increase in the amplitude of sound waves in the fluid of the middle ear. The combination of both of these amplifications increases the pressure at the oval window about 35 times, enabling us to hear sounds whose energies are about 1,000 times weaker than we could hear otherwise.

The cavity behind the eardrum is normally filled with air. The air reaches this space through the <u>eustachian tube</u> (Figure 4), which connects with the pharynx. Under normal conditions the eustachian tube functions to equalize air pressure between the auditory canal and middle ear. When there is a significant difference in pressure between the middle ear cavity and the auditory canal, the eardrum becomes stretched much like a ballon. When it is stretched, it responds to sound waves less effectively.

We are all familiar with efforts to "pop" our ears by swallowing or yawning. These actions open the slit-like opening of the eustachian tube in the pharynx and allow air to pass into or out of the middle ear, thus relieving the eardrum of pressure. As the pressure is relieved our eardrums "pop."

22-4 The Inner Ear

How do we perceive pitch and loudness?

The oval window, to which the stapes is attached, is at the entrance to the <u>cochlea</u> (Figure 5). It is in the cochlea that the physical vibrations of sound waves are converted into electrical nerve impulses (i.e., action potentials). These impulses are transmitted to the brain by way of the auditory nerve. The cochlea is spiral-shaped and small. If straightened out, the cochlea would be about four cm long. In its normal coiled state it occupies a space the size of a pea.

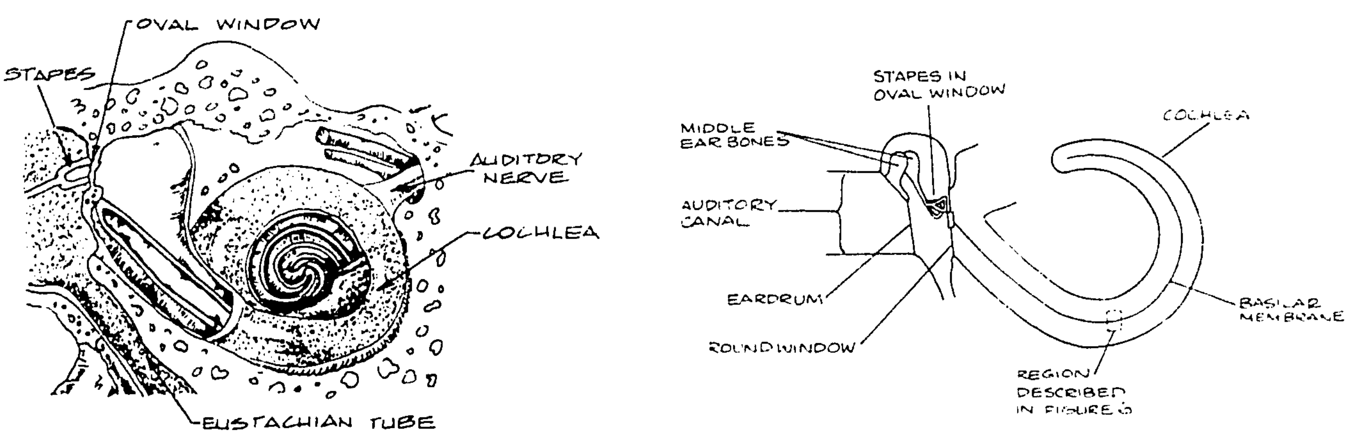


FIGURE 5: Two views of the cochlea. On the left it is shown in its normal coiled state. On the right it is shown schematically and partially uncoiled.

As the stapes vibrates in the oval window, sound waves are set up in the fluid of the cochlea. Once in the cochlea, soundwaves vibrate the basilar membrane (Figure 5, right side).

The basilar membrane is at the heart of our hearing apparatus. Near the oval window the basilar membrane is stiff and vibrates most easily in response to the highest frequencies we can hear (near 20,000 cps). The farther away from the oval window, the more flexible the basilar membrane becomes. The very end of the membrane vibrates most easily in response to the lowest audible frequencies (about 20 cps). In such a way, the various frequencies are sorted out along the length of the basilar membrane.

Figure 6 shows a cross-sectional view of the basilar membrane and its associated sensory-neural structure. The location of Figure 6 in relation to the cochlea and the basilar membrane is shown on the right side of Figure 5. In Figure 6 the long dimension of the basilar membrane runs perpendicular to the page.

Riding on the basilar membrane is the organ of Corti. It is the organ of Corti that translates the vibrations of the basilar membrane into action potentials. Notice what happens when the basilar membrane vibrates up and down. The hairs touch an overhanging membrane. This stroking of the hairs is eventually converted into action potentials, and information about the movement of the basilar membrane enters the central nervous system. The louder the sound, the more violently the hairs will collide with the overhanging membrane. This results in more energy being transmitted from the affected nerves. This increase in transmitted energy tells our brain that the sound is louder.

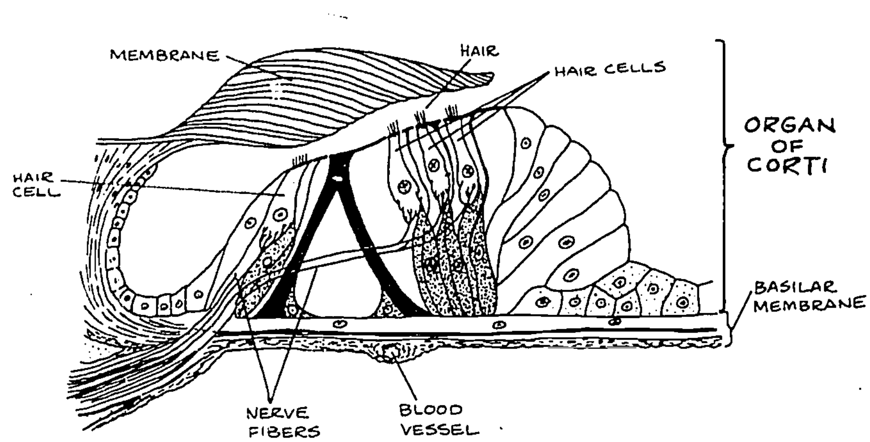


FIGURE 6: A cross-sectional view of the basilar membrane and its associated sensory-neural structure.

Our perception of pitch is related to the location of antinodes (locations of maximal vibration) in the basilar membrane. The lower the frequency, the farther away from the oval window will be the location of maximal vibration. The sensory neurons of the organ of Corti at this location will be stimulated more than sensory neurons at other locations, and our brains interpret this information in terms of pitch.

Trace the path of a sound wave from the outer ear to the basilar membrane.

How might a bug in the auditory canal be encouraged to leave?

How does the structure of the middle ear lead to amplification of soundwaves?

Describe how vibrations of the basilar membrane lead to the generation of action potentials.

What part of the basilar membrane vibrates most easily in response to low frequencies? high frequencies?

Vocabulary:

auditory canal (AW-dih-TOR-ee)--The tube leading from the outer ear to the eardrum.

basilar membrane (BASE-uh-lur)--The membrane running down the center of the cochlear spiral, upon which the mechanical movements of sound waves are converted into action potentials.

cochlea (KO-klee-uh)--the sensing device of the inner ear.

eardrum--the membrane at the end of the auditory canal.

eustachian tube (yew-STAY-shun)--connects the middle ear with the pharynx, allowing the air pressure in the middle ear to equilibrate with that of the outside environment.

organ of Corti--The structure of membranes, hair cells and nerves which rides on the basilar membrane and translates its movements into action potentials.

otoscope (OH-toe-SCOPE)--a device for viewing the eardrum.

oval window--the membrane at the entrance to the cochlea.

resonant frequency--A frequency at which standing waves are produced.

stapes(STAY-peez)--the bone in the middle ear which is attached to the oval window.

SECTION 23: COMMON HEALTH PROBLEMS AFFECTING THE EAR

23-1 Disorders of Hearing

What causes us to lose our hearing?

Recall the Rinne test from Laboratory 22. This test compares the difference between air conduction of sound and bone conduction of sound. A person with normal hearing will hear the tuning fork longer by air conduction than by bone conduction. If a person hears the tuning fork longer by bone conduction, sound is not being carried from the eardrum to the sensitive hair cells properly and we say a conduction impairment is present. If sound waves reach the hair cells normally but are not heard, a perception impairment is present. Conduction hearing loss will be discussed first.

Sound waves must first strike the eardrum. What can prevent this? The commonest cause is a heavy build-up of wax in the ear canal. People vary greatly in this regard. Some people make so much wax that they periodically must go to a health professional to have the wax removed. The wax is removed by a gentle stream of water that is washed into the external ear canal.

If the sound reaches the eardrum, what next? The drum itself must be free to move. If the eardrum has been damaged, usually by an injury or a childhood ear infection, it will not move the ear bones properly, and some sound energy will be lost. The sound waves next travel as vibrations of the ear bones. Scarring around these bones, due to an infection, can reduce these vibrations so that less sound reaches the next part of the chain, the oval window. A problem at the oval window occurs in about 0.5% of young adults called "otosclerosis." This condition, apparently hereditary, results in an excessive growth of bone near the oval window and the stapes becomes fixed in place and can't transmit sound vibrations to the fluid of the inner ear. Fortunately, some delicate surgical procedures have been developed to restore partial hearing. A common type of surgery involves removing the stapes and replacing it with a prosthesis and repairing the oval window with a small vein graft. Figure 1,on the following page, shows the stapes before surgery and after replacement by a plastic prosthesis.

If sound vibrations reach the inner ear normally but hearing is impaired, a perception defect is present. Perception defects are commonly the result of one of three things: damaged hair cells, failure of cells in the organ of Corti to convert sound vibrations into nerve impulses and failure of the hearing nerve to conduct impulses from the organ of Corti to the hearing center in the brain.

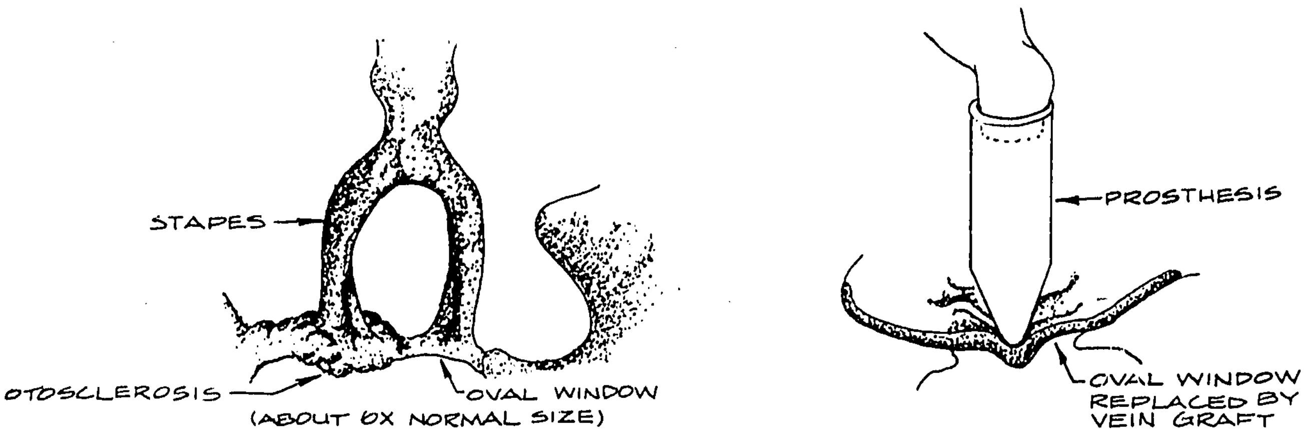


FIGURE 1: Surgical treatment of otosclerosis.

Extremely loud noise for even a short period of time can directly damage the hair cells. This results in excessive movement of the basilar membrane, which causes impacts in the hair cells to be too great. This is especially true if the frequency of the noise is near the natural resonance of the external auditory canal, which is around 4,000 cycles per second.

The commonest cause of premature perception loss is recurrent exposure to noise not loud enough to damage the hair cells directly. This kind of situation frequently occurs with occupations such as sandblasting and work with heavy machinery. Noise in the 1,000 to 3,000-cycle range is most likely to cause problems. How does this cause hearing loss? The mechanism by which this occurs has to do with the body's physical reactions to sound that exceeds the 80-decibel level: this is the constriction of certain very small arteries. The organ of Corti has a limited blood supply available to it for the exchange of nutrients and waste products. When blood vessels constrict, this blood supply is decreased. It has been suggested that when this deficiency continues over a period of time the cells in the organ of Corti that are responsible for converting sound vibrations into nerve impulses die.

The ears are more susceptible to damage by high-frequency, loud sounds because its protective mechanisms act mainly at lower frequencies. For example, in the middle ear there are two small muscles whose function it is to protect the ear from loud, low-frequency sounds. They do this by pulling the bones of the middle ear into such positions that the elasticity of the middle ear is greatly reduced and it no longer conducts vibrations through to the inner ear. However, this mechanism does not operate at high frequencies, permitting vibrations of harmful intensity to pass to the inner ear.

As people grow older, there is a tendency for hearing to diminish. This appears to be due to a combination of repeated exposure to noise and a gradual impairment of circulation due to atherosclerosis (just one more reason to try to reduce one's risk of circulatory disease by using some of the preventive methods covered in Units II and III).

The third cause of perception hearing loss is the result of some impairment of the hearing nerve that conducts impulses from the organ of Corti to the brain's hearing center. This nerve, called the "acoustic" nerve, can be damaged by certain drugs or be affected by events in the brain such as tumors or injury. Drugs that cause "ringing in the ears" as a side-effect are capable of permanently damaging hearing if used too long. Even commonly used medications like aspirin will cause ringing in the ears if taken in too large a dose.

23-2 Testing the Hearing

How can an audiogram help?

As a part of the activities connected with Laboratory Activity 21, you measured hearing thresholds. While your measurements were not accurate enough to replace a professionally made audiogram, the technique used was similar to that used by an audiologist. The audiogram is a basic tool for the hearing specialist. In addition to an air-conduction audiogram, as in the activity, the professional may also perform a bone-conduction audiogram. Only air audiograms are discussed here.

Figure 2 shows an audiogram of two people: one with good hearing and one with a conduction impairment.

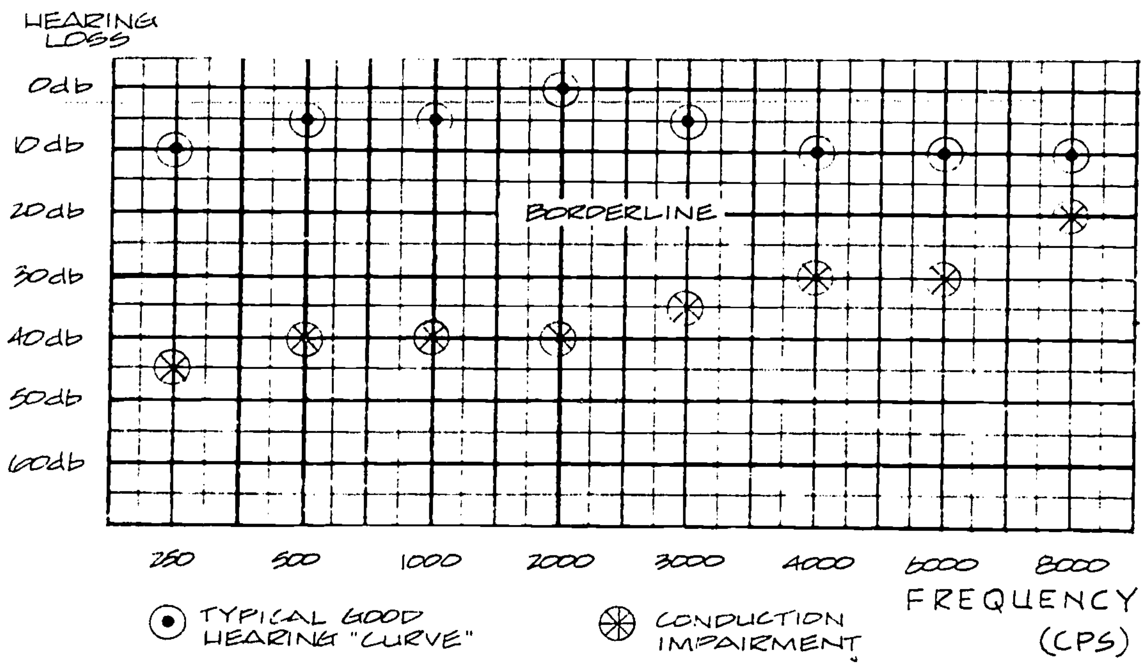


FIGURE 2: Normal and conduction-impairment audiograms.

Notice that in the good-hearing curve, all marks are above the 20-db line. (The lower the db number, the better the hearing. A person with "perfect" hearing would show 0 db at all frequencies). Notice that a conduction impairment affects the lower frequencies most and the higher frequencies least.

Figure 3, on the following page, shows the same good-hearing curve compared with a perception impairment.

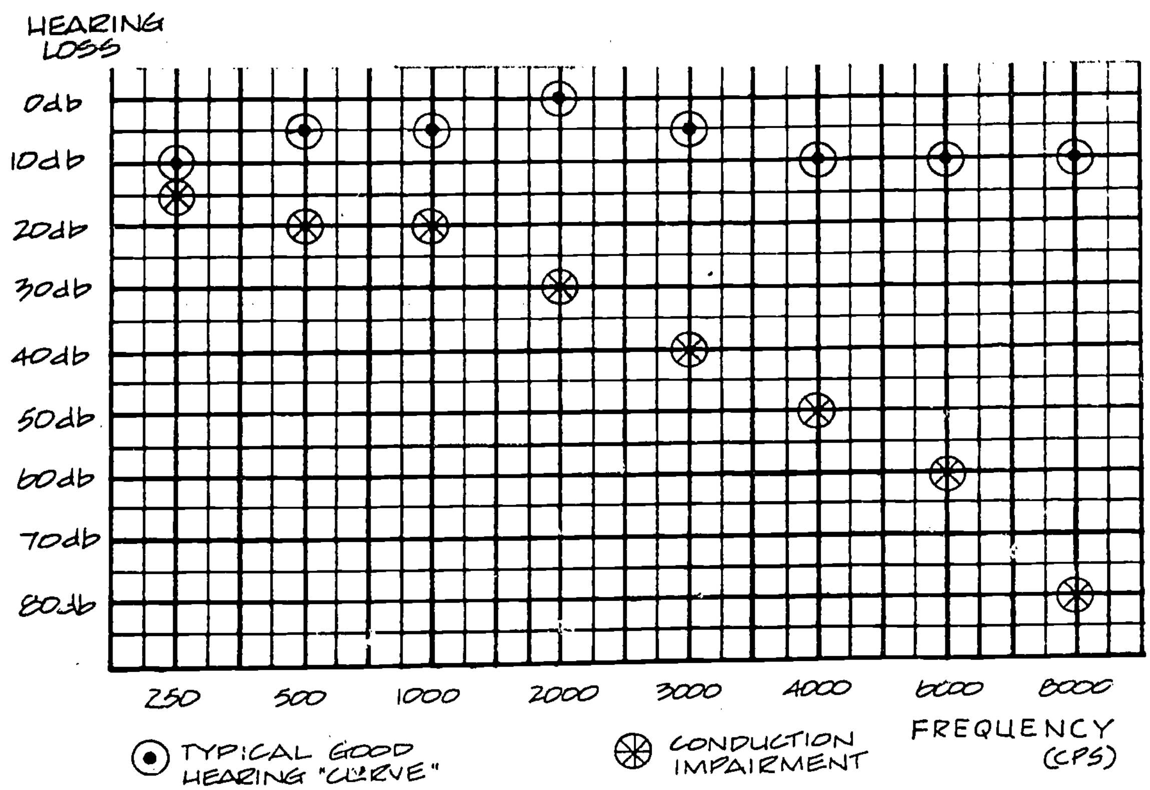


FIGURE 3: Normal and perception-impairment audiograms.

Notice that this audiogram shows almost the opposite of the conduction-impairment curve. That is, the low frequencies are affected least and the high frequencies the most.

Figure 4 shows a typical hearing curve in someone who has developed early hearing loss due to excessive noise exposure. The good-hearing curve is not shown.

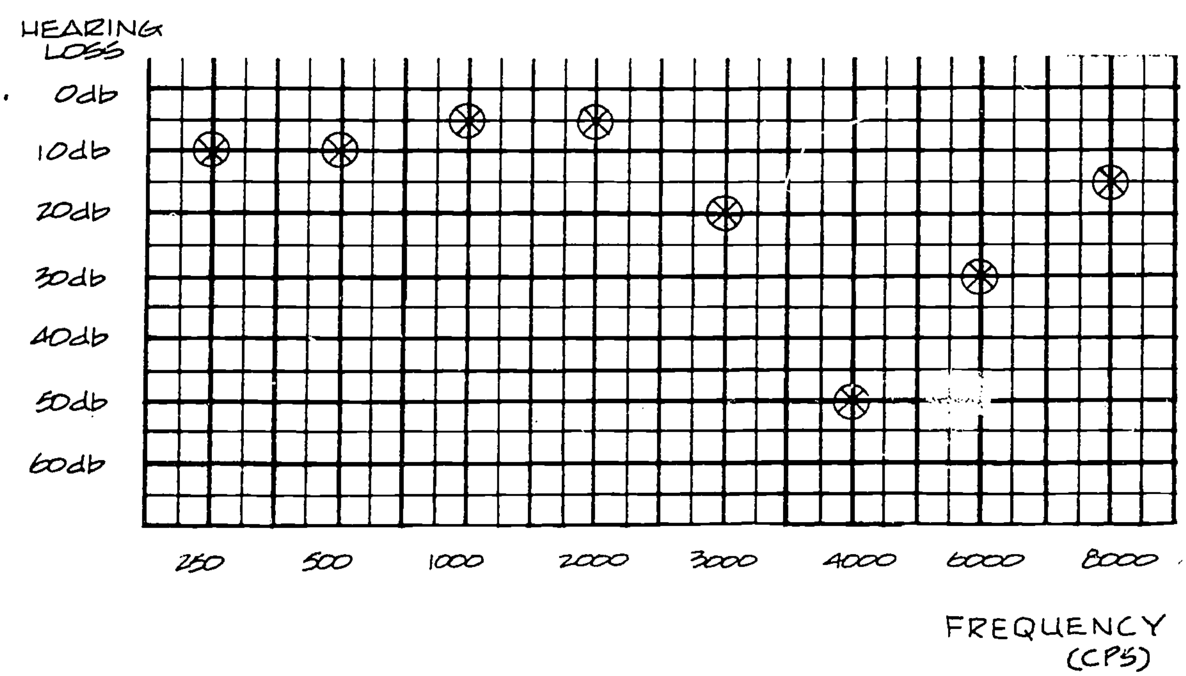


FIGURE 4: Hearing-loss pattern from excessive noise exposure.

Notice that hearing is good at all frequencies except 4,000 and 6,000 cycles with 4,000 cycles being affected the most.

23-3 Middle Ear Infection

What makes an ear ache?

One of the commonest of all medical problems in childhood is an earache. This is frequently an indicator of serious infection. Recall from Section 22-1 the anatomy of the middle ear. If the eustacian tube becomes plugged up by congestion from a cold, our ears may feel uncomfortable or "full" because pressure is not exactly the same in the middle ear as it is in the external ear canal. However, serious problems may occur if we blow our nose in such a way as to force infected material from the throat into the middle ear. This may be sufficient to start a bacterial infection called "middle-ear infection" or otitis media. In the years before antibiotics, the infection was often serious and scarring occurred which permanently affected hearing. The warning signs of otitis media: (1) a fever following what appears to be an ordinary cold and (2) severe earache. A health professional can determine whether infection is present by looking at the eardrum with an otoscope. The eardrum will appear red and possibly swollen. This technique was performed in Laboratory Activity 22.

23-4 Noise Pollution

Can noise affect our general health?

It is never truly quiet. There is always some sound. But some low-level sounds are restful like wind in trees or splashing water in a water fountain. What about loud mufflers, a jackhammer or a noisy elevator? There is some evidence that our bodies react negatively to noise we can't control. It is the opposite of what we get through biofeedback: blood pressure may go up, heart rate may increase, gastric juice secretion may change. Can noise be related in any way to coronary heart disease, high blood pressure, or peptic ulcer? The fact is, we don't know for sure. However, we do know that many modern diseases seem to be the result of several factors operating together, often in unexpected ways. Maybe a Biomed student will someday establish the role of noise in causing medical problems that are unrelated to hearing.

Vocabulary:

conduction deafness--loss of hearing due to impairment of sound conduction in the external, middle, or inner ear.

otitis media--middle ear infection, often due to bacteria.

perception deafness--loss of hearing due to damaged hair cells or nerves from the hair cells to the brain's hearing center.

prosthesis (prahss-THEE-sus)--an artificial substitute for a missing or removed body part.

SECTION 24: SPEECH

24-1 Introduction

Humans differ from other species in several important ways. We alone have an erect stance. Our tool-making ability is far more developed than that of any other species. And, because we are able to speak, we have developed the use of language as a means of communication. Of all the differences, speech has probably contributed more to the present condition of the human species than any other single factor. As far as we know, no other species possesses a communication capability comparable to human speech. Most of the time we take our ability to speak for granted. However, when we watch little children learn to speak, or when we try to communicate with someone who doesn't speak our language, we are reminded of the complexity of speech.

Why is speech so important? Many other species have the ability to signal to each other, to make sounds that have a communication function. Some species make sounds to signal an alarm when danger is present, or to drive off intruders. Sounds are used as signals to attract mates. Sounds may be used to establish a territory and warn away other members of the species who may be in that territory. Sounds may be used by parents to locate their offspring. But these sounds are not speech. (There are probable exceptions to this statement. Scientists now believe that dolphins are able to use sounds in much more advanced ways than simple signaling. Experiments with chimpanzees indicate that they can learn rather complicated language patterns.)

Speech is important because it allows the development of language. Language consists of words put together in ways that communicate ideas. Words are symbols; they represent something. You know what is meant by the word "hour" even though you cannot see an hour. And because we can use symbols, we communicate more effectively than other species. In addition, language is fundamental to human thought processes. Things for which we have words, we remember more easily. For example, some languages have no word for "yellow." People who speak these languages have great difficulty in selecting yellow test cards when asked to select a yellow card from a collection of colored cards.

Another advantage of speech and the language it allows is its importance to the development of human culture. In almost all species, one generation is able to teach the next generation. Parents raise offspring by preparing them to act in the same way as they do. But humans are able to pass knowledge across generations. Knowledge first acquired thousands of years ago in Greece, or China, for example, is available to us today. The culture you possess consists of many ideas and beliefs about the world that have developed over thousands of years. In Social Science you learned that culture consists of shared ideas; these ideas could not be shared without language.

In this section you will learn how people speak--what our bodies do that allows us to communicate through speech. This is a very complicated process. There are health professionals who specialize in speech problems and their correction. For example, speech therapists help those with stuttering problems. They can also help the deaf learn to communicate, even though they cannot hear speech.

24-2 Speech Production--An Overview

Is a license required to make plosives?

A diagram of the vocal organs is given in Figure 1. As air is forced up from the lungs, it passes through the vocal cords, which are part of the larynx, then into the pharynx, or throat. At the back of the mouth, part of the air may be diverted out through the nose by way of the nasal cavity. More commonly the soft palate shuts off this passage and the air travels out the mouth during speech.

Together, these organs form a complicated "tube." The part of the tube above the vocal cords is called the vocal tract and consists of the pharynx, mouth and nose. This tube has natural resonant frequencies, much like the open-ended tube that you experimented with in Laboratory Activity 23. By varying the shape of the tube, with our tongue and soft palate for example, we can change its natural resonant frequencies. We use this technique to make different kinds of sounds.

The source of energy for speech is the stream of air that comes from our

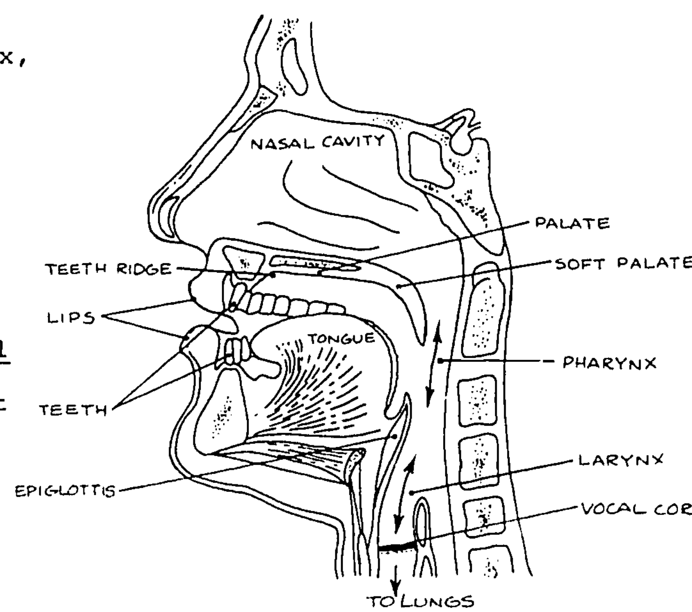


FIGURE 1: A cross-sectional view of the vocal tract.

lungs as we exhale. When we breathe normally, the stream produces no sound. It can be made to produce sound by setting it into rapid vibration. There are several ways to do this, but the most common one involves vocal-cord action.

The vocal cords (Figure 2) are part of the larynx. You can locate the larynx easily because part of it is the projection on your throat known as the Adam's apple. You may feel the vocal cords vibrating if you place your thumb and index finger on your Adam's apple and say, "Ahhh."

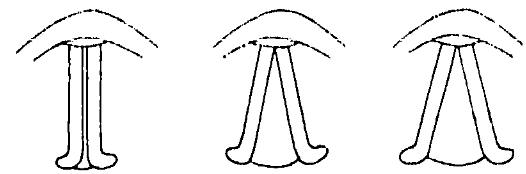


FIGURE 2: The vocal cords, closed, partially open and open.

The vocal cords form an adjustable barrier across the air passage coming from the lungs. As we talk the vocal cords open and shut rapidly, breaking the airstream into a sequence of puffs. During speech, standing waves are set up in the vocal cords much like the ones you produced in the strings in Laboratory Activity 24. One way we may vary the natural resonant frequency of our vocal cords is by varying the tension on them. The range of vocal-cord frequencies used in normal speech varies from about 60 cps to 350 cps, or more than two octaves. However, for a particular person, the range is only about 1.5 octaves.

The nature of the buzz produced by the vocal cords is modified by the resonating properties of the vocal tract, the open-ended tube beginning at the vocal cords and ending with the mouth or nose. The natural resonant frequencies of these two vibrating systems (the vocal cords and the vocal tract) are generally different although they may be identical. It is the combination of these two independent resonators that produces the characteristic sounds of speech. During speech we are continually changing both the vibrational frequency of our vocal cords and the shape of our vocal tract.

Adjusting the shape of the vocal tract to produce different sounds is called articulation; the separate movements of the lips, tongue, palate, etc., are called articulatory movements.

In addition to the process just described, some languages such as English make use of two other processes to make sounds. When we make hissing sounds like "s" and "sh" we are forcing the flow of air through a narrow constriction. These sounds are called fricatives. The other method is to stop the flow of air momentarily by blocking the vocal tract with either the tongue or the lips and then suddenly releasing the air pressure built up behind this block. Sounds such as "p" and "k" are made by this blocking process and are called plosives.

It should be remembered that the second and third methods described are independent of vocal-cord activity although the speaker may vibrate the vocal cords simultaneously. Whichever of the three methods is used, the resonances of the vocal tract still affect the nature of the basic sounds produced by hiss, plosion or vocal-cord vibration.

What is the source of energy for speech?

How may the resonant frequencies of the vocal tract be changed?

How may the vibrational frequency of the vocal cords be changed?

Give two examples of fricative sounds.

Give three examples of plosive sounds.

Vocabulary:

articulation (ar-TICK-you-LAY-shun)--the process of adjusting the shape of the vocal tract to produce different sounds.

fricative (FRICK-uh-tive)--a sound produced by forcing air through a narrow constriction.

plosive (PLO-siv)--a sound produced by suddenly releasing blocked air.

soft palate--the portion at the back of the mouth that controls the passage of air between the pharynx and nasal cavity.

vocal tract--the "tube" that begins at the vocal cords and ends at the mouth and/or the nose.

SECTION 25: ENGLISH SPEECH SOUNDS

25-1 Voiced and Unvoiced Sounds

How is the "s" sound different from the "z" sound?

Quietly make "s" and "z" sounds to yourself. How are they different? Does the position of your tongue change? Does the shape of your mouth change? Do your vocal cords vibrate for one of the sounds and not the other? Only this last question may be answered, "Yes." The vocal cords vibrate during a "z" and not during an "s." In the language of linguists both are said to be articulated identically. The difference is in the voicing. "s" is an unvoiced sound while "z" is a voiced sound.

Vowel sounds are always voiced while consonants may be either voiced or unvoiced. In the table at the right we have listed consonant pairs which have the same articulation but different voice.

	VOICED	UNVOICED
PLOSIVE	b	p
	d	t
	g	k
FRICATIVE	v	f
	th	θ
	z	s
	zh	sh

Notice the entries in the table for "th" and "θ." The written English language makes no distinction between the voiced and unvoiced "th." However the spoken language makes use of both sounds. Say the phrase, "The thing," quietly to yourself. Which "th" sound is voiced and which is unvoiced? The "th" in "the" is voiced while the "th" in "thing" is unvoiced. The Greek symbol θ is used to indicate the unvoiced kind of "th."

A similar situation exists for the "zh" and "sh" sounds. Although the "zh" (as in Asia) exists in the spoken language, the letters "zh" together do not exist in the written language.

As a speech therapist, you would need to know the manner in which all English sounds are made. For example, in working with people who are learning English as a second language you would need to be able to tell your subjects how to make both the "θ" and "th" sounds, and when to use each.

25-2 Vowels

What is the vowel quadrilateral?

Vowels are those sounds that are made entirely by altering the resonating characteristics of the vocal tract, primarily by movements of the lips and tongue. They never involve sound-making movements of the plosive or fricative type. Consonants, on the other hand, are made by creating a partial or complete obstruction of the passage of air from the lungs to the mouth.

Say the following sequence of sounds quietly to yourself.

1. "ee" as in "flee"
2. "oo" as in "cool"
3. "aw" as in "call"
4. "ae" as in "had"

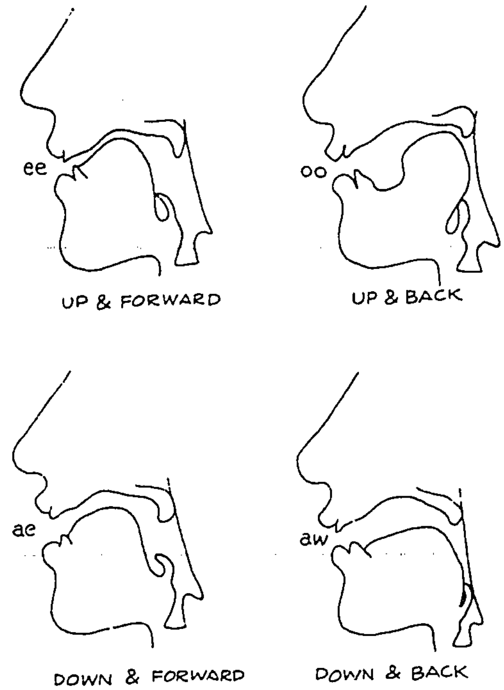
Go back to 1 and repeat. Note the positions of your tongue as you repeat this sequence over and over (Figure 1). Notice that as you repeat this sequence, your tongue traces out a four-sided figure, i.e., a quadrilateral.

Many of us were told that there are five vowels in the English language (a, e, i, o and u). However, linguists now tell that there are at least 11 distinct pure vowel sounds in the English language. The approximate position for each in relation to the vowel quadrilateral is shown in Figure 2 below.

In addition to the 11 pure vowel sounds, there are five vowel sounds that are combinations of two other vowel sounds (e.g., the "oi" sound in "toil"). These sounds are called "diphthongs."

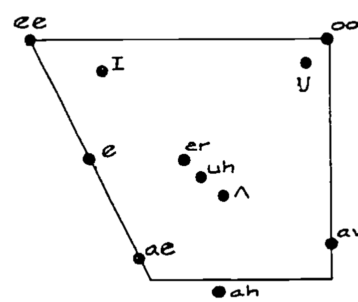
Return to the list of four vowel sounds at the beginning of this section. Repeat the sequence once again, but this time note the shape of your lips as you go through the sequence. Notice that your lips are spread when your tongue is forward; they are rounded when your tongue is back. You might think that these lip shapes and tongue positions must necessarily go together if you are a native speaker of English; however, this is not so.

In French, for example, there is a vowel with the tongue forward and up that is made with the lips rounded instead of spread. Place your tongue in the position for "ee," but round your lips. It is the elusive sound used in "rue," the French word for street.



THE SPEECH CHAIN

FIGURE 1: Tongue positions for the English vowel quadrilateral.



THE PURE VOWELS

ee	heat	ah	father
I	hit	aw	call
e	head	U	put
ae	had	oo	cool
uh	the	Λ	ton
er	bird		

THE DIPHTHONGS

ou	tone
ei	take
ai	might
au	short
oi	toil

FIGURE 2: The 16 distinct vowel sounds and approximate tongue positions for the 11 pure vowels.

25-3 The Physics of Speech Production

If the maximum vibration rate of the vocal cords is about 350 cps, then how are frequencies of up to 10,000 cps produced during speech?

Imagine a bell or a gong that is being struck regularly with a hammer. In addition to the regular strikes of the hammer we will hear the higher pitches of the bell ringing at its own natural resonant frequencies. A similar situation takes place in our throats during speech. The sound waves produced by the vocal cords "ring" the vocal tract in much the same way. When someone speaks we hear both the fundamental frequency produced by the vocal cords and the higher resonant frequencies of the vocal tract as it "rings" to the sound waves produced by the vocal cords.

The vocal tract may be considered to be a tube about 17 cm long, open on one end (the mouth) and closed on the other (the vocal cords). If it were as evenly shaped as the open-ended tube in Laboratory Activity 23, its resonant frequencies would be about 500 cps, 1500 cps, 2500 cps and so forth (Figure 3 on the following page). The natural resonant frequencies of the vocal tract are not so evenly spaced because it is not so evenly shaped as a cylinder. Both the fundamental resonant frequency and the spacing of the higher resonant frequencies may be changed by articulatory movements. It is these differences in frequency and spacing of overtones that give the different vowels their characteristic sounds.

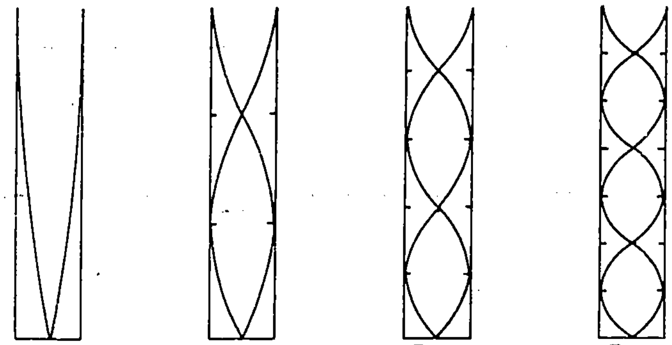


FIGURE 3: Successive resonant standing wave patterns for a 17-cm, uniform tube.

Scientists have found that at least two harmonics above the fundamental resonant frequency are required to be understood. For women, the frequency of the third harmonic may be as high as 4000 cps; therefore, we may say that the normal range of speech frequencies runs from about 60 cps, the lowest fundamental frequency of the vocal cords to 4000 cps, the highest harmonic of the vocal tract required for intelligibility. It is possible to be understood without difficulty using an even narrower band of frequencies. Telephones use frequencies between 200 cps and 3200 cps.

What is the difference between a voiced and an unvoiced sound?

Not all consonants are listed in the table. Determine an English consonant that has no voiced or unvoiced companion in spoken English.

Describe how the position of the tongue relates to the vowel quadrilateral.

What is the relationship between tongue position and lip shape for English vowels?

What is the "speech range" of frequencies?

Vocabulary:

voiced sounds--sounds made with the vocal cords vibrating.

vowel quadrilateral--the positions taken by the tongue as it moves through the extreme positions required to form vowels.

REVIEW SET 25:

1. Waves transmit an important physical quantity. What is it?

2. Why would life be impossible without waves?

3. Two of our senses are based on the reception and interpretation of waves. What are they?

4. We also generate waves. What kind and for what purpose?

5. Sound waves are (longitudinal, transverse).

6. Describe the process of pure-tone audiometry.

7. How do standing waves differ from traveling waves?

8. If the frequency of a wave is 300 cps and the wavelength is 2.2 meters, what is the wave speed?

9. What two functions are performed by the auditory canal?

10. What function is performed by the eardrum?

11. What are three functions of the bones in the middle ear?

12. Describe how the various frequencies are sorted out along the basilar membrane.

13. Describe how vibrations of the basilar membrane lead to the generation of action potentials.

14. How is pitch information collected in the cochlea?

15. Why does a normal Rinnè test subject hear the tuning fork longer by air conduction than by bone conduciton?

16. What information of medical significance may be learned from a visual examination of the eardrum?

17. Hearing impairments may be classified as either conductive or perceptive. State which kind of loss is associated with the items listed below.

   a. In the Rinné test a subject hears better by bone conduction.

   b. Damage to the haircells in the cochlea.

   c. Scarring of the middle ear bones due to otitis media.

   d. Rupture of the eardrum.

   e. Blockage of the auditory canal with wax.

   f. Prolonged exposure to loud noise.

   g. A build-up of pus in the middle ear cavity.

   h. Otosclerosis.

   i. Damaged auditory nerve.

   j. A reduction in the blood supply to the organ of Corti.

   k. An audiogram showing marked hearing loss in the lower frequencies.

   l. An audiogram showing marked hearing loss in the upper frequencies.

18. What environmental problem is associated with a "4000-cps dip" (i.e., an audiogram showing a sharp hearing loss around 4000 cps with some recovery in the higher frequencies).

19. Suppose a tube filled with carbon dioxide, open at one end, is found to resonate at about 25 cm and again at 75 cm to a 259-cps tuning fork. What is the speed of sound in CO_2?

20. An air-column open on one end resonates at about 330-cps and again at 990-cps. Assume that s, the speed of sound, is 330 m/sec. How long is the tube?

21. What are the first two resonant frequencies of an air-filled tube, open on one end, that is 30 cm long?

22. Describe the pattern of successive resonant frequencies of an air-filled tube, open on one end, of a given length.

23. Name two important resonating air columns in the human body.

24. Describe how the following factors affect the fundamental resonant frequency of a stretched string.

a. effective length

b. tension

c. linear density

25. a. Which factor in Problem 24, when doubled, will halve the fundamental frequency?

b. Which factor needs to be quadrupled to double the fundamental frequency?

26. Describe the pattern of successive resonant frequencies of a stretched string.

27. As we grow from children to adults the basic pitch of our voice changes. For each of the following factors, state whether it will <u>increase</u> or <u>decrease</u> the basic pitch of our voices.

a. The vocal tract lengthens.

b. The vocal cords become more massive.

c. The vocal cords lengthen.

28. How do we change the fundamental frequency of our vocal cords at will?

29. What may happen to make the vocal cords more difficult to vibrate? State two causes.

30. State three examples of voiced plosives.

31. State four English unvoiced fricatives.

32. How many harmonics of the vocal tract are required for intelligibility?

33. What happens to the spacing of resonant frequencies as we change our lip and tongue positions during articulation?

34. How many pure vowel sounds does English use? How many diphthongs?

35. What is the difference between a pure vowel and a diphthong?

36. Describe how our vocal tract produces frequencies of up to 10,000 cps, when our maximum vocal-cord frequency is about 350 cps.

SECTION 26: INTRODUCTION TO LIGHT AND VISION

26-1 <u>The Vision Unit</u>

How do we see?

To answer this question, we will need to study light and its properties. We will also need to study the anatomy and physiology of the eye. Our study of light will take a little longer than our study of sound did, because light is more complex than sound.

This sequence will have personal meaning to many students, because anyone that needs glasses has an eye problem. If we live long enough, all of us will eventually need glasses. Eye problems other than those affecting vision are also common. Finally, several important careers relate to vision, especially those of ophthalmologist, optometrist and optician.

26-2 Light--An Introduction

How are light and sound similar? How are they different?

Sound is a type of longitudinal wave; it travels through a substance by changes in the density (and pressure) of the substance. But what is light? How does light differ from sound?

A simple answer is that we hear sound and see light, but this does not help us understand light, or understand how our eyes convert light into the images that we perceive.

One characteristic that distinguishes light from sound is that light can travel through empty space, while sound must travel through matter (since sound involves movement of matter). If a bell is placed in a sealed jar and the air is pumped out of the jar, the sound of the ringing bell becomes progressively fainter as the density of the air in the jar decreases. But we can still see through the jar.

A second difference between light and sound is that light, with certain exceptions that we will discuss, travels in a straight line, while sound can more easily travel around corners. We are able to hear music coming from a radio that we cannot see, but we can't watch a TV program from behind the set unless we use a mirror. Any model that we use to explain light must take into account these differences between light and sound.

Light puzzled scientists for a long time, and it was not until relatively recently that a satisfactory model was developed. We call a model satisfactory if all observed phenomena can be explained in terms of the model.

For several centuries scientists disagreed as to whether light should be treated as particles or waves. The results of some experiments strongly suggested that light behaves as waves. But other experiments suggested just as strongly that light consists of particles. According to modern physics, light may be treated as either waves or particles. But in our study of the properties of light, it will be more convenient to treat light as waves; so we will use a wave model for light.

The direction of a light wave can be changed in four ways. The most familiar way is probably by reflection, as in a mirror. Another familiar way is by refraction, a process you observed while using the hand-magnifier otoscope in Laboratory Activity 22. A less familiar way of changing the direction of light is by diffraction. We will study diffraction first, because it will help explain the behavior of light and it provides a means of measuring the wavelengths of different colors of light. The last way of bending light is called scattering, which is responsible for the blue color of the sky. We will not investigate scattering, but mention it only for completeness' sake.

26-3 Diffraction

How is diffraction related to phase?

Even though light and sound are different, they share certain properties of waves. For example, the waves travel at characteristics speeds, i.e., "the speed of light" and "the speed of sound." The waves also have frequencies and wavelengths. Furthermore, for both light and sound these variables are related to each other as described by the formula $s = f\lambda$.

A wave property shared by light and sound is <u>diffraction</u>. When waves of the same wavelength start from two different points the waves add together in all possible phase relationships. At certain points they will be completely in phase and add together. At other points they will be completely out of phase and tend to cancel each other out. The patterns of addition and cancellation so produced are called "diffraction patterns." Diffraction patterns may be seen by means of a device known as a ripple tank. They may be heard by means of two speakers hooked to a BIP. In Laboratory Activity 26, you will see and measure the diffraction of light and use your measurements to calculate the wavelengths of different colors of light.

The phenomenon of diffraction has many important biomedical implications. It is diffraction that limits the size of the smallest thing we can see with our naked eyes. It is diffraction that limits the size of the smallest thing that may be seen with a light microscope. And it is also diffraction that limits the resolving power of large telescopes.

26-4 Diffraction and Wavelength

Suppose two speakers are hooked up to a BIP as shown in Figure 1. When both speakers are producing the same note, differences in amplitude may be heard in different locations in the room. Why is this? It is related to the idea of phase, which was discussed in Mathematics Section 26 If the waves from the two speakers arrive at your ear in phase, the amplitudes will add and you will hear a louder sound. If they arrive out of phase, they will tend to cancel and a softer sound will be heard. What governs the phase relationship between the two waves? In Figure 2 we have diagrammed some maximum and minimum sound positions.

When waves travel the same distance to the listener, both waves will be in phase (Figure 3).

When the waves travel different distances, they will take different amounts

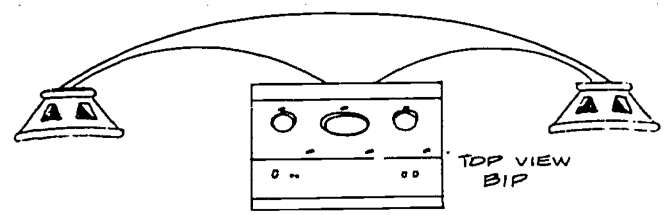


FIGURE 1: An arrangement of speakers and a BIP which may be used to hear diffraction effects.

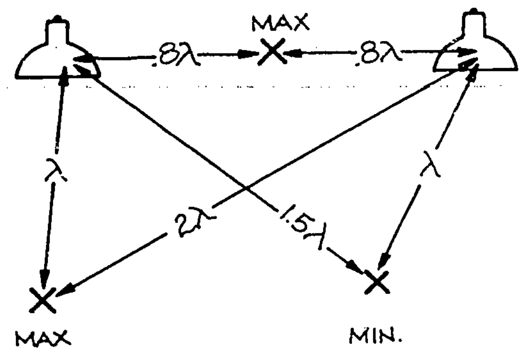


FIGURE 2: Some locations where the sound will be of maximum and minimum loudness.

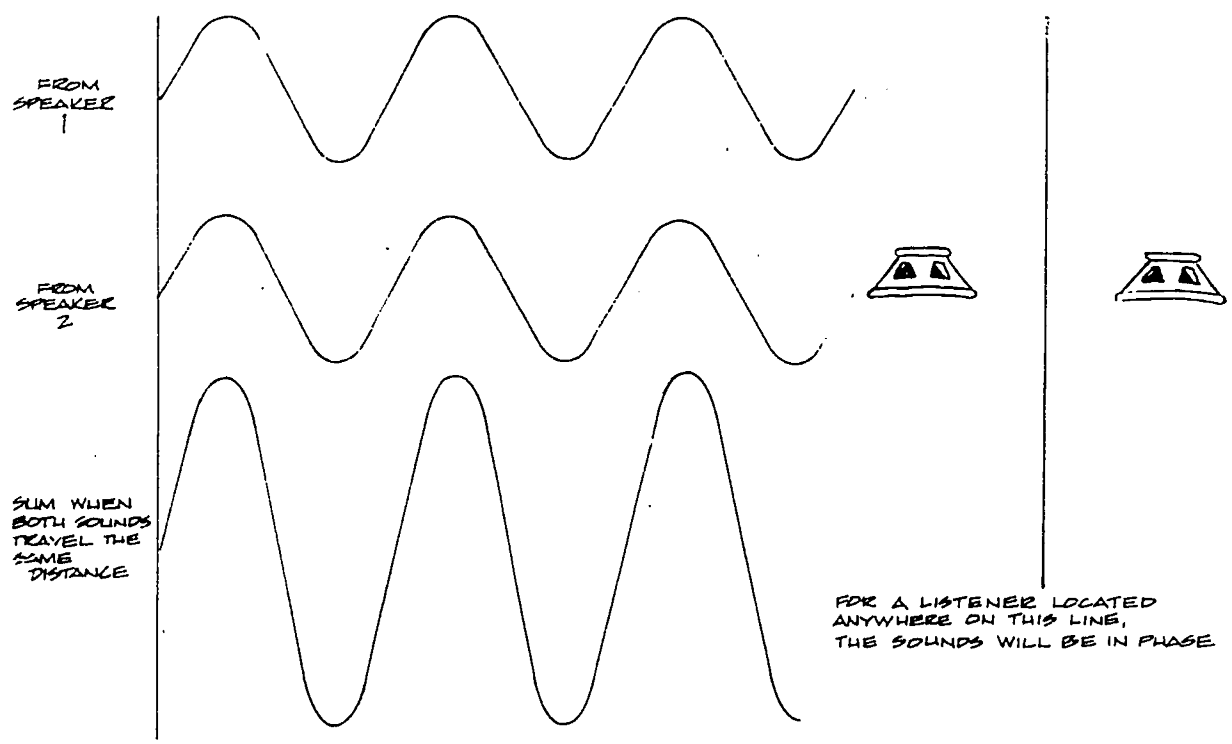


FIGURE 3: Phase relationship when both waves travel the same distance from source to listener.

of time to reach the ear. This time difference can produce a difference in phase at the location of the listener. Suppose that the listener is $\frac{1}{2}\lambda$ closer to speaker one than to speaker two. Then it will take longer for waves from the farther speaker to reach his ear. Specifically it will take $\frac{1}{2}$T sec longer. This time difference will produce a 180° phase relationship between the two waves and they will tend to cancel each other out (Figure 4). (They will not cancel completely because the waves from the closer speaker will be of greater amplitude.)

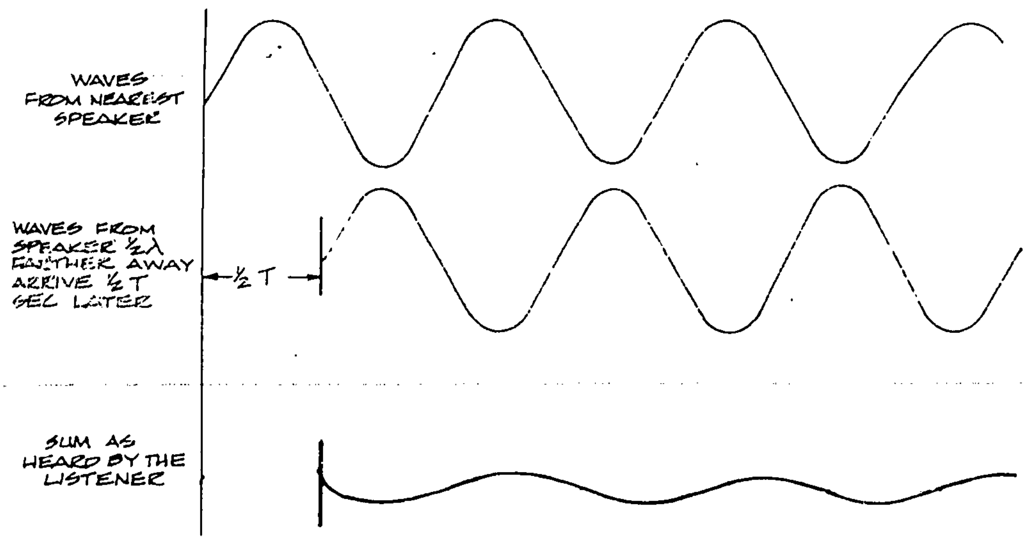


FIGURE 4: Phase relationship between waves coming from two speakers, one being $\frac{1}{2}\lambda$ farther away than the other.

When one speaker is one wavelength farther away, the waves will once again be in phase at the location of the listener. This occurs because the waves from the farther speaker will arrive one period later and, once again, wave peaks from both speakers will be arriving at the ear at the same time (Figure 5).

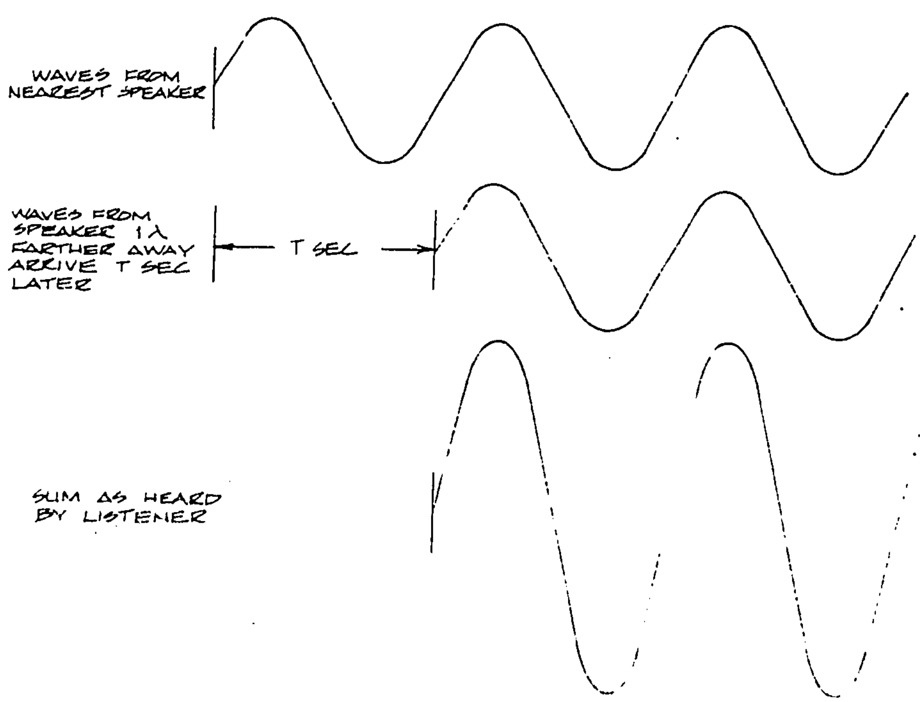


FIGURE 5: Phase relationship between waves coming from two speakers, one being λ farther away than the other.

These observations may be easily confirmed in practice by locating positions of relative minimum or maximum loudness and making measurements. If you do this, you will find that the general relationships for positions of maximum and minimum loudness are:

(1) Maximums: The difference in distance to the two speakers is a whole-number multiple of λ.

(2) Minimums: The difference in distance is $\frac{\lambda}{2}$ more than a whole-number multiple of λ. For a particular BIP tone, λ can be calculated from the formula

$$\lambda = \frac{s}{f}$$

where: s = speed of sound, approximately 330 meters/sec

f = the frequency in cps as read from the BIP dial

26-5 The Diffraction of Light Waves

How may diffraction be used to measure the wavelength of light?

Suppose that a light source is positioned behind two parallel slits. This arrangement is used to provide two light sources. The light will spread out as shown in Figure 6.

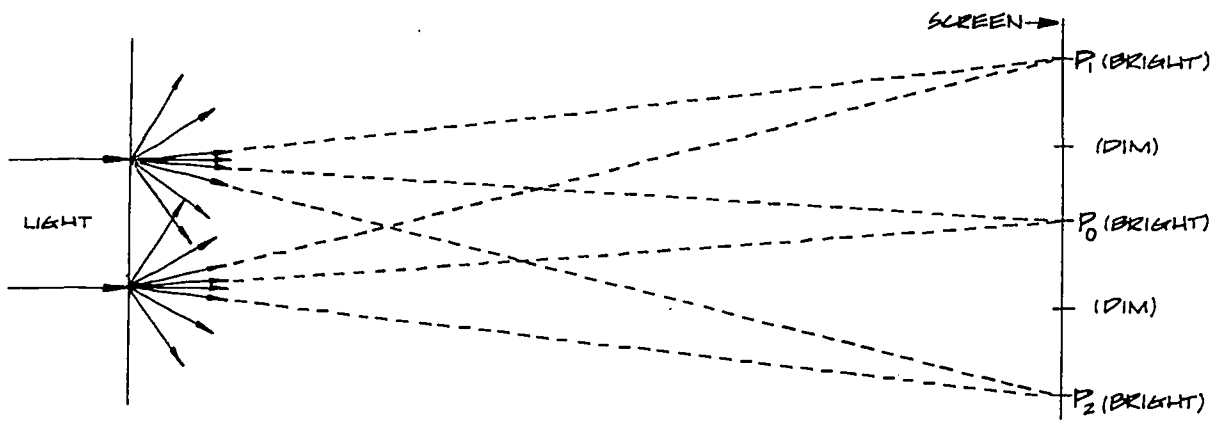


FIGURE 6: The spreading of light waves by two slits.

The light waves coming through the slit interact in the same way that sound waves from two speakers do. In some locations the waves will be in phase and the light will be bright. In others, waves coming from the two slits will be out of phase and the light will be dim. Whether the light will be bright or dim at a particular location depends upon how far the location is from each of the two slits. If the difference in distance is one wavelength, the light will be bright; if the difference is one half wavelength it will be dim.

Now suppose we let the light that is coming through the slits fall on a screen, as shown in Figure 7 on the following page. Further, suppose we find that a bright spot is located at P_0. Since P_0 is the same distance from both slits, light coming from both slits will be in phase. Moving upward from P_0 we will find that the light becomes bright again at another point. We have labeled this point P_1. In Figure 7 we have struck an arc of radius r, the distance from P_1 to the closer slit (A). As indicated in the figure, λ is the additional distance from P_1 to the other slit (B). Notice that the angular separation θ of P_0 and P_1, is a function of wavelength. If λ is shorter, then P_0 and P_1 will be closer together and $\angle\theta$ smaller. Also notice that P_0 and P_1 may be separated more by making d, the distance between the slits, smaller.

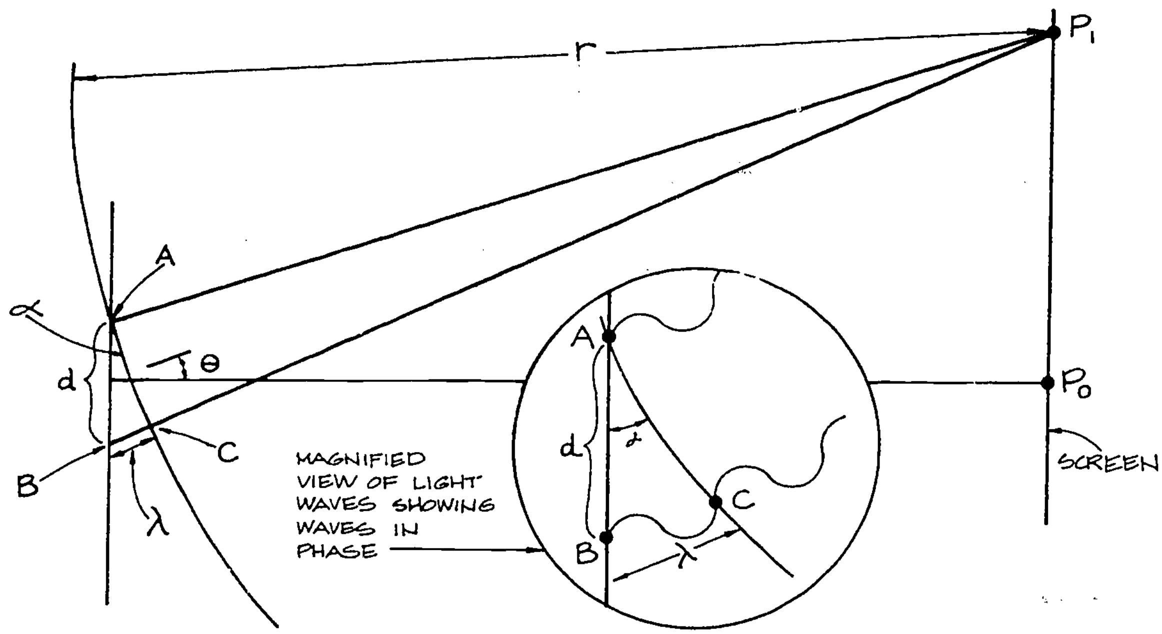


FIGURE 7: Geometrical relationships between two slits and two bright locations in a diffraction experiment.

It turns out that λ, the wavelength of light creating the bright spot at P_1, may be easily calculated from quantities that are easily measurable in such an experiment. The angular separation of P_0 and P_1 is easily measurable. You will use a protractor in Laboratory Activity 26 to measure it. Fortunately this angle is a very good approximation of $\angle\alpha$ in Figure 7. We will not trouble you with the details of demonstrating this fact, but you can trust that it is nevertheless true. The near equivalance of $\angle\alpha$ and $\angle\theta$ allows us to write a trigonometric equation that relates θ, d (the distance between the slits) and λ.

The figure ABC in Figure 7 has been redrawn as a right triangle in Figure 8. This is another very good approximation that we will not derive. Notice that λ, the wavelength, is the side opposite $\angle\alpha$ and that d, the distance between the slits, is the hypotenuse; therefore,

$$\sin\alpha \simeq \frac{\lambda}{d}$$

and since $\angle\alpha \simeq \angle\theta$

$$\sin\theta \simeq \frac{\lambda}{d}$$

After multiplying both sides by d, we get

$$d\sin\theta \simeq \lambda$$

Both d and θ in the above equation may be measured, which allows λ to be calculated. This is what you will do in Laboratory Activity 26.

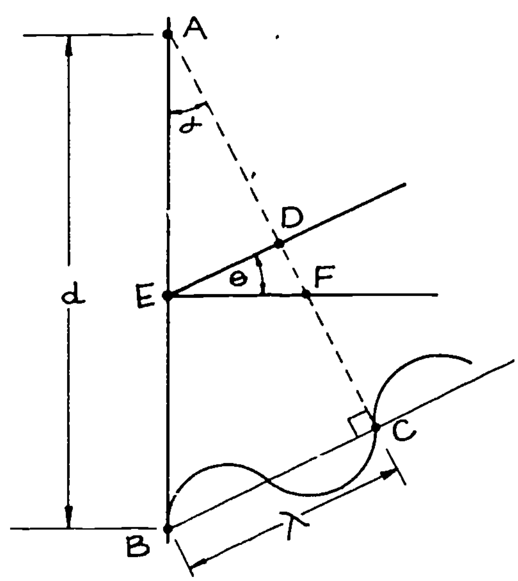
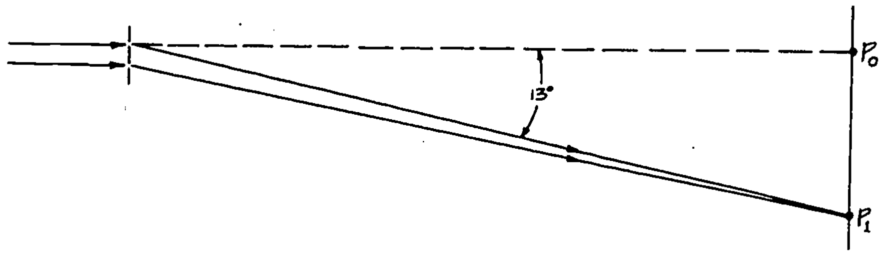


FIGURE 8: A blow-up of figure ABC in Figure 7.

EXAMPLE:

The distance between two slits is 2.54×10^{-6} meters. A beam of yellow light causes a bright spot 13 degrees from the central bright spot. What is the wavelength of yellow light?



SOLUTION:

$d = 2.54 \times 10^{-6}$ m

$\theta = 13°$

$\sin \theta = .225$

$$\lambda \simeq d \sin \theta$$

$$\simeq (2.54 \times 10^{-6})(.225)$$

$$\simeq 5.715 \times 10^{-7} \text{ meter}$$

or, equivalently $\lambda \simeq .5715 \times 10^{-6}$ meter

Why should we be interested in the wavelength of light? Remember that the wavelengths of sounds had important implications for the way sounds were produced (speech) and the way they were heard (hearing). Similarly, the wavelengths of light will be considered in discussion of vision.

26-6 Diffraction Gratings

In practice, the devices used for measuring the wavelengths of light have many more than two slits. But the explanation we gave using two slits is still valid, as can be seen from Figure 9, which shows a situation with four slits.

If the waves are approximately parallel, the difference in path length of any two adjacent waves is the same. Wave a in the drawing travels λ farther than wave b. Wave b travels λ farther than c, etc. If a and b arrive at a point in phase, c and d will also be in phase with them.

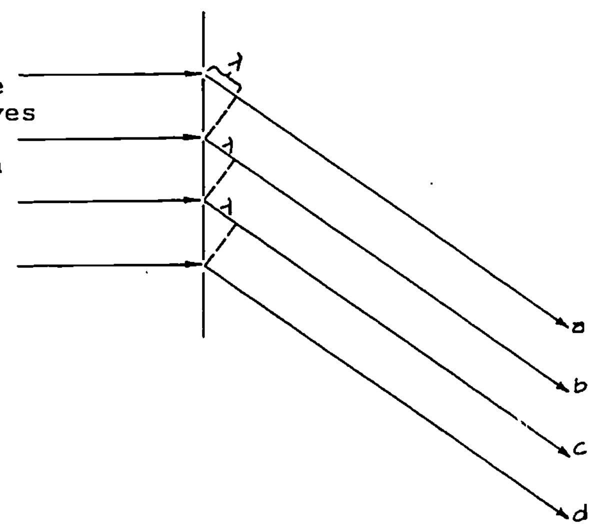


Figure 9: Light passing through four slits.

We have been considering light of a single wavelength, but most light is made up of many wavelengths. The angles at which waves are in phase and bright spots occur we have seen to depend on wavelength; bright spots occur at different places for different wavelengths.

Color is dependent on wavelength; we see different wavelengths as different colors. White light is composed of a combination of colors, or wavelengths. If white light passes through a series of slits, bright spots of various colors appear at different places. By measuring the angles through which a color is diffracted, its wavelength can be calculated from the formula

$$\sin \theta \simeq \frac{\lambda}{d}$$

Or, rearranging,

$$\lambda \simeq d \sin \theta$$

26-7 Diffraction and Microscopes

What is the smallest thing that may be seen with a microscope?

As a Biomed student you have had many opportunities to look through microscopes. These devices magnify the images of tiny objects so that we may observe them. However, there is a limit to the power of these devices. One of the effects of diffraction is that it is impossible to see anything smaller than the wavelength of the light being used. The wavelength of visible light is on the order of 5×10^{-4} mm, or one half of a thousandth of a millimeter! Figure 10 shows the relative sizes of various microscope objects. Objects on the scale that are bigger than the wavelength of visible light may be seen with a light microscope. To view smaller objects it is necessary to use an electron microscope. It is possible to view the smaller objects with an electron microscope because the wavelengths of high-speed electrons are much shorter than those of visible light.

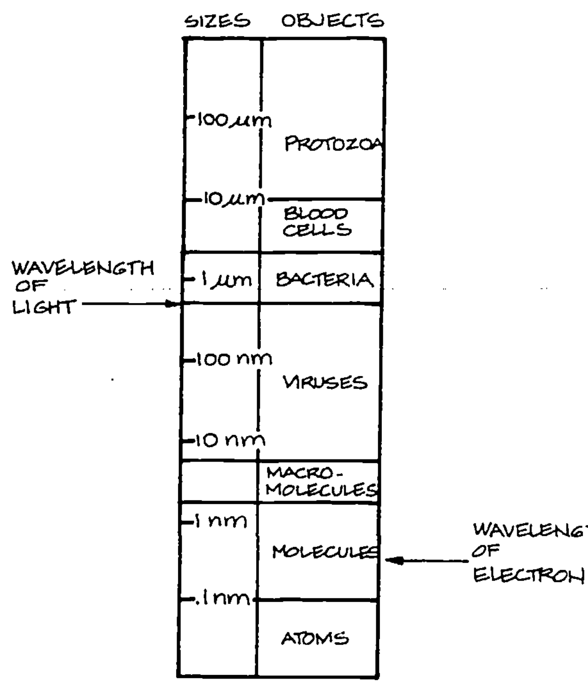


FIGURE 10: Sizes of objects in relation to wavelengths of light and electrons 1,000 nm (nanometers) = 1 μm)

Sound waves require a medium to travel through. Do light waves also require a medium?

In what four ways may the direction of light be changed?

What relationship between the distances from two wave sources will result in a maximum wave sum? a minimum? Explain.

May a light microscope be used to view a protein? Explain.

Vocabulary:

diffraction (dih-FRAK-shun)--the breaking up of traveling waves into regions of relative maximum and relative minimum amplitude. For light this amounts to breaking up light into regions of bright and dark bands or colors.

PROBLEM SET 26:

The formula $\lambda \approx d \sin \theta$ may be used to calculate λ when d and θ are known, where d and θ are the quantities described in Figure 8 of this section. The sine of θ may be found in the table at the end of the Mathematics Text.

1. A certain diffraction grating states that it has 5,000 grooves per cm.

   a. Use dimensional algebra to convert this quantity to units of cm per groove.

   b. State your answer to Part a in scientific notation.

   c. Use the conversion factor $\frac{10^7 \text{ nm}}{1 \text{ cm}}$ to convert your answer to Part a to units of nanometers.

For Problems 2 through 5 convert "grooves per cm" to "m per groove."

2. 2,500 grooves per cm
3. 3,300 grooves per cm
4. 4,000 grooves per cm
5. 7,500 grooves per cm

6. A certain diffraction grating states that is has 10,000 grooves per inch.

   a. Use dimensional algebra to calculate the number of inches per groove.

   b. State the result of Part a in scientific notation.

   c. Use the conversion equality 1 inch = 2.54 cm to convert the answer to Part b to cm.

   d. Use the conversion equality 10^7 nm = 1 cm to convert your answer to Part c to nanometers.

7. Write a dimensional-algebra statement that does all of Problem 6 in one step.

For Problems 8 through 10 use dimensional algebra to convert "grooves per inch" to "nanometers (nm) per groove."

8. 25,400 grooves per inch. 9. 12,700 grooves per inch. 10. 20,000 grooves per inch.

11. Suppose d = 2,000 nm and $\theta \approx 15°$. Calculate λ.

12. Suppose d = $\frac{5,000}{3}$ nm and $\theta \approx 18°$. Calculate λ.

13. Suppose d = 1,500 nm and $\theta \approx 20°$. Calculate λ.

SECTION 27: THE NATURE OF LIGHT

27-1 Light Waves

The nature of light waves is not as easy to explain as sound waves, which may be described in terms of changes in density or displacement of molecules. Our description of light waves will have to be incomplete, because an adequate explanation requires an advanced knowledge of electricity and magnetism.

The wave model of light was proposed by the Scottish mathematician and physicist James Clerk Maxwell during the 1860's. Maxwell confronted the problem of how waves can travel through empty space, a problem that had made several generations of scientists uncomfortable. The question of how waves travel through empty space is related to another one that makes some people uncomfortable, how one object can exert a force on another when the two are separated by empty space. Maxwell proposed a model involving the concept of fields.

When we think of an object exerting a force on another object, we think of the two being in contact. You can push this book only if you are touching it. The ability of a magnet to attract a pin from a distance always seem a bit magical.

Yet there is a force that acts at a distance that is so commonplace that we are likely to overlook it. This is the force of gravity. If you throw a ball into the air, it falls back toward the earth. This is such a common experience that we are not inclined to wonder how the earth "tells" the ball to begin falling.

Scientists like to explain things in terms of models. The purpose of a model is to make matters easier to visualize and understand. The model used to explain the action of the earth on a ball, and the action of a magnet on a pin, is the field. According to the model, the earth is surrounded by a gravitational field. The field is not composed of matter; in fact it can exist in empty space. It has no mass and cannot itself be seen, but it can be detected: the fact that a ball falls to the ground indicates the presence of a gravitational field.

A magnet is surrounded by a magnetic field. This field can be detected by placing a pin near the magnet. Similarly, an electric charge is surrounded by an electric field.

If you take a wire that is carrying current and move it near a magnetic compass in a certain way, the compass needle is deflected. This phenomenon may be explained by assuming that a changing electric field creates a magnetic field. (Do not try this experiment with the usual household pair of wires, because current is flowing in opposite directions in the two wires, and the e ects of their electric fields cancel.)

It is also possible to cause current to flow in an elec l circuit by moving a magnet in a certain way near the circuit. The fan b t f an automobile turns a magnet that is encircled by coils of wire. Electric current is generated in the coils; this is a generator. We explain the ability of a moving magnet to generate electricity by saying that a changing magnetic field creates an electric field.

A changing electric field creates a magnetic field, and a changing magnetic field creates an electric field. Maxwell examined (mathematically) the possibility that a continuously changing electric field could produce a continuously changing magnetic field, which in turn could produce a continuously changing electric field, and so on. He found that, in theory, this is possible, and that these oscillations should travel at approximately 3×10^8 meters per second, very close to the measured speed of light. This led Maxwell to suggest that light consists of oscillating electric and magnetic fields, or <u>electromagnetic waves</u>.

Maxwell did not live to see his model verified by experiment; but in 1888, within ten years of his death, a German scientist named Heinrich Hertz designed equipment that could produce electromagnetic waves. (His apparatus was a spark coil much like that in an automobile engine.) Hertz not only determined that the electromagnetic waves he produced traveled at the same speed as light, he also found that these waves are reflected, refracted and diffracted in the same ways that light is. Hertz's experiments verified Maxwell's theory of light as electromagnetic waves, and Maxwell's theory is now a fundamental part of physics.

27-2 Electromagnetic Waves

The type of electromagnetic radiation predicted by Maxwell has a fixed speed in empty space but can have any frequency and wavelength. Electromagnetic waves of a wide range of frequencies and wavelengths in fact exist; they are classified in Figure 1 on the following page (although the boundaries are only approximate).

Observe that a specific frequency corresponds to a specific wavelength; this is because the product of frequency and wavelength is always equal to the speed of light.

At present, the most generally agreed-upon figure for the speed of light in empty space is 2.997925×10^8 meters per second. This number is conveniently close to 3.00×10^8 meters per second, and we will use this approximate value in our study of light.

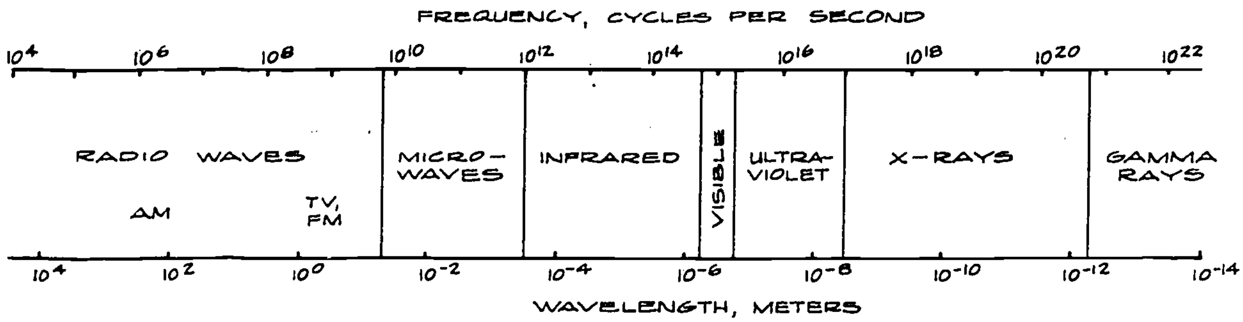


FIGURE 1: Wavelengths and frequencies of vari .s kinds of electromagnetic radiation.

Light travels at 3.00 x 10^8 meters per second in empty space, but at slower speeds in matter. (Recall that matter is composed of electrons and protons; these particles have electric charge and thus are surrounded by electric fields, which interact with the electric and magnetic fields of light and slow down the light waves.) The speed of light in air at 20 °C is only .03 per cent less than it is in empty space, but the speed of light in water is 2.25 x 10^8 meters per second and in one common type of glass is only 1.97 x 10^8 meters per second.

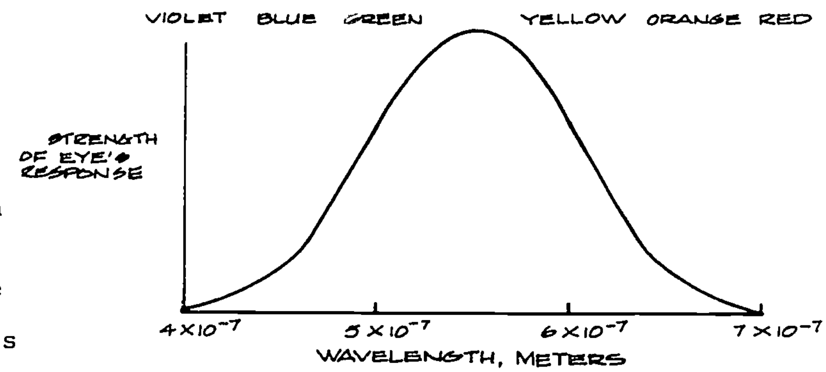


FIGURE 2: The wavelengths of visible light.

The region of the electromagnetic wave spectrum that is visible light is small. It extends from wavelengths of about 4 x 10^{-7} meters (violet) to about 7 x 10^{-7} meters (red). Our eyes are not equally sensitive to all light within that range, but are more sensitive to colors in the middle of the range, being most sensitive to colors between yellow and green.

In Laboratory Activity 26 you observed what are called monochromatic colors, colors whose frequency ranges are quite narrow. For example, when light of the single wavelength 580 nanometers (1 nm = 1 x 10^{-9} m) is detected by our eyes, we perceive it as yellow. Does this mean that everything we perceive as yellow sends light with a wavelength of 580 nm to our eyes? Unfortunately not. Our sense of color perception is quite complicated and will be dealt with in Laboratory Activity 27.

27-3 Huygens' Principle

The properties of light, such as reflection, refraction, diffraction and scattering, can be explained by equations of electromagnetism, but these equations are very complex. Fortunately, a simpler model may be used to explain the properties we are concerned with. This model was proposed by Christian Huygens, a Dutch physicist, in 1678, almost two centuries before Maxwell proposed the electromagnetic theory of light, and over 100 years before the phenomenon of diffraction was recognized by scientists.

Huygens' theory simply assumed light to be waves, without considering the kind of wave, whether they are transverse or longitudinal, or the speed at which they travel.

To understand Huygens' principle, consider a coiled spring which we can oscillate. When we oscillate a coiled spring, we are dealing with a single train of waves, traveling toward a single point. But sound and light (and water waves) travel along many lines at once; we must consider many trains of waves to understand sound and light.

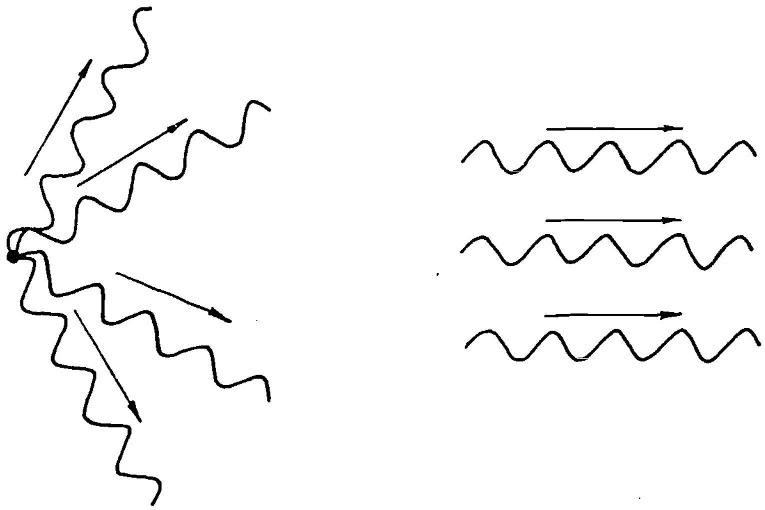


FIGURE 3: Wavetrains.

It is convenient to think of such waves in terms of wavefronts. A wavefront is a surface (which appears as a line on this two-dimensional page) connecting points that are in phase (Figure 4).

FIGURE 4: Wavefronts.

(You are familiar with the wavefront of a water wave. Wavefronts are the "breakers" at the seashore; or, if you live inland, wavefronts are the circles that radiate outward when a stone is thrown into a pool of water.)

According to Huygens' Principle, each point along a wavefront is a source of wavelets (small waves). In other words, waves radiate from each point along a wavefront, much as waves radiate from the point where a stone has been dropped into water (Figure 5 on the following page).

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Huygens' Principle further states that these wavelets form a new wavefront. The new wavefront intersects each of the individual wavelets at one and only one point. (Figure 6). Every point along this new wavefront in turn is the source of a wavelet; in this way a wave travels, or propagates.

In Section 28 we will see how Huygens' principle may be used to help explain how light is bent when it is refracted.

What is produced by a changing electric field?

What is produced by a changing magnetic field?

What is Maxwell's theory of light?

How was Maxwell's theory verified?

What range of wavelengths are our eyes sensitive to?

Describe how wavelets create wavefronts.

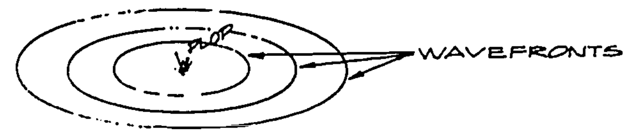

FIGURE 5: Waves radiate from each point on a wavefront just as waves radiate from the point at which a stone is dropped into water.

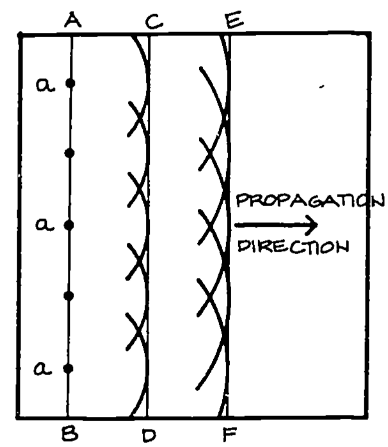

FIGURE 6: Wavefront AB advances to CD and then to EF. The black dots along AB are all sources of Huygens' wavelets. The wavelets touch each new wavefront at only one point.

Vocabulary:

electromagnetic waves--oscillating electrical and magnetic waves ranging from radio waves at the low-frequency end to gamma rays at the high-frequency end of the spectrum.

monochromatic (MON-oh-kro-MAT-ik)--describing light waves with a very narrow band of frequencies, derived from words for "one" (mono) and "color" (chromo).

wavefront--a traveling wavecrest.

SECTION 28: REFRACTION AND THE SPEED OF LIGHT

28-1 Refraction

What happens when light passes from one medium to another?

The phenomenon of refraction is at the very center of our sense of vision. It is refraction that allows us to focus sharp visual images in our eye. And it is an understanding of refraction which makes it possible to correct many vision-related problems.

If you half-submerge a pencil in water, the pencil appears to be bent at the surface of the water (Figure 1 on the following page). The pencil is not actually bent, but the light emerging from the water is. The light is said to be refracted.

Refraction may best be studied by observing from the side a beam of light passing from one medium to another, for example, from air to water (Figure 2).

We will often consider light as traveling in "rays." Rays are infinitely thin, as geometric lines are, and do not actually exist, but they are often convenient when we are concerned with the geometric properties of light.

The ray from the source to the boundary between air and water is the incident ray. The ray that results from the bending of light at the surface is the refracted ray.

The direction of these rays is defined in terms of lines perpendicular to the boundary between the two media (Figure 2).

Angle α is the angle between the incident ray and a line perpendicular to the boundary and is called the angle of incidence. Angle β is the angle between the refracted ray and the line perpendicular to the boundary; it is called the angle of refraction.

The degree of refraction as light passes from one medium to another is usually expressed by the index of refraction. Index of refraction, commonly symbolized n, is defined as the ratio of the sine of the angle of incidence to the sine of the angle of refraction.

$$\text{Index of Refraction} = n = \frac{\sin \alpha}{\sin \beta}$$

In Laboratory Activity 28 you will determine the index of refraction for certain pairs of media under various conditions.

28-2 Index of Refraction and Speed of Light

Why is the ratio (sin α/sin β) a constant for a given pair of media?

Imagine a wavefront approaching an air-water boundary (Figure 3). One time unit later the wavefront has advanced one wavelength in air (Figure 4 on the following page). After the next time interval, part of the wavefront has passed into the water (Figure 5 on the following page). Since light travels more slowly in water than in air, its wavelength in water (λ_w) will be shorter than λ_a. The direction of light ray A is changed because Huygens' principle requires that each wavelet touch the next wavefront at only one point.

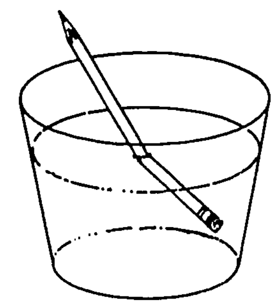

FIGURE 1: Apparent bending of a pencil in water.

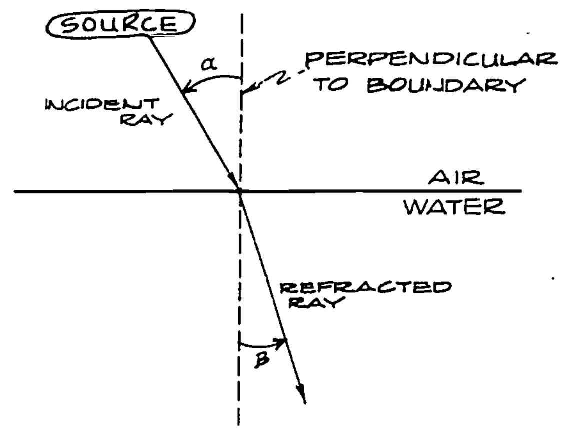

FIGURE 2: A ray of light bends at an air-water boundary.

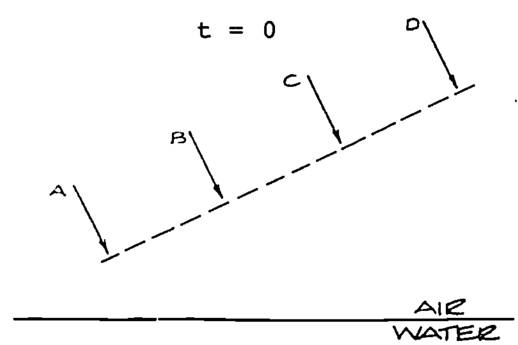

FIGURE 3: A wavefront approaching a water surface.

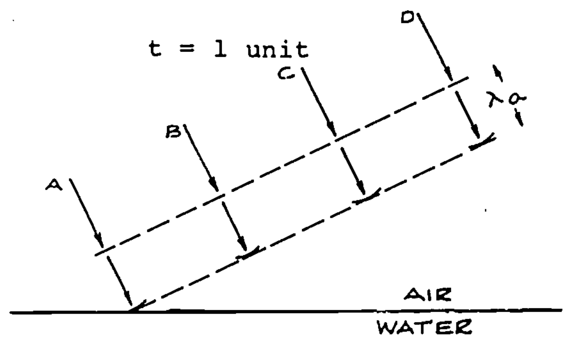

FIGURE 4: One period later the wavefront has traveled one wavelength in air (λ_a).

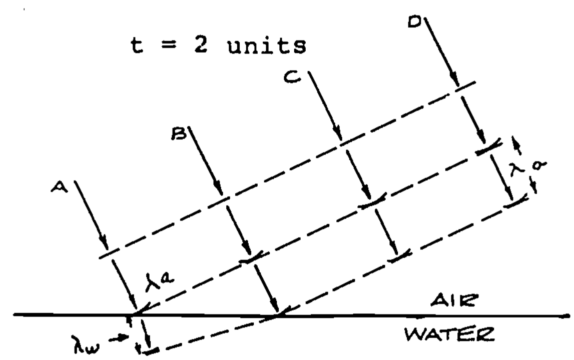

FIGURE 5: Two periods later light ray A has traveled one wavelength in air (λ_a) and one wavelength in water (λ_w).

In other words, ray A must remain perpendicular to the new wavefront in water and the only way for this to happen is for the direction of ray A to change.

Eventually the entire wavefront is moving at the speed of light in water (Figure 6). However, in passing from air to water the wavefront changed direction, because part of it traveled at a slower speed for a greater time.

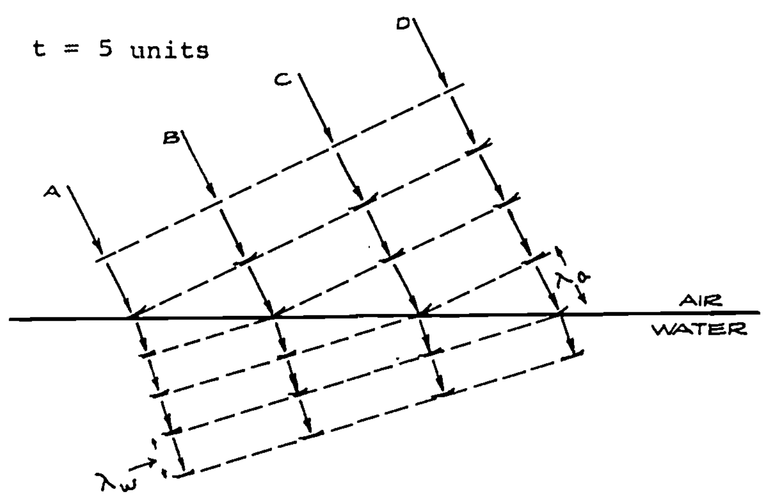

FIGURE 6: After 5 periods the entire wavefront is under water.

We say that the light was refracted. And we may use trigonometry to derive a relation between the index of refraction for two media and the speed of light in the two media.

Let us redraw the incident and the refracted rays A and B in Figure 6 and label a few dimensions. The angle of incidence is α; the angle of refraction is β (Figure 7 on the following page).

From the geometrical and trigonometric relationships shown in Figure 7, we can answer the question, "Why is the ratio $\sin \alpha / \sin \beta$ a constant for a given pair of media?" First locate angles α and α' in Figure 7. They are equal because either angle α or α' plus angle θ is 90°. This can be true only if $\alpha = \alpha'$. Next locate angles β and β'. They are also equal, for a similar reason. Notice that $\beta + \phi = 90°$ and also $\beta' + \phi = 90°$; therefore, $\beta = \beta'$.

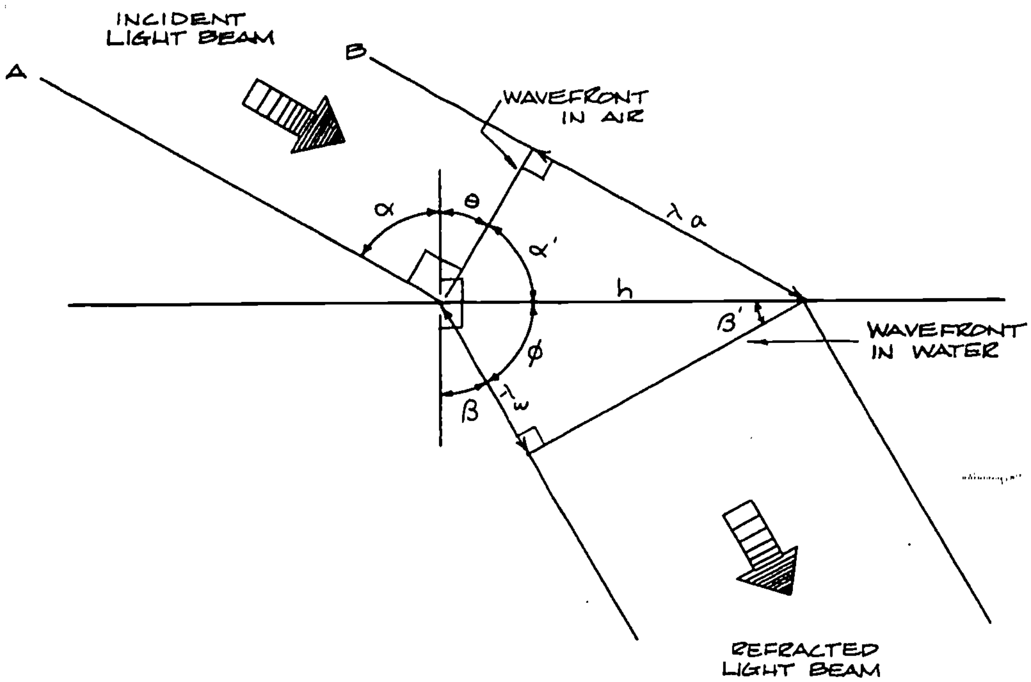

FIGURE 7: The various important angles and lengths for a refracted beam of light.

From the Mathematics course we know that in a right triangle,

$$\text{sine of an angle} = \frac{\text{length of side opposite the angle}}{\text{length of hypotenuse}}$$

From an inspection of Figure 7, we can see that

$$\sin \alpha' = \frac{\lambda_a}{h} \quad \text{and} \quad \sin \beta' = \frac{\lambda_w}{h}$$

The ratio of sin α' to sin β' is

$$\frac{\sin \alpha'}{\sin \beta'} = \frac{\frac{\lambda_a}{h}}{\frac{\lambda_w}{h}} = \frac{\lambda_a}{h} \cdot \frac{h}{\lambda_w} = \frac{\lambda_a}{\lambda_w}$$

Now we use the facts $\alpha = \alpha'$ and $\beta = \beta'$ to write

$$\frac{\sin \alpha}{\sin \beta} = \frac{\lambda_a}{\lambda_w}$$

Note that this equation relates angles α and β to the wavelengths of light in the two media, air (λ_a) and water (λ_w).

The distance traveled in a period of time is the product of the speed and the time interval. Distances λ_a and λ_w are distances traveled by rays during the same time interval, which we will call t. If c_a is the speed of light in air and c_w is the speed of light in water,

$$\lambda_a = c_a t$$

and

$$\lambda_w = c_w t$$

If we substitute these two expressions in the expression for the ratio of sin α to sin β, we obtain

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$$\frac{\sin\alpha}{\sin\beta} = \frac{c_a \not{t}}{c_w \not{t}}$$

$$\frac{\sin\alpha}{\sin\beta} = \frac{c_a}{c_w}$$

The ratio of the sine of the angle of incidence to the sine of the angle of refraction is equal to the ratio of the speed of light in air to the speed of light in water. Since this ratio is constant, the ratio of the sines will also be constant. In other words,

$$n \text{ (index of refraction)} = \frac{\sin\alpha}{\sin\beta}$$

The fact that the index of refraction is a constant for a given pair of media is known as Snell's Law.

28-3 Reference Values for n

What is meant by, "The refractive index of glass?"

In reference books you will find lists of the refractive indices of various substances. In all cases, the incident ray is considered to be in a vacuum and the refracted ray in the stated medium. Thus, literature values for refractive index give the ratio of the speed of light in a vacuum to the speed of light in the substance. For example when we say, "The refractive index of glass is 1.5," without mentioning a second medium, we mean,

$$1.5 = \frac{\text{speed of light in a vacuum}}{\text{speed of light in glass}}$$

In Laboratory Activity 28 you will measure the refractive index of an air-water boundary. This number will be a very good approximation to the refractive index of a vacuum-water boundary because the speed of light in air and the speed of light in a vacuum are nearly equal.

What causes light to be refracted?

What is the second medium understood to be when we say, "The refractive index of glass is 1.5?"

Vocabulary:

angle of incidence(α)--the angle between the incident ray and a line perpendicular to the boundary between two media.

angle of refraction(β)--the angle between the refracted ray and a line perpendicular to the boundary between two media.

incident ray--a ray from the light source to the boundary between two media.

index of refraction(n)--sin α/sin β.

refracted ray--the ray that results from the bending of light at the boundary between two media.

Snell's Law--states that the index of refraction will be constant for a given pair of media.

PROBLEM SET 28:

1. $\alpha + \theta = ?$

2. $\alpha' + ? = 90°$.

3. From Problems 1 and 2:

   α' = (a) $90°/\alpha$
   (b) $90° + \alpha$
   (c) α

4. The sine of an angle = ?

   (a) $\frac{\text{length side adjacent}}{\text{length side opposite}}$

   (b) $\frac{\text{length hypotenuse}}{\text{length side opposite}}$

   (c) $\frac{\text{length side opposite}}{\text{length hypotenuse}}$

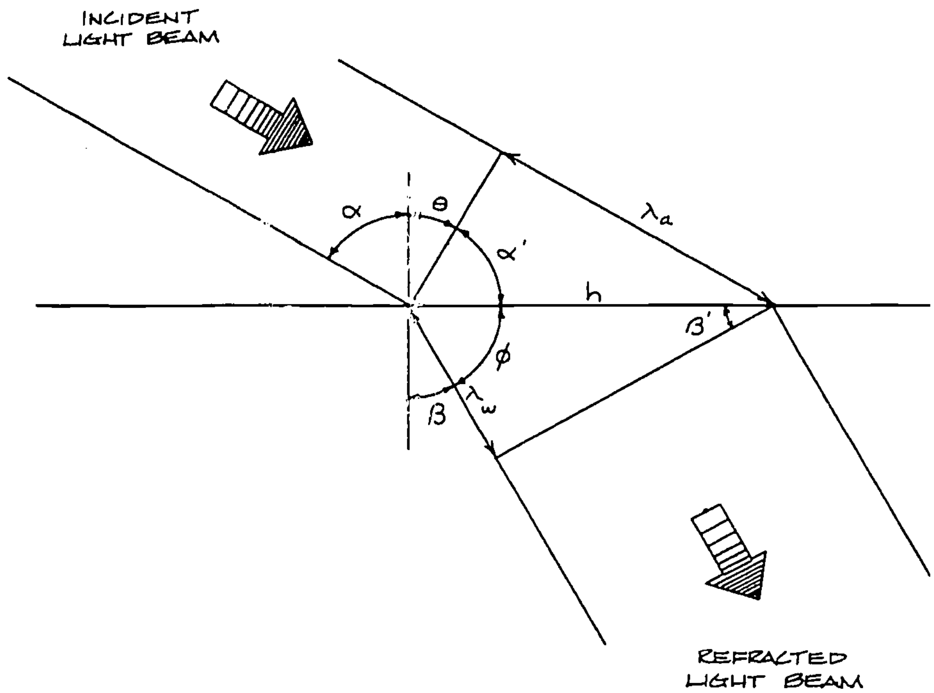
5. $\sin \alpha' = \frac{?}{h}$ $\quad \sin \beta' = ?$

6. $\sin \alpha = ?$ $\quad \sin \beta = ?$

7. $\frac{\sin \alpha}{\sin \beta} = ?$ (a) $\frac{\lambda_w \cdot h}{h \cdot \lambda_a}$

   (b) $\frac{\lambda_a}{\lambda_w}$

   (c) $\frac{\lambda_a}{h} \cdot \frac{\lambda_w}{h}$



8. λ_a = distance traveled by light beam in air

   c_a = speed of light in air

   t = time to travel distance, λ_a

   Which is correct? (a) $\lambda_a = \frac{t}{c_a}$

   (b) $\lambda_a = c_a \cdot t$

   (c) $\lambda_a = \frac{1}{t} \cdot c_a$

9. The index of refraction for light passing from air into water is

   $n = \frac{\sin \alpha}{\sin \beta} = \frac{\lambda_a}{\lambda_w} = ?$ (a) $\frac{c_w}{c_a}$

   (b) $\frac{c_a}{c_w}$

   (c) $\frac{c_a - c_w}{c_w + c_a}$

SECTION 29: LENSES

29-1 Light Passing Through a Flat Piece of Glass

Is the direction of a ray of light changed when it passes through a flat piece of glass?

When light passes from one medium to another, it is refracted. The angle of incidence (α) and angle of refraction (β) are measured in relation to a line perpendicular to the boundary between the two media (Figure 1).

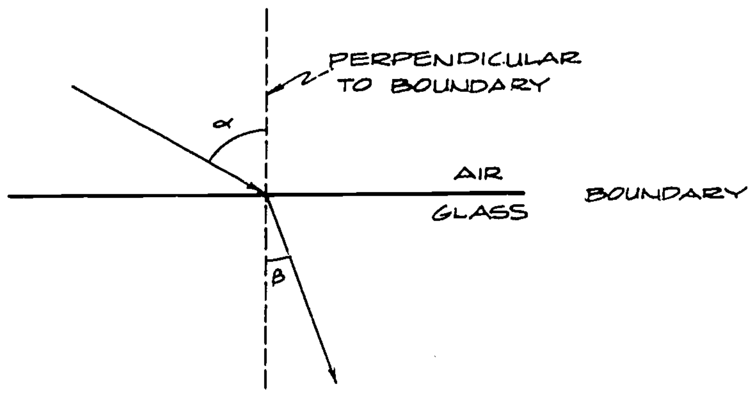


FIGURE 1: Light striking an air-glass boundary.

If the index of refraction of the second medium is greater than that of the first medium, light is bent away from the surface and toward the line perpendicular to the boundary. For example, glass has a higher index of refraction than air does, so light entering glass from air is refracted toward the perpendicular line.

Light passing from a medium of higher refractive index into a medium of lower refractive index, however, is bent toward the surface (Figure 2).

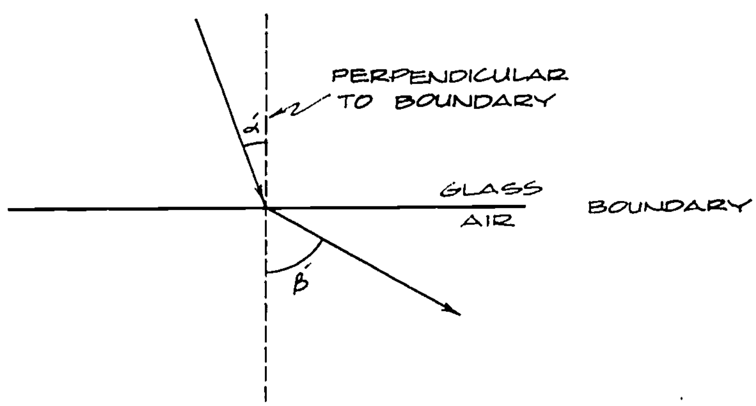


FIGURE 2: Light striking a glass-air boundary.

When light passes through a plane piece of glass, it is refracted twice: when it enters the glass and when it leaves the glass (Figure 3 on the following page).

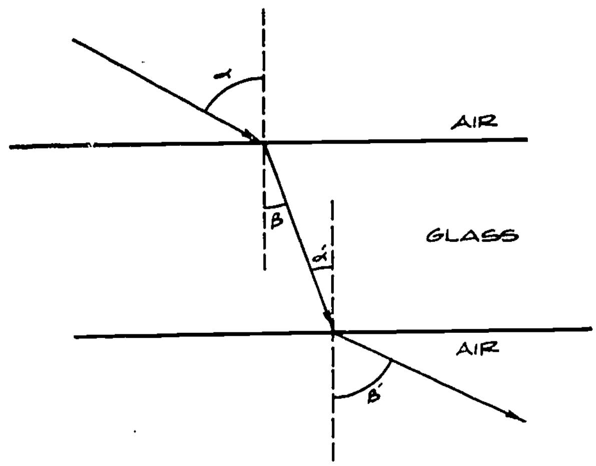


FIGURE 3: Light passing through a plane piece of glass.

The angle of incidence and angle of refraction when light enters glass from air are related to the speed of light in air (c_a) and in glass (c_g).

$$\frac{\sin \alpha}{\sin \beta} = \frac{c_a}{c_g}$$

The angles of incidence and refraction as light passes form glass to air are also related to the speed of light in the two media.

$$\frac{\sin \alpha'}{\sin \beta'} = \frac{c_g}{c_a}$$

Comparing the two equations we see that

$$\frac{\sin \alpha}{\sin \beta} = \frac{\sin \beta'}{\sin \alpha'}$$

It is also true that $\beta = \alpha'$ for geometric reasons. After substituting β for α' on the right we obtain

$$\frac{\sin \alpha}{\sin \beta} = \frac{\sin \beta'}{\sin \beta}$$

Then we multiply both sides by $\sin \beta$ to give

$$\sin \alpha = \sin \beta'$$

which implies that the angles are equal

$$\alpha = \beta'$$

This means that light emerging from a plane piece of glass travels in the same direction as the incident light.

29-2 Lenses

How does a lens make things look larger?

In Laboratory Activity 22 you used a hand magnifier to make the eardrum look larger. Both sides of the lens bulged outward from the center of the lens. Such a lens is called a convex lens. Unlike a flat piece of glass, a convex lens changes the direction of light rays that pass through it.

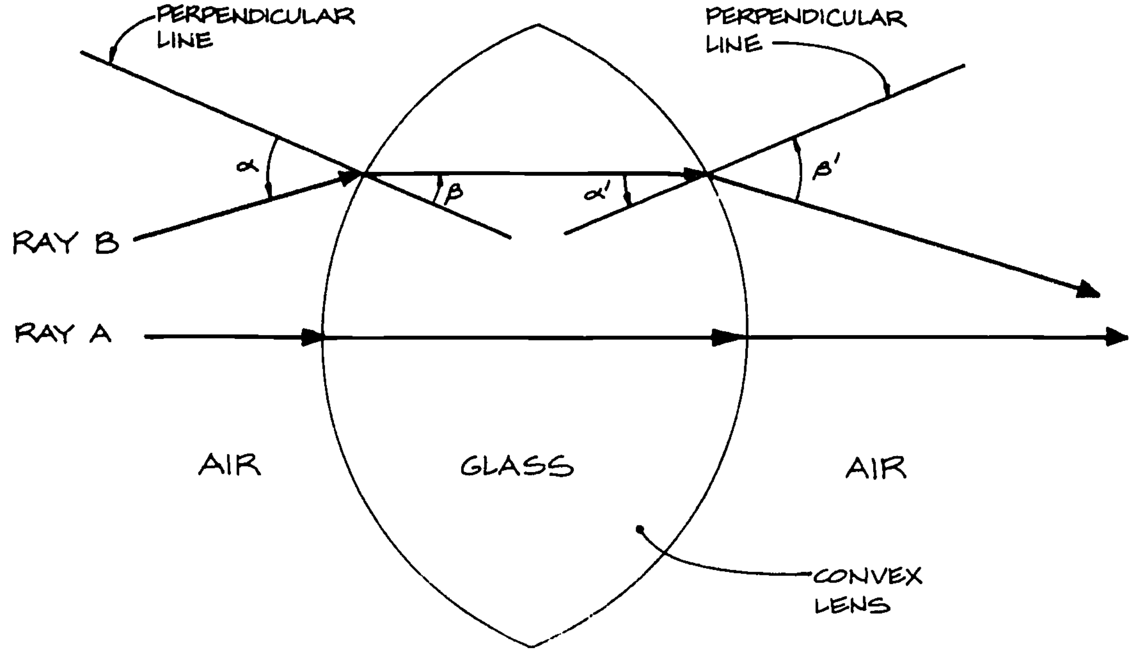


FIGURE 4: Light rays passing through a convex lens.

Light ray A in Figure 4 strikes the glass perpendicularly and exits the same way. For ray B, however, the path is more complicated. As ray B strikes the glass it is bent toward the perpendicular line, because light travels more slowly in glass. When it leaves the glass it bends away from the perpendicular line because light travels faster in air. The net result is that light ray B is bent toward light ray A.

The kind of light bending done by convex lenses may be used to focus parallel light rays (Figure 5). The distance from the center of the lens to the focal point is called the <u>focal length</u> of the lens.

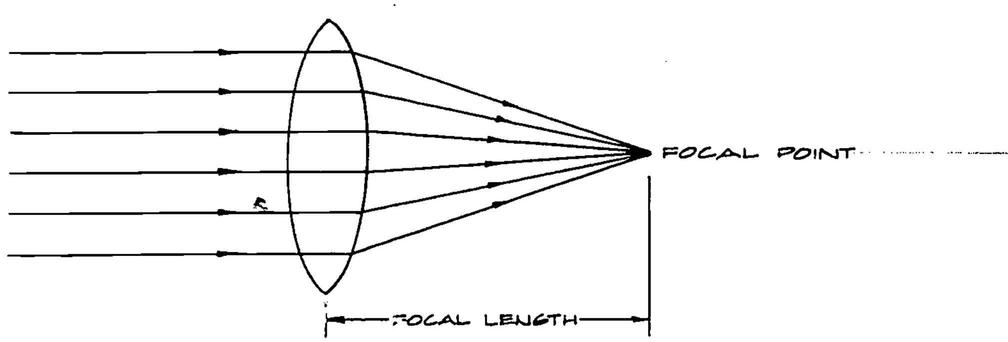


FIGURE 5: How a convex lens focuses light.

The focusing ability of convex lenses may be used to form optical images larger than the original object. Figures 6 a, b and c, on the following page, illustrate how devices like slide or movie projectors form images on a screen that are larger than the images on the film.

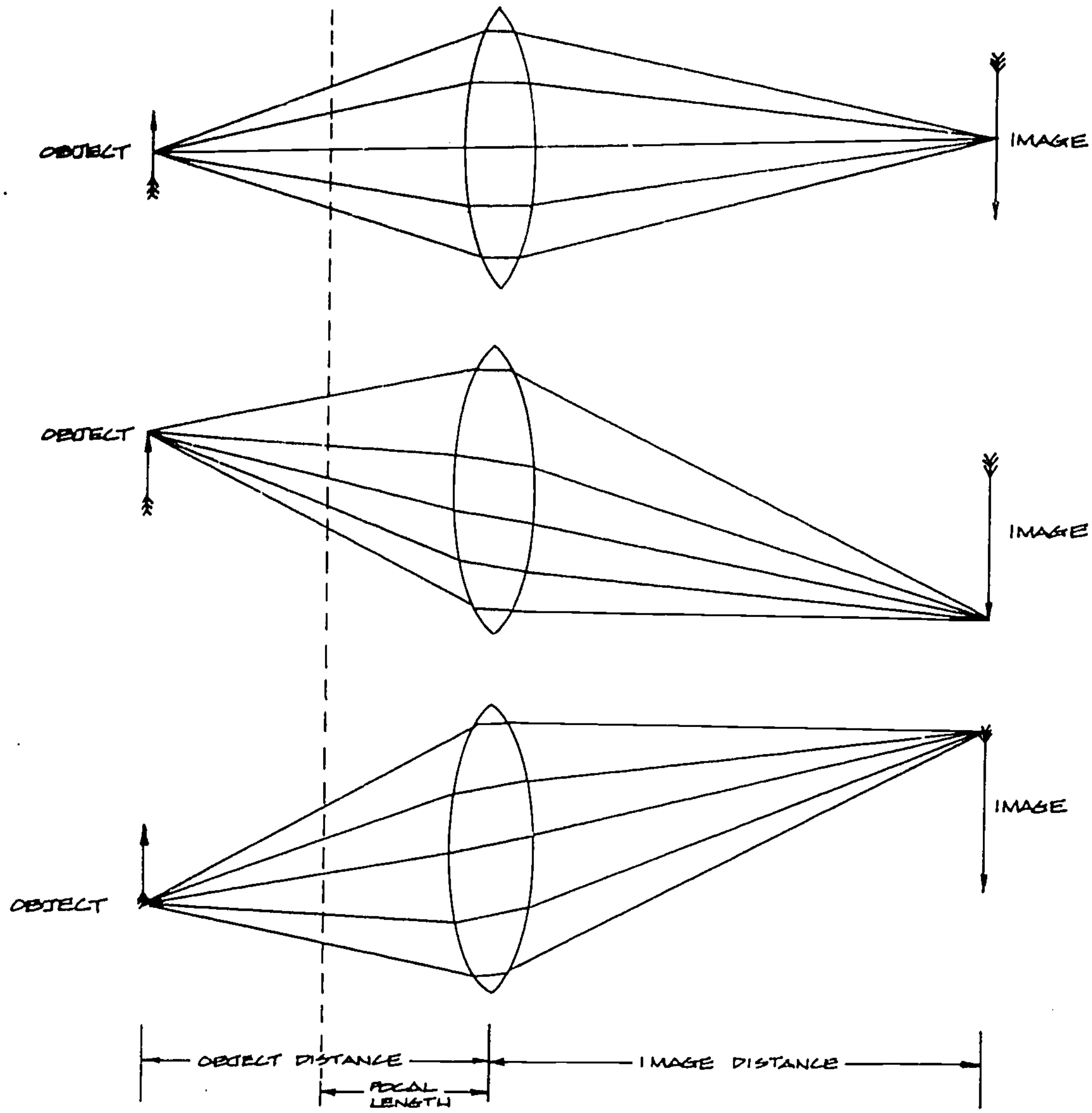


FIGURE 6: How a convex lens forms a real image.

Notice that the lens takes rays of light from a single point on the object and refocuses them at a single point on the image. In such a way a complete image is constructed at another location. Notice also that the image is upside down in comparison to the object. An inverted image is formed when the distance from the object to the lens is greater than the focal length. In such a situation the image formed is called a real image.

When you looked at the eardrum, the situation was different. The distance between the lens and the eardrum was less than the focal length of the lens. In addition, both the object and the image were on the same side of the lens instead of on opposite sides. When a lens magnifies an object under these conditions, the image is not inverted and is called a virtual image. Figure 7, on the following page, illustrates how this happens.

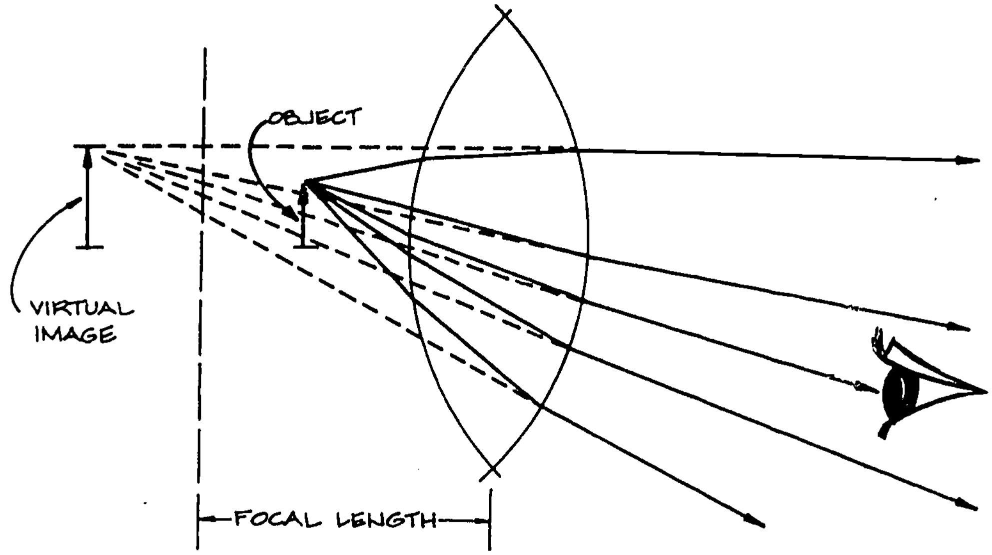


FIGURE 7: How a convex lens forms a virtual image.

When an object is located within the focal length of the lens, the lens cannot focus light coming from a point on the object to a point on the other side of the lens. Nevertheless, the lens reduces the spreading of the rays. When we look through the lens it appears as if light were coming from the larger virtual image.

29-3 Image Distance, Object Distance and Focal Length

If the object distance and focal length are known, how may the image distance be calculated?

The distance at which the rays from an object converge and the image is focused is called the image distance, d_i (Figure 6). The distance of the object from the lens is the object distance, d_o. A formula can be derived that relates the focal length of a lens (f) to the distance of an object from a lens (d_o) and the distance of its image from the lens (d_i). The formula is

$$\frac{1}{f} \approx \frac{1}{d_i} + \frac{1}{d_o}$$

The formula is more nearly exact the thinner the lens is. A lens has its own particular focal length, just as it has its own particular mass. The focal length of a lens depends on two characteristics of a lens, which you may try to guess, and which we will discuss in Section 30.

If two of the three distances are known, the third may be found by this formula. For example, if the focal length of a lens and the distance of some object from the lens are known, the image distance may be predicted. The focal length of a lens may be determined if the distances of both an object and its image are known.

(Note that if an object is very far from a lens so that d_o is very large, $\frac{1}{d_o}$ is very small. If it is so small that it may be neglected, the formula reduces to

$$\frac{1}{f} \approx \frac{1}{d_i}$$

$$f \approx d_i \quad \text{(for large object distances)}$$

This is consistent with our definition of focal length as the image distance of parallel light rays.)

Which of the following properties of light is used to focus light: reflection, refraction, diffraction, or scattering?

Describe how a convex lens changes the direction of light rays.

Describe how a convex lens forms a real image.

Describe how a virtual image is formed.

Under what conditions will a real image be formed? a virtual image?

Vocabulary:

convex lens--a lens in which both faces bulge outward from the center.

focal length--the distance from the center of a convex lens to the point at which parallel light rays are focused.

real image--an inverted image formed by a convex lens.

virtual image--an image seen from one side of a convex lens and appearing on the other, formed when the object is closer than one focal length to the lens. A virtual image is right-side up.

SECTION 30: THE LENS MAKER'S FORMULA

30-1 The Lens Maker's Formula

What determines the focal length of a lens?

The greater the refractive index of one medium with respect to another, the more light is refracted when it passes from one medium to the other. For this reason the focal length of a lens depends on the indices of refraction of the material from which it is made and the medium that surrounds it. The greater the difference between refractive indices (Δn), the more the rays will be bent and the shorter will be the focal length (Figure 1).

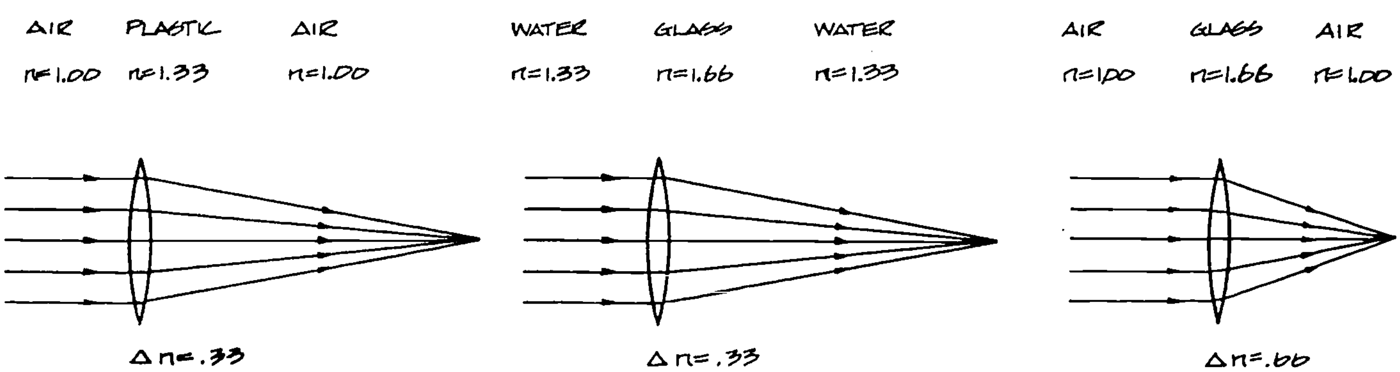


FIGURE 1: The greater the difference between the refractive indices of the lens and the surrounding medium (Δn), the shorter the focal length.

Notice that the plastic lens in air has the same focal length as the glass lens in water because Δn is the same in both cases. When the difference between refractive indices is large, the difference between the speeds of light in the two media will also be large. And it is differences in the speed of light which cause refraction. For example, most of us cannot focus our eyes under water as sharply as in air because when our eyes are surrounded by water, light is bent less at the surface of the eye and we are unable to focus normally.

A second factor is the shape of the lens, defined in terms of radius of curvature. A lens has two surfaces, and each surface of a convex lens may be viewed as part of a sphere. (And the cross section of each may be considered as part of a circle, as indicated in Figure 2 on the following page.)

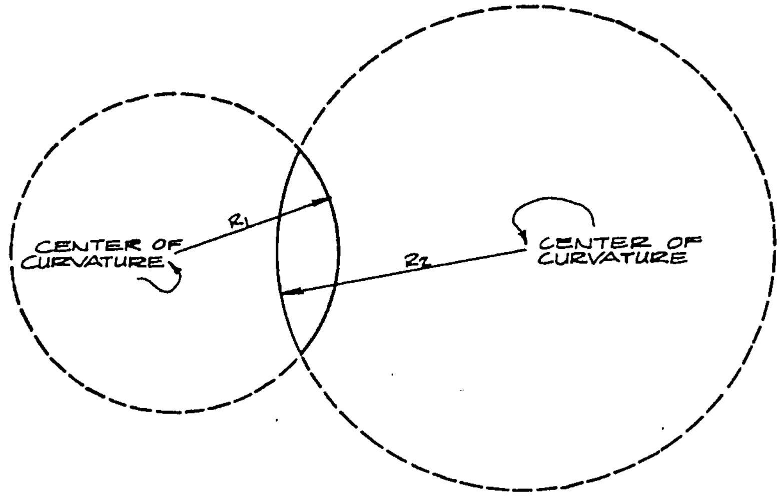


FIGURE 2: A cross-sectional view of a lens having surfaces with different radii of curvature.

The radii of these spheres or circles are the radii of curvature of the surfaces of the lens. The radii of curvature of the lens in Figure 2 are R_1 and R_2. A line from the center to a point on a circle is perpendicular to the circle at the point of intersection. So the angle of incidence of a ray striking a lens surface is the angle between the ray and a line from the center of curvature (Figure 3).

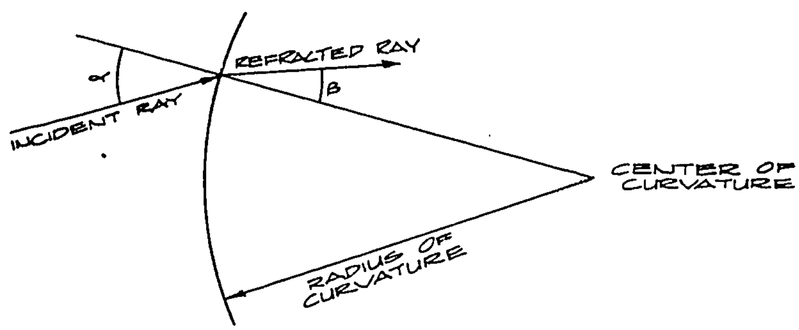


FIGURE 3: How α and β are measured on spherical surfaces.

If we compare two lenses with different radii of curvature, we see that incident parallel rays strike corresponding points on each lens at different angles (Figure 4).

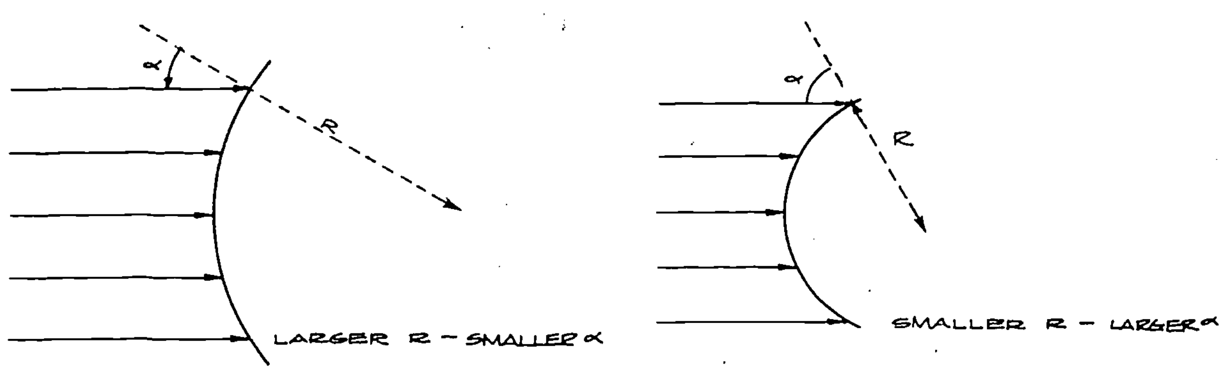


FIGURE 4: An incident ray on the lens with the larger R forms a smaller α than the corresponding ray on the other lens.

The corresponding angles of incidence are different, and so the corresponding angles of refraction are different. The angles of incidence are greater when the radius of curvature is smaller, so the angles of refraction are also greater. As a result the focal length is shorter for a lens with a smaller radius of curvature, or what you may think of as a "thick" lens. (For simplicity Figure 5 shows lenses in which both surfaces have the same radius of curvature.)

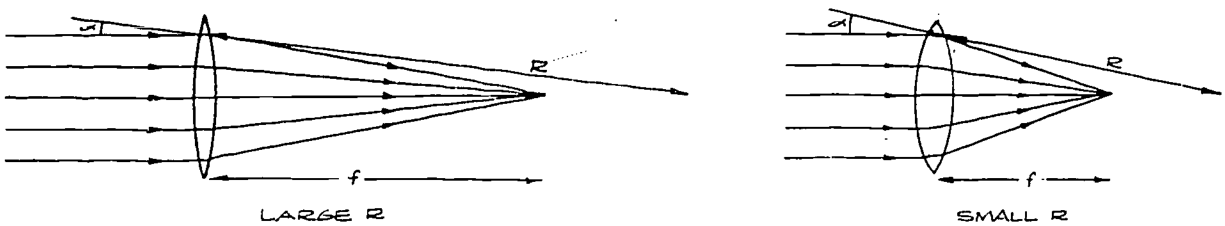


FIGURE 5: "Thicker" lenses will have shorter focal lengths.

The lens maker's formula relates focal length to the index of refraction and the two radii of curvature of a lens. The formula is

$$\frac{1}{f} = (n_2 - n_1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

The index of refraction of the lens is n_2; the index of refraction of the other medium is n_1. When this other medium is air, n_1 is approximately equal to 1. If we call the index of refraction of the lens simply n, we can rewrite the formula

$$\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

An optometrist, a person who prescribes glasses, must be very familiar with all the implications of this formula because few of the lenses that he or she prescribes will have the same value for R on both surfaces.

When $R_1 = R_2$, the above formula simplifies to

$$f = \frac{R}{2(n-1)}$$

The lens maker's formula agrees with two observations we have already made: that as the index of refraction increases the focal length decreases, and that as the radius of curvature increases the focal length increases.

The following example demonstrates the use of the lens maker's formula.

EXAMPLE:

A lens made of glass with a refractive index of 1.5 has radii of curvature of 20 cm and 30 cm.

a. Determine the focal length of this lens.

b. If an object is placed 72 cm from the lens, how far from the lens will the image be?

SOLUTION:

a. The lens maker's formula is

$$\frac{1}{f} = (n - 1)(\frac{1}{R_1} + \frac{1}{R_2}$$

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We substitute $n = 1.5$, $R_1 = 20$ cm and $R_2 = 30$ cm.

$$\frac{1}{f} = (1.5 - 1)(\frac{1}{20} + \frac{1}{30})$$
$$= .5(\frac{3}{60} + \frac{2}{60})$$

We combine the two terms on the right and simplify the expression.

$$\frac{1}{f} = .5(\frac{5}{60})$$
$$= .5(\frac{1}{12})$$
$$= \frac{1}{24}$$

We invert both sides to obtain the focal length.

$$f = 24 \text{ cm}$$

b. Object distance, image distance and focal length are related by

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Since $f = 24$ cm and $d_o = 72$ cm, we have

$$\frac{1}{24} = \frac{1}{72} + \frac{1}{d_i}$$

$$\frac{1}{d_i} = \frac{1}{24} - \frac{1}{72}$$

We find a common denominator for the terms on the right and combine the terms.

$$\frac{1}{d_i} = \frac{3}{72} - \frac{1}{72}$$
$$= \frac{2}{72}$$

We simplify and invert.

$$\frac{1}{d_i} = \frac{1}{36}$$

$$d_i = 36 \text{ cm}$$

30-2 Radius of Curvature of a Watch Glass

How may the radius of curvature of a watch glass be determined?

The radius of curvature of a lens is not easy to measure directly, but when a watch glass is used in the construction of a lens, as in Laboratory Activity 29, its radius of curvature can be measured relatively simply. All that is required is the measurement of the dimensions and the use of the Pythagorean Theorem. The two dimensions are the width of the watch glass (w) and its depth (d) (Figure 6).

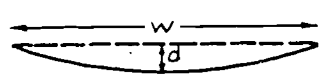


FIGURE 6: Dimensions of a watch glass.

These dimensions and the radius of curvature (R) are indicated in Figure 7.

We are dealing with a right triangle, so we may apply the Pythagorean Theorem. The hypotenuse is R; the other two sides are R-d and $\frac{w}{2}$.

$$R^2 = (\frac{w}{2})^2 + (R-d)^2$$

$$= (\frac{w}{2})^2 + R^2 - 2Rd + d^2$$

Each side contains an R^2, so we may subtract R^2 from both sides.

$$0 = (\frac{w}{2})^2 - 2Rd + d^2$$

$$2Rd = (\frac{w}{2})^2 + d^2$$

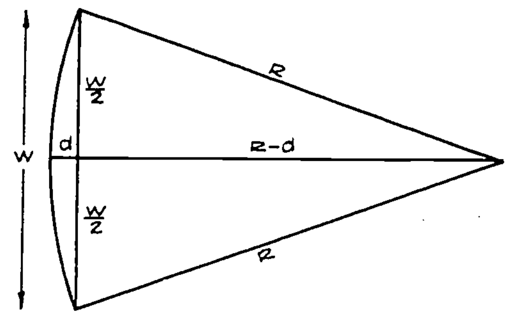


FIGURE 7: Relation of the radius of curvature, R, to the width, w, and depth, d, of a watch glass.

If we divide both sides by 2d, we are left with an expression for R in terms of d and w.

$$R = \frac{(\frac{w}{2})^2 + d^2}{2d}$$

If we measure w and d, we may calculate the radius of curvature, R, of the watch glass.

What factors influence the focal length of a lens?

What is the focal length of a lens in air for which $R_1 = R_2 = 20$ cm and $n = 1.4$?

Why can't you focus your eyes as well under water?

If a camera is focused at a given distance in air, will it still be focused at the same distance in water? To focus it at the same distance in water, should the lens be moved closer to the film or farther away?

Vocabulary:

radius of curvature--the distance from the center of curvature of a lens surface to the surface.

SECTION 31: ANATOMY AND PHYSIOLOGY OF THE EYE

31-1 The Eye

What are the main features of the eye?

Our eyes are the organs of our bodies that convert electromagnetic radiation with wavelengths between about 4×10^{-7} m and 7×10^{-7} m into impulses that are transmitted to our brains. Understanding this process requires knowledge of the laws of refraction and lenses, and also of the anatomy of the eye (Figure 1 on the following page).

The eye is surrounded by a protective layer, called the sclera. The part of the sclera in the front of the eye is transparent and is called the cornea.

Underneath the sclera lies a layer of tissue called the choroid. The choroid contains blood vessels that bring nourishment to the eye. Toward the front of the

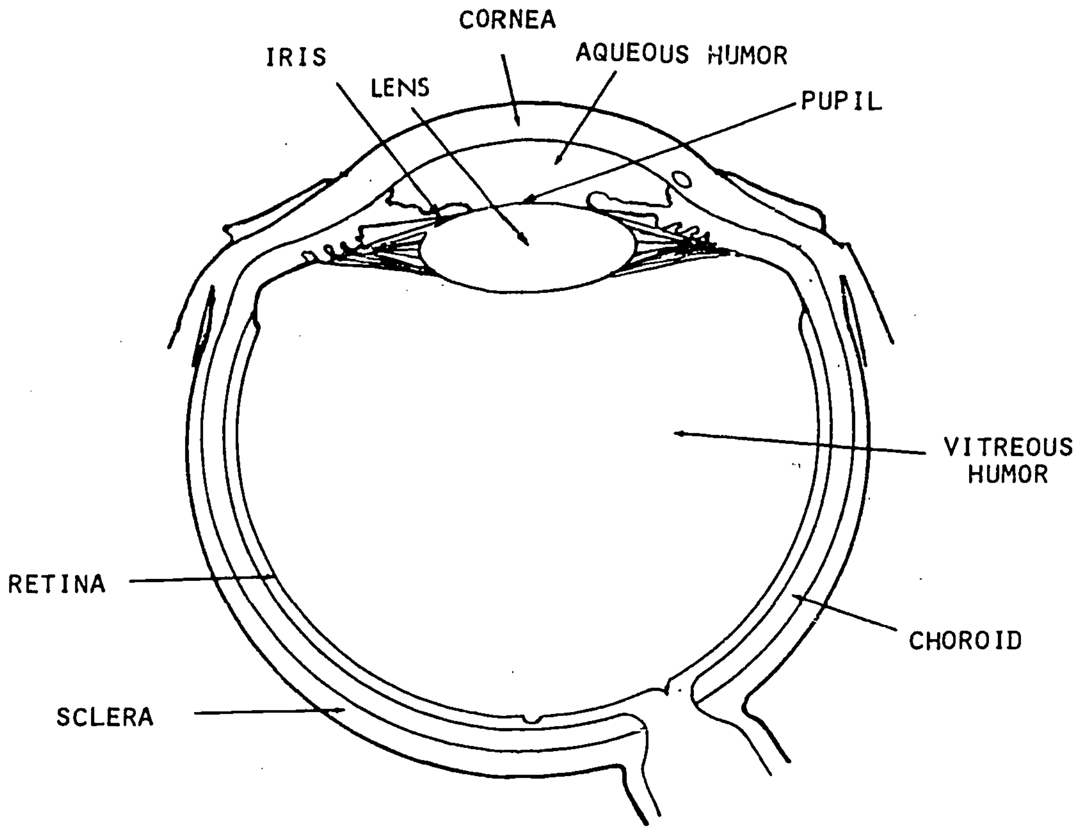


FIGURE 1: The anatomy of the eye.

eye the choroid gives rise to the iris. The iris is the pigmented or colored part of your eye that is visible from outside. It is not transparent, but there is a hole in its center called the pupil, through which light can pass. (The pupil is the small, black circle in the center of the iris.) The iris contains muscles that regulate the size of the pupil, and thus the amount of light entering the eye.

Between the iris and the cornea is clear, watery fluid called the aqueous humor. The function of the aqueous humor is to give the proper curvature to the the cornea.

Behind the iris is the lens, the function of which is to help focus the light that enters the eye. The light is focused on nerve tissue containing receptor cells, called the retina.

Between the lens and the retina, filling the middle of the eye, is the vitreous humor. The vitreous humor is soft and gelatinous; it maintains the spherical shape of the eye.

31-2 The Formation of an Image on the Retina

How is an image formed on the retina?

Light is bent, or refracted, when it crosses the boundary between two media with different refractive indices. The degree of refraction depends upon the degree of difference between the refractive indices of the two media; the greater the difference, the greater the bending of light.

The indices of refraction of the parts of the eye through which light passes are indicated in Figure 2 on the following page.

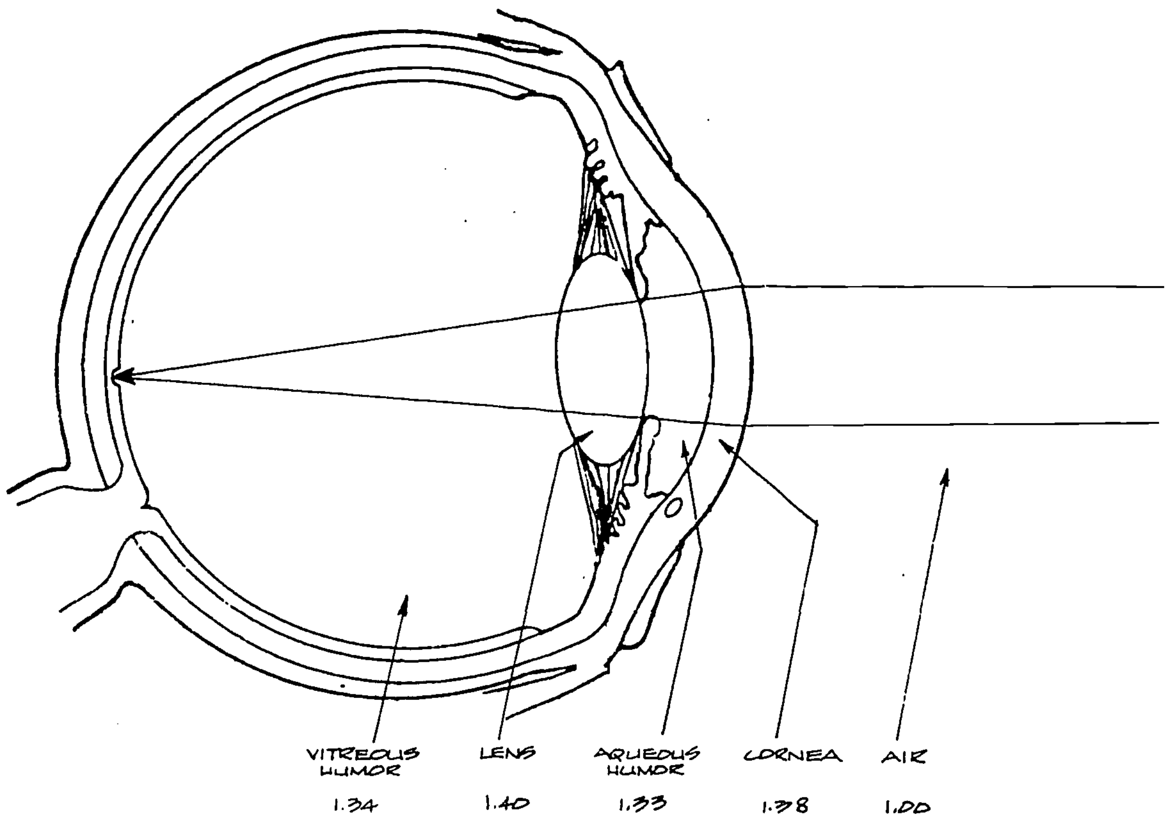


FIGURE 2: The refractive indices of different parts of the eye.

The indices of refraction of the cornea, aqueous humor, lens and vitreous humor are nearly equal, so little refraction occurs as light passes from one to the other. But the difference between the index of refraction of the cornea and that of air is large (1.38 - 1.00 = .38). Most of the bending of light entering the eye occurs between air and the cornea. For the moment, let us assume that all bending of light takes place at this surface. This will allow us to understand how an image is formed on the retina. After we have done this, we will discuss refraction at the surfaces of the lens and the important function of the lens in focusing the images of nearby objects.

Figure 3 is a simplified outline of light rays entering the eye.

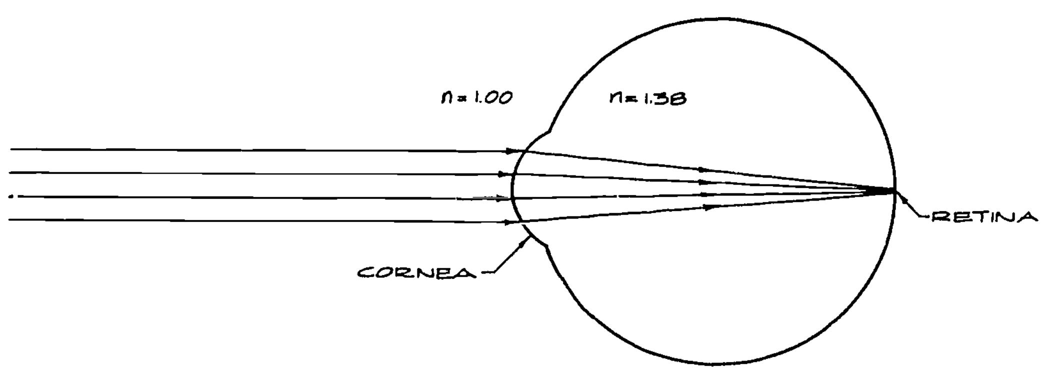


FIGURE 3: Refraction of light waves entering the eye.

Light entering the eye from a distant point is refracted at the surface of the cornea and converges (ideally) at a single point on the retina. In this manner an image of an object is formed on the retina (Figure 4). Note that the image appears upside down.

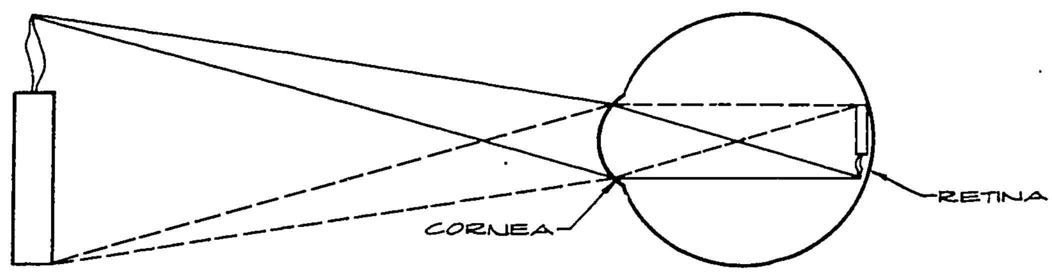


FIGURE 4: The formation of an inverted image on the retina.

31-3 Accommodation

How does the eye focus images of objects at different distances?

The refraction that occurs at the outer surface of the cornea, plus the small amount that takes place at other surfaces in the eye, is sufficient to focus the images of distant objects on the retina. But light rays from nearer objects must be bent to a greater degree to focus on the retina.

Recall the formula

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

where f is the focal length of the lens, d_i the distance of the image from the lens and d_o the distance of the object from the lens. As an object comes closer to a lens, its image is farther from the lens (Figure 5).

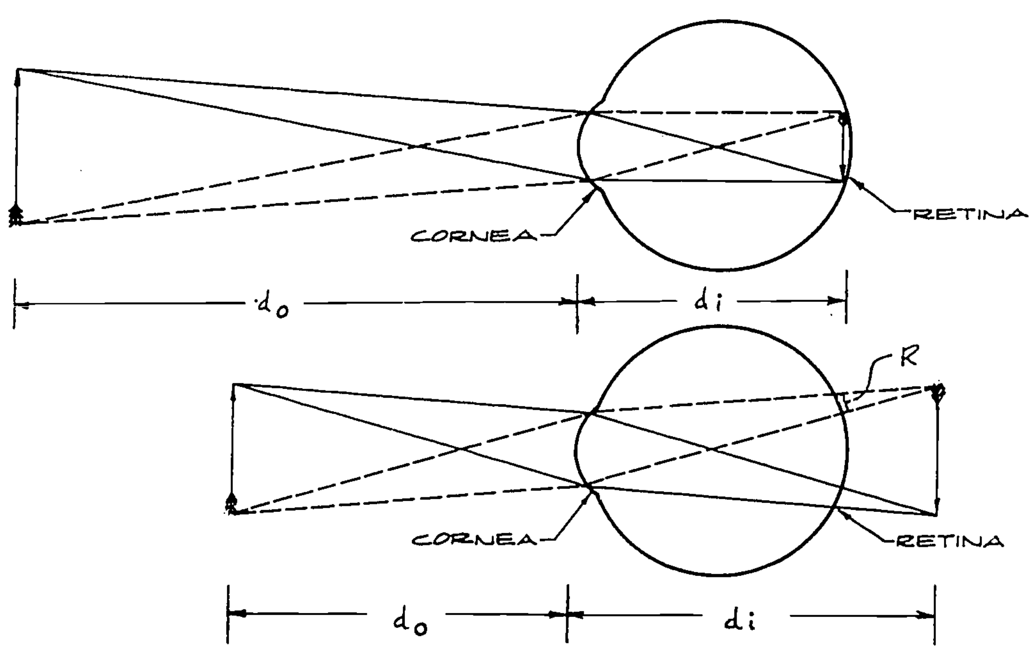


FIGURE 5: Without accommodation closer objects are out of focus at the retina.

In Figure 5B the rays from one point--for example, the tail of the arrow--do not converge at a single point on the retina. They are spread out along the region labeled "R." The image of the tail at R will be out of focus. If the light rays could pass through the retina they would converge at a point behind it. In this case, the image distance is longer than the distance from the cornea to the retina, resulting in an out-of-focus image on the retina.

As an object moves nearer, the eye cannot change the required image distance, the distance from the cornea to the retina. But it can change the focal length, f. Recall the lens maker's formula,

$$\frac{1}{f} = (n_2 - n_1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

This formula applies to a lens that is spherical on both sides, which is not quite the situation with the eye, but it can help us to understand the problem.

The eye cannot change the required image distance, nor can the indices of refraction (n_2 and n_1) of the various parts be changed, but radii of curvature (R_1 and R_2) can vary. The radius of curvature of the cornea is fixed, but the radii of curvature of the lens can change (Figure 6). The process by which the lens of the eye helps focus images on the retina is called <u>accommodation</u>.

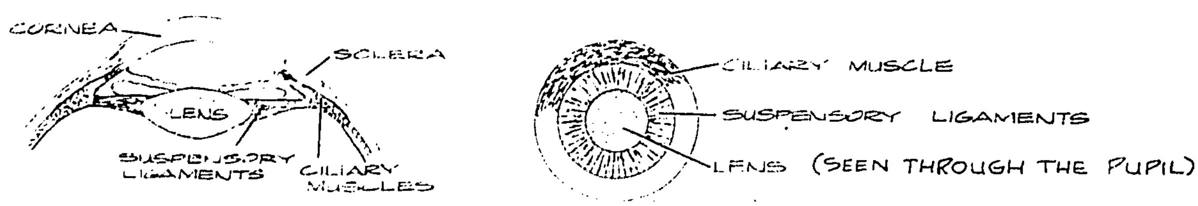


FIGURE 6: The accommodating mechanism of the eye.

The lens is suspended by ligaments, and these ligaments are attached to <u>ciliary muscles</u>. When the ciliary muscles are relaxed, the ligaments connecting these muscles to the lens are stretched and the lens is comparatively flat (Figure 7A). When the ciliary muscles contract, however, they contract toward the lens (Figure 7B). The ligaments are not stretched; the pull on the lens is relaxed and the lens becomes rounder. When the lens is rounder, its radii of curvature are less. The degree of refraction as light passes through the lens is greater; the focal length is less and the image of a near object is focused on the retina.

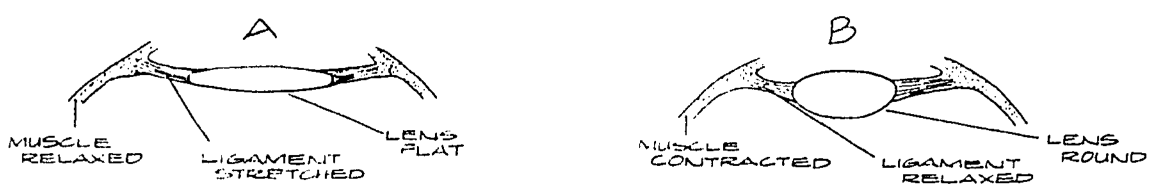


FIGURE 7: How the lens changes its radii of curvature.

Thus when you are looking at a near object, the ciliary muscles are tenser in order to decrease the focal length of the lens and bring the image of the near object into focus on the retina. It is often recommended, when reading for a long period of time, that one occasionally look at a distant object. This relaxes the ciliary muscles and avoids eyestrain, just as putting down a heavy load that one is carrying relaxes the arm muscles and also prevents strain.

31-4 Pupil Size

What effects does pupil size have?

The pupil is the opening in the iris through which light passes. You have probably observed that the size of the pupil varies with light conditions. In sunlight, when it is bright, constriction of the iris makes the pupil small and limits the amount of light that reaches the retina. In darker conditions the iris relaxes, the pupil enlarges and more light passes through. Were it not for the ability of the iris to change the diameter of the pupil, the retina would not be able to function over such a wide range of brightness.

The size of the pupil has another effect in addition to its primary function of controlling the amount of light reaching the retina. If the pupil size is small enough, visual acuity may be increased somewhat. In some cases, this increase is enough to allow a person with a vision problem to pass a visual acuity test. For this reason it is important to consider the brightness of the environment in which a visual acuity test is given: the brighter it is, the smaller the pupil becomes. You have probably noticed that increasing the light on fine print or a map makes it easier to read. This too is explained by the fact that increased light makes the pupil smaller and increases your visual acuity somewhat.

How exactly does pupil size affect visual acuity? To answer this question we first consider an extreme situation, the pinhole camera (Figure 8). Since only one ray of light may pass through the pinhole from a point, no gathering or focusing is required. In a sense, images are in focus at any distance from the pinhole.

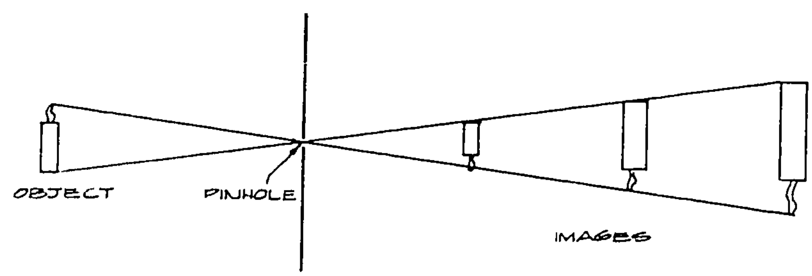


FIGURE 8: A pinhole camera.

As pupil size decreases, the entire visual system of the eye behaves more and more like a pinhole camera. For a pinhole-sized pupil, focused images would occur at any distance from the iris (Figure 9). Therefore a person who could not focus an image on the retina under normal lighting conditions may have more success when it is very bright and the pupil is small.

Pinholes would have important implications for photography and vision, were it not for two difficulties. One is that the smaller a lens opening or pupil size, the less the amount of light that passes through. As a pinhole becomes smaller, the amount of light passing through approaches zero.

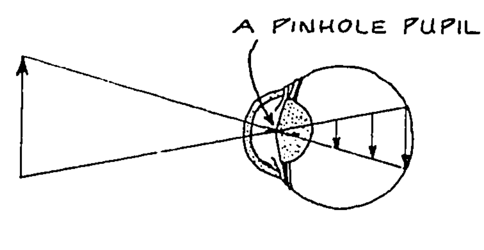


FIGURE 9: The eye as a pinhole camera.

The second difficulty is one of the other ways in which light may be bent, diffraction. Recall that when an opening has a width about the same as the wavelength, the waves passing through the opening are diffracted, or bent in many directions. We considered diffraction through two or more slits and the resulting interference, but the same phenomenon occurs with a simple pinhole.

In Figure 10 the ray passing through the bottom of the pinhole travels a slightly greater distance to reach point P than the ray passing through the top of the pinhole does. If this difference is half a wavelength, or $1\frac{1}{2}$ wavelengths, the waves arrive at P out of phase and P appears dark. If the difference is a whole number of wavelengths, the waves arrive at P in phase and P appears bright. A photograph of a circular object taken with a very small lens opening looks much like Figure 11.

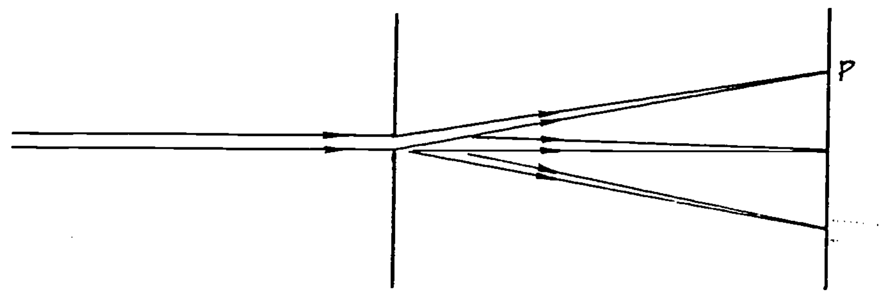


FIGURE 10: Diffraction through a pinhole.

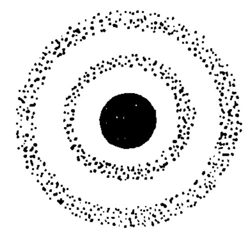


FIGURE 11: A point source as seen through a very small lens opening.

Consequently, the focusing ability of the eye cannot be improved indefinitely by decreasing the size of the pupil, because of diffraction and because the amount of light passing through diminishes.

Where does the greatest amount of refraction occur as light passes through the eye?

At what part of the eye should the image be in focus?

What part of the eye makes it possible to focus the images of objects at different distances? How is this done?

What part of the eye controls the amount of light that enters?

Vocabulary:

accommodation (uh-KOM-uh-DAY-shun)--the process by which the lens of the eye helps focus images on the retina.

aqueous humor (A-kwee-us)--the fluid that separates the lens and the cornea.

choroid (KOR-oyd)--the layer surrounding the eyeball just beneath the sclera.

ciliary muscles (SIL-ee-air-ee)--the muscles that control the shape of the lens.

cornea (KOR-nee-uh)--the transparent portion of the outer coat of the eye through which light rays first pass.

iris--the round, colored ring of tissue surrounding the pupil.

sclera (SKLAIR-uh)--the protective outer layer of the eye.

vitreous humor (VIH-tree-us)--the fluid in the main body of the eye.

SECTION 32: THE RETINA IN VISION AND DIAGNOSIS OF DISEASE

32-1 The Retina

What structures in the retina permit us to see in black and white and in color?

Light enters the eye through the cornea and passes through the aqueous humor, the lens and the vitreous humor. The light rays are mainly refracted at the corneal surface. This refraction causes light to be focused on the retina.

The retina is a multilayered structure containing special receptor cells. When light strikes these cells they respond by triggering nerve impulses. The nerve impulses then travel to the brain, where they are somehow translated into a visual image.

One of the amazing things about light receptors of the eye is that they not only respond to light, but they respond differently to different wavelengths of light. This phenomenon accounts for our ability to see things in color as well as in black and white.

One type of receptor found in the retina is the rod. The name is derived from the receptor's appearance--it looks like a long, thin rod. Rods are not able to distinguish colors, but they can sense dimmer, less intense light than the cones can. Therefore, rods are important for vision at night.

You may recall from the Nutrition Unit that Vitamin A is important for night vision. This is due to the fact that Vitamin A is required to synthesize the protein <u>rhodopsin</u>, a light-sensitive pigment contained in the rods. This pigmented protein is required for us to see objects. But rhodopsin is constantly being broken down by exposure to the light entering the eye. Therefore, there is a continuous demand for Vitamin A to resynthesize it.

The fact that light causes the breakdown of rhodopsin is also responsible for a phenomenon known as <u>dark adaptation</u>. You have certainly noticed that when you pass from a brightly lit room to a dimly lit one, it takes a certain amount of time for your eyes to adapt to the dimmer environment. This period of adaptation is proportional to the time it takes to replace the rhodopsin that has been broken down by exposure to the bright light.

The receptors in the retina that come into play when you see color have a conical appearance, hence their name, <u>cones</u>. You learned earlier (Laboratory Activity 27) that there are three different types of cones (B, G and R) each containing a different type of pigment. The degree to which each of these pigments responds to light striking it depends on the wavelengths present in the light.

Experiments have shown that the maximum response of one of the pigments contained in the cones occurs at approximately 450 nm (B receptor), while the other two pigments respond maximally at about 550 nm (G receptor) and 590 nm (R receptor). The colors that we actually see are the product of the combined responses of the B, G and R receptors in the retina. For example, suppose that the light being reflected from an object has a wavelength of 450 nm. This wavelength of light will stimulate the B receptor the most, the R receptor to some degree and the G receptor the least. This combination of responses results in our seeing an object of blue-violet color.

When one or more of the color receptors of the retina is missing or nonfunctional, the result is a disorder called <u>color blindness</u>. People who are color blind are not able to distinguish between different colors in the visible-light spectrum. Exactly which colors they do see will depend upon which color receptors are still functioning.

The distribution of rods and cones on the retina is not uniform. It varies with location. The number of rods is highest around the edge of the retina and decreases toward the center. Cones, on the other hand, are rare on the extreme edge of the retina and increase in number near the center. In fact, there is one central area of the eye where there are no rods at all, only cones. This section of the retina is called the <u>fovea centralis</u>. Visual acuity is greatest at this point.

There is also one area of the retina where there are no receptors for light at all: no cones and no rods. This area is termed the "blind spot" and corresponds to the place where the optic nerve connects to the retina. In Laboratory Activity 8 you mapped the location of your blind spot using the "tangent-screen" technique.

32-2 Transmission of the Visual Image from the Retina to the Brain

How can a knowledge of the pathways followed by the optic nerves be helpful in diagnosing a brain tumor?

We mentioned earlier that rods and cones respond to light and cause neural impulses to be transmitted to the visual center of the brain. There are four groups of nerve fibers for each eye, which are responsible for transmitting these impulses to the visual center. Each set of fibers carries information from one quadrant of the retina.

The four groups of nerve fibers form the optic nerve for each eye. This nerve carries impulses from the eye to the brain. The two optic nerves converge at a location in the brain called the optic chiasma. From the optic chiasma the nerve fibers from the right quadrants of both eyes connect to one part of the brain, while the nerve fibers from the left quadrants join to another part of the brain. The arrangement is shown in Figure 1. Note that the nerve fibers from the left halves of both retinas go to the left side of the brain, and the nerve fibers from the right halves of both retinas go to the right side of the brain.

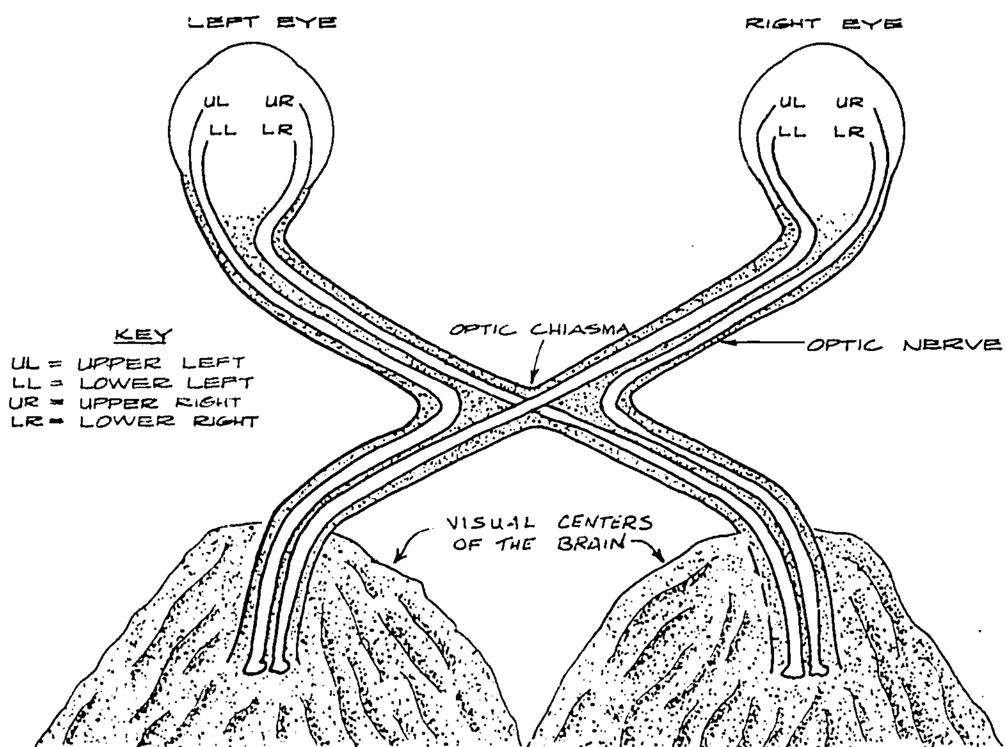


FIGURE 1: Neural pathways of the optic nerves.

The brain assimilates the information brought by all these nerve fibers and somehow translates it into a single image of the visual fields of both eyes. (The visual field is that area that can be seen with one eye when it is focused on a particular point.)

The usefulness of mapping a person's visual fields in diagnosing brain tumors was discussed earlier in relation to pituitary tumor (Section 8). The case history in Section 8 stated that the patient lost his vision in the outer portion of the field of vision of each eye. The cause of this particular defect can be understood by looking at two things: (1) what happens to light as it passes through the eye and (2) the pathways that the nerve fibers follow from the retina to the brain.

Recall that a convex lens inverts an image (i.e., turns it upside down and reverses left and right). So when light passes through the eye to the retina, the left quadrants detect the right side of the visual field, while the right quadrants sense the left side (see Figure 2). Since the images on the retinas are reversed as shown in Figure 2, the right half of the visual field of both eyes goes to the left side of the brain, and the left half of the visual field of both eyes goes to the right side of the brain.

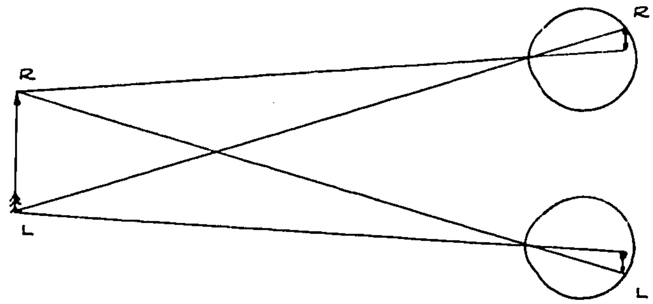


FIGURE 2: Inversion of the visual image on the retina.

A tumor of the pituitary gland may compress the optic nerves in the region of the optic chiasma and obstruct the passage of nerve impulses in this region. When this happens the result is a decrease in the right side of the visual field of the right eye and the left side of the visual field of the left eye (Figure 3).

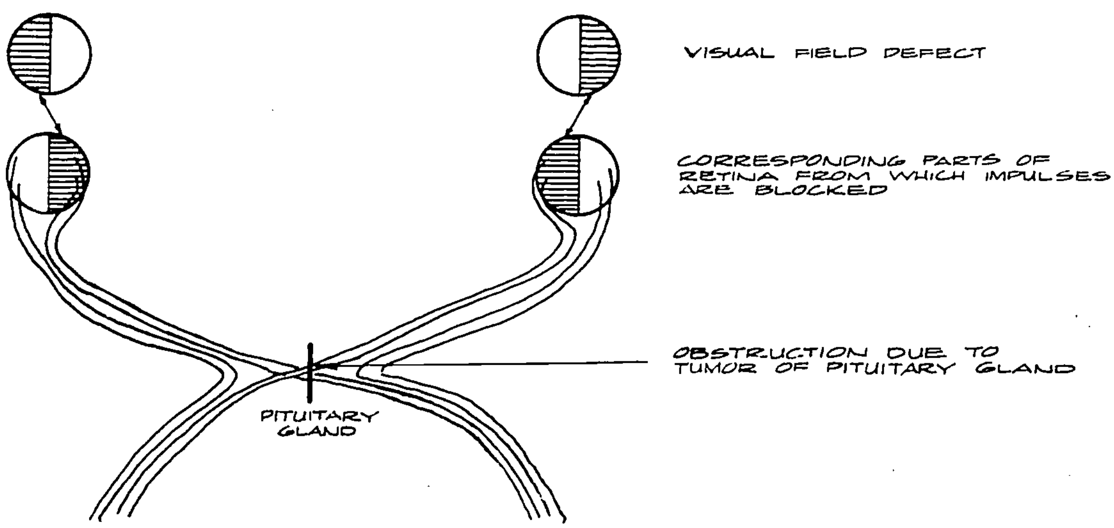


FIGURE 3: Visual field defects caused by obstruction of optic nerves by a pituitary tumor.

Visual field testing may also be helpful in locating other types of brain tumors and in diagnosing diseases that cause destruction of parts of the retina, thus impairing one or both visual fields.

32-3 The Retina and Diagnosis of Systemic Disease

What information can the retina give us about diseases such as diabetes and hypertension?

As stated earlier, the retina contains visual receptors (rods and cones). It also has another unique characteristic. The eye is the only part of our bodies where blood vessels and nerve fibers can be seen directly, without surgery. These blood vessels can be seen through the pupil by means of an ophthalmoscope. There is also a way to observe blood <u>flow</u> in the retina, using a special filter. At some time during the class period you will be given the opportunity to use this filter to observe the flow of red blood cells through your own retina.

Many diseases involve changes in the blood vessels. Since these changes can be seen with an ophthalmoscope, examination of the retina is often useful not only in diagnosing a disease, but also in determining the progress and extent of the disease. Two diseases where such an examination may be very useful have already been discussed in the Nutrition Unit. They are diabetes and hypertension.

Diabetes, a very common cause of severe vision problems, affects the capillaries of the retina. The result is often tiny hemorrhages (Figure 4) or other changes that may impair vision and ultimately lead to blindness. There are new treatments, one of which uses laser rays, that can slow down the rate of retinal damage.

In hypertension, the arterioles become narrower but the venules don't change. When viewing the retina, the health professional estimates the diameter of the arterioles as compared with that of the venules. The ratio is usually about 0.7 or more. With hypertension the ratio is 0.5 to 0.6 and in severe cases may actually be as low as 0.3 (see Figure 4). Hemorrhages (similar to those seen in Figure 4) also occur with resulting vision impairment. Fortunately, hypertension can be treated and eye complications can usually be prevented.

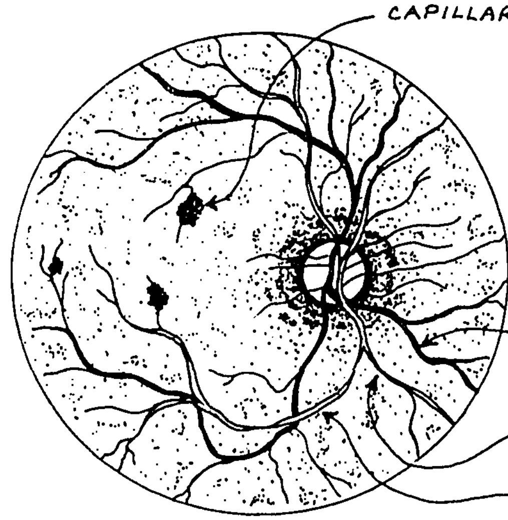


FIGURE 4: Capillary hemorrhages and compression of arterioles in the retina.

What kind of receptor in the retina is responsible for vision in dim light?

Why is Vitamin A important to the proper functioning of the rods?

What is dark adaptation and why does it occur?

What kind of receptor in the retina is responsible for color perception?

What is color blindness?

How are the rods and cones distributed on the retina?

Where on the retina is visual acuity the greatest?

How can mapping of a person's visual fields be used in determining the location of a brain tumor?

What characteristic does the retina possess that is of diagnostic use in certain diseases?

Vocabulary:

color blindness--a disorder characterized by partial or total inability to distinguish one or more colors.

cones--visual receptors responsible for color vision.

dark adaptation--the replacement of rhodopsin and other changes in the eyes, which enable us to adjust to conditions of reduced illumination.

fovea centralis (FO-vee-uh sen-TRAL-us)--an area of the retina containing densely packed cones but no rods, where visual acuity is greatest in bright light.

optic chiasma--that location in the brain where the two optic nerves converge and parts of them cross over each other.

rhodopsin (ro-DOP-sun) a light-sensitive protein found in the rods.

rods--visual receptors responsible for vision in dim light.

SECTION 33: THE SNELLEN VISION SCREENING TEST

33-1 Vision Screening

What does 20/20 vision mean?

The optics of the eye--the mechanisms by which the images of objects are focused on the retina and converted to nerve impulses--are extremely complex. The diagnosis of dysfunctions of the eye and their correction are correspondingly complex. It is not practical to test the entire population for all the various dysfunctions.

However, it is possible to screen every person for visual dysfunctions. Screening does not allow diagnosis of specific disorders, but it does suggest who should be referred for professional diagnosis. The reliability of vision screening is a matter of interest and will be introduced in Mathematics Section Z.

Vision screening is commonly carried out using the Snellen test. You will give this test to children in an elementary school. There are two common types of Snellen charts shown in Figure 1.

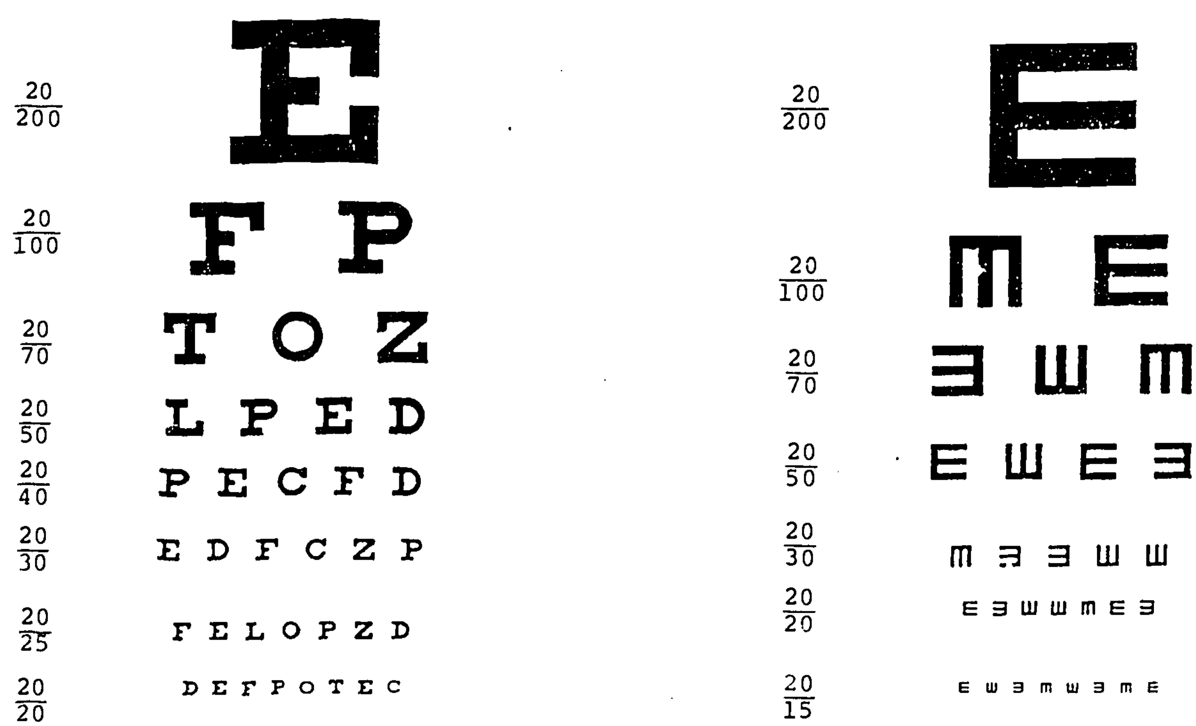


FIGURE 1: Two Snellen-type charts.

When the card shown on the left is used, the person being tested identifies the letters, beginning with the large ones at the top. When the right-hand card is used, the viewer indicates the direction in which the "legs" of the E point. The Snellen test measures visual acuity, the ability to distinguish small detail.

Observe that to the left of each line is a notation, such as $\frac{20}{200}$. This notation indicates the size of the letters on that line. The upper number indicates the distance in feet at which the test is made. This distance is usually 20 feet, as it is on the cards shown. The lower number indicates the distance in feet at which a letter on that line subtends an angle of $\frac{1}{12}$ degree (Figure 2). That is, if lines were drawn from the eyeball of the person being tested to the top and bottom of the letter, the angle between the two lines would be $\frac{1}{12}$ degree.

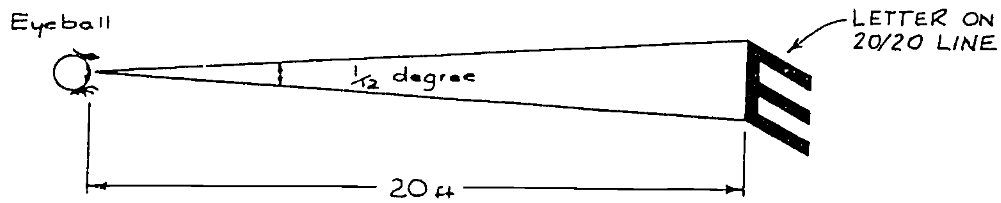


FIGURE 2: An E on the 20/20 line subtends a $\frac{1}{12}°$ angle at a distance of 20 ft.

Similarly, a letter on the $\frac{20}{15}$ line subtends an angle of $\frac{1}{12}$ degree when it is 15 feet from the viewer (Figure 3).

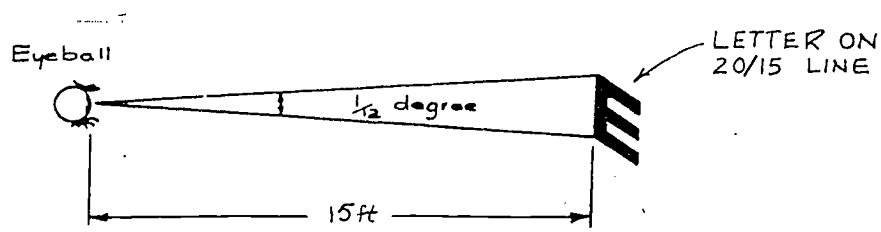


FIGURE 3: An E on the 20/15 line is smaller and subtends a $\frac{1}{12}°$ angle at 15 ft.

Incidentally, you have probably heard that $\frac{20}{20}$ visual acuity is "normal." What is meant by "normal"? It does not mean perfect vision, or even ideal, because many individuals have better visual acuity--for example, being able to read letters on the $\frac{20}{15}$ line. Nor does "normal" mean "average"; $\frac{20}{20}$ vision is better than average. Perhaps "normal" is best defined as simply meeting some standard for acceptable vision, in this case the standard of being able to read the $\frac{20}{20}$ line at a distance of 20 feet.

What information does the Snellen test give? It measures visual acuity, but what does visual acuity indicate? You have done research on, or heard from classmates about, several dysfunctions of the eye. Some of these dysfunctions can cause poor performance on the Snellen test.

One of these is myopia, commonly known as nearsightedness, which results in poor distance vision. Myopia is present when distant objects are not brought into proper focus on the retina. If an image is not in proper focus, it is not sharp, but rather is diffuse or "fuzzy." If the image of the legs of the letter E are sufficiently diffuse, they overlap; the letter appears as a square, and the viewer cannot tell in what direction the legs point.

Hyperopia, commonly known as farsightedness, results in poor vision in regard to near objects. Twenty feet is a relatively large distance, and hyperopia is usually detected by the Snellen test only if it is extreme--for instance, so extreme that objects at all distances are out of focus.

Astigmatism limits a person's ability to focus exactly at any distance. Therefore, the Snellen test detects some individuals who have reduced visual acuity because of astigmatism.

Dysfunctions that affect only one eye may sometimes be detected by the Snellen test as a difference in visual acuity between the two eyes.

Glaucoma and other organic dysfunctions are not detected by a test of visual acuity.

You should be aware of the limitations of the Snellen test. Its purpose is to screen large numbers of people for referral, not to diagnose specific dysfunctions. Diagnosis is a job for professionals; we will discuss the various eye-related professions shortly.

Many other tests are also used for vision screening. For example, if a child's reading ability is not as good as other factors indicate it should be, this may be taken as a suggestion of visual dysfunction and the child may be referred for professional diganosis.

Various factors can influence a subject's performance on a Snellen test. One such factor is the intensity of the light illuminating the chart. Recall that the size of the pupil is related to the intensity of light; as intensity increases, pupil size decreases. Recall also that decreased pupil size (or lens opening in a camera) increases the sharpness of focus of an image. Reduction in pupil size increases visual acuity; therefore, visual acuity improves as light intensity increases.

Squinting also can improve visual acuity by partially blocking the opening, which has the same effect as reducing pupil size. For this reason, individuals being given the Snellen test should not be permitted to squint.

33-2 Eye Practitioners

What are the differences between an ophthalmologist, an optometrist and an optician?

The purpose of the Snellen test is to screen individuals; those who have poor visual acuity may be referred to a professional. Several professions are involved in diagnosing, treating and correcting dysfunctions of the eye; confusion often occurs because of the similarities among their names.

An ophthalmologist (or oculist) is an M.D. who specializes in eyes. He or she performs diagnosis, surgery and other treatment, as well as prescribing glasses.

An optometrist does not diagnose or treat organic eye diseases (such as glaucoma), but may prescribe glasses and prescribe physical therapy (such as eye exercises). Optometrists take at least 3 years of college education plus four more years of specialized training from which they graduate with the degree of Doctor of Optometry. To practice optometry in a particular state the optometrist must also pass the State Board Examination of Optometry for that state.

An optician specializes in making glasses according to prescription, just as a pharmacist provides medication according to prescription. An optician does not diagnose dysfunction nor prescribe correction. The training required to become an optician varies from state to state. Usually no formal education past high school is necessary, but an apprenticeship with a registered optician is required. In California this apprenticeship is for 5 years.

What does the Snellen test measure?

What is the function of the Snellen test?

What dysfunction of the eye may be detected by the Snellen test?

What may an ophthalmologist do that an optometrist may not do? What may they both do?

Vocabulary:

astigmatism (uh-STIG-muh-TIZM)--a refractive error, due to a non-spherical cornea, that affects visual acuity at all distances.

hyperopia (HY-pur-OH-pee-uh)--commonly known as farsightedness; a condition involving inadequate visual acuity at near distances.

myopia--commonly known as near-sightedness; a condition involving inadequate visual acuity at far distances.

screening test--a test designed to be given to large numbers of people for the purpose of referral to professionals.

visual acuity--the ability to distinguish fine detail in visual images.

SECTION 34: MEAN, MEDIAN AND MODE

34-1 Introduction

The material in this section may not, at first glance, seem related to the eye. However, you will be using the methods presented here to determine the mean, median and mode of the data you obtain by administering the Snellen test to a class of elementary-school students. It is also probable that you will see these three terms many times in the future. The mean, median and mode are often used to evaluate the results of scientific investigations, such as surveys of per-capita income and research on the effects of drugs. Therefore, it will be helpful to you to have an understanding of these statistical tools and the kinds of information they provide.

34-2 Mean, Median and Mode

What do the mean, median and mode tell you about a set of data?

When a series of measurements is made, or a set of data is gathered, a collection of numbers is obtained. Often it is desired to state not the entire collection of numbers, but one value that best represents the whole set. We will discuss three such values, the mean, the median and the mode.

The mean of a set of values is the sum of the values divided by the number of values in the series. The mean is what we commonly refer to as the "average." The mean of the series of numbers $x_1, x_2, x_3, \ldots, x_n$ is

$$\frac{x_1 + x_2 + x_3 + \ldots + x_n}{n}$$

We have discussed a more compact form for expressing the numerator: summation notation (Mathematics Text, Unit IV, Section Xl.

$$x_1 + x_2 + x_3 + \ldots x_n = \sum_{i=1}^{n} x_i$$

Using summation notation, the mean of a series of n values $x_1, x_2, x_3, \ldots, x_n$ is

$$\frac{\sum_{i=1}^{n} x_i}{n}$$

As an example, the mean of 9, 12, 17, 18, 19 and 21 is

$$\frac{9 + 12 + 17 + 18 + 19 + 21}{6}$$

$$= \frac{96}{6}$$

$$= 16$$

The mean is the most common of the three methods used to provide a single value for a set of data or measurements. One reason the mean is more commonly used is that it tends to be a more precise predictor. For example, let us say that the mean, median and mode are determined for a sample of values taken from a large set of data. This process is then repeated for several other samples taken from the same set of data. The means of the various samples will usually be in better agreement than their medians or their modes.

Similarly, if you measure some physical quantity, such as mass or length, several times, the mean is usually a better approximation of the true value than either the median or the mode. Another reason the mean is commonly calculated is that it is used in determining other quantities, for example, the standard deviation.

The median is the middle number in an ordered series, if the series contains an odd number of values. By "ordered series" we mean a series arranged in either increasing or decreasing order. For example, 3, 4, 6, 9, 10 is an ordered series. The median of this series is the middle which is 6.

If an ordered series contains an even number of values, the median is the mean of the two middle values. The median of the ordered series 1, 2, 4, 8, 11, 13 is the number midway between 4 and 8; it is 6.

One advantage of the median is that it is easy to obtain. The numbers are simply listed in order and either the middle number is found or the middle pair is found and averaged. The median is often used by teachers who "grade on the curve." For example, if the grades on a test were 25, 39, 50, 61, 62, 65, 65, 68, 70, 75, 80, 85, 95 and 100, the median would be 66.5 (the mean of 65 and 68).

The mean, as we stated, is the most commonly used of the three measures but in some cases the median is better. Consider the following table.

PERSON	ANNUAL INCOME
Ambergrist	$ 7,400
Balthazar	7,900
Clatterfield	8,300
Dundereilli	9,400
Easelworth	650,000

The mean annual income of this group is $136,600, while the median income is $8,300. Which value best represents the group? Obviously the median does; if a person is chosen randomly from the group, his income is likely to be closer to $8,300 than to $136,600.

The median is a more representative expression when the sample is skewed greatly in one direction, that is, when the numbers are not distributed symmetrically in both directions from the center.

The mode is the number that appears most frequently in a series of numbers. For example, 4 is the mode of the series 1, 1, 2, 2, 3, 4, 4, 4, 5.

The word "mode" is often used to describe what is fashionable, for instance a style of dress. In this sense it means the clothing that is most frequently worn. Similarly, the term is used in statistics to mean the number that most frequently occurs in a set of data.

Suppose that you were making a survey of the automobiles owned by families in a particular community, and that they were manufactured in these years: 1957, 1957, 1959, 1961, 1961, 1961, 1961, 1961, 1965, 1966, 1966, 1967, 1968, 1973 and 1974. The mean year in this set is approximately 1964; the median year is 1961. Yet these numbers are perhaps not as interesting as the mode, which is 1961. The popularity of 1961 automobiles is perhaps the most interesting aspect of your survey.

It should be pointed out that some sets of data may have more than one mode. For example, the series 1, 2, 2, 3, 5, 5, 9, 14 has modes of 2 and 5. A series such as the following

1, 2, 4, 7, 11, 17, 44

in which each number appears the same number of times (once, in this case), is said to have no mode.

EXAMPLE:

The following table gives the heights of 15 adult males.

164 cm	178 cm	182 cm
168 cm	180 cm	183 cm
170 cm	180 cm	184 cm
170 cm	182 cm	187 cm
175 cm	182 cm	190 cm

Determine the mean, median and mode of this series of measurements.

SOLUTION:

The mean is the sum of the heights divided by the number of males in the sample, which is 15.

$$\frac{\sum_{i=1}^{15} x_i}{15} = \frac{164 + 168 + 170 + \ldots + 190}{15}$$

$$= \frac{2675}{15}$$

$$\approx 178.3 \text{ cm}$$

The median is the middle value, since there is an odd number of values. Therefore, the median is 180 cm.

The mode is the most frequently occurring value, which is 182 cm.

Explain how the mean, median and mode are obtained for a set of data.

How does the method for determining the median for a set of numbers vary with the total number of values in the set?

Give an example of a situation in which the median is a better measure of the central tendency of a set of data than the mean.

Vocabulary:

mean--the sum of a group of values divided by the total number of values in the group.

median--the middle value in an ordered set of values, or if the number of values is even, the mean of the two middle values.

mode--the most frequently occurring value in a set of data.

PROBLEM SET 34:

Each of the following lists represents a small sample made from a larger group. State whether the mean, median or mode is most appropriate for providing a single representative value for the data. Then determine the value of the one you have chosen.

1. Automobile color preferred by consumers

beige	maroon
beige	maroon
robin's egg blue	maroon
bilious yellow	visual purple

2. Ages of spectators at rock concert of Gene and the Mutants

13	16	17
15	16	18
15	17	18
16	17	97 (Gene's great aunt)

3. Mass in lb of offensive linemen on Denver Brochioles

TE	230	C	250
LT	270	RG	240
LG	260	RT	280

SECTION 36: SENSES OTHER THAN HEARING AND SIGHT

36-1 The Senses

How many senses do we have? How do we sense things?

In order for our brains to control our bodies, they must receive information about what is happening in our surroundings. This information is provided by our sensory organs. We have discussed two senses, sight and hearing, in some detail.

Traditionally we are considered to possess five senses: in addition to seeing and hearing, we can taste, smell and touch. The idea of only five senses, however, is not adequate; as many as twenty senses have been identified. Many of these monitor internal conditions. We encountered an example of an internal sense in the Respiration Unit: the sensing of the pH of the blood by the respiratory center of the brain.

Certain sense receptors inform the brain of the orientation of the body by detecting the positions and movements of bones and joints. Other receptors respond to the contraction of muscles and the stretching of ligaments (tissues that connect bones). The function of all sense receptors that inform the brain of the positions and movements of the body are grouped together as one sense, the <u>kinesthetic sense</u> (kine = motion, esthesia = perception).

The various sensations that we call the kinesthetic sense and the sensations produced by other conditions within the body are not included in the five traditional senses. However, all senses function in the same manner. Information is gathered by receptor cells and converted into nerve impulses. The impulses are transmitted by nerves to various centers of the brain.

Besides the twenty senses that have been identified, there may be others that we do not know about. For example, individuals who raise the temperature of their fingers during biofeedback training apparently do so by increasing the rate of blood flow in their fingers. They may do this by relaxing the arterioles in the fingers, so that these vessels widen. Such people may have a sen[illegible] how relaxed the arterioles are. Another sense may be responsible for the hor[illegible] instinct of many animals. There is evidence that pigeons and honeybees have [illegible]ay of orienting themselves according to the Earth's magnetic field.

36-2 Touch and Other Senses in the Skin

What sense receptors are found in the skin?

The five senses most often referred to are sight, hearing, taste, smell and touch. But what is commonly referred to as "touch" is actually a number of separate senses, and the skin has several different types of receptors to detect various sensations and convert them into nerve impulses. The word "cutaneous" means "pertaining to the skin," and these senses are referred to as cutaneous senses. The cutaneous senses include touch, pressure, warmth, cold and pain. Two cutaneous receptors are shown in Figure 1.

Neurophysiologists believe that each of the different kinds of receptors is generally associated with a different sensation. However, in some cases, a single kind of receptor structure is associated with more than one kind of sensation. The mechanism of skin sensation is not yet well understood.

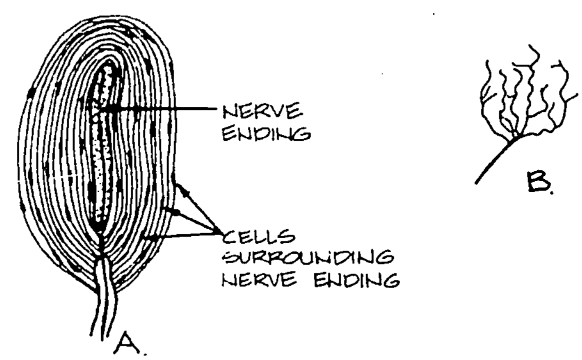


FIGURE 1: Two kinds of cutaneous receptors. A. pressure receptor. B. pain receptor.

Touch receptors are often associated with hairs on the skin, as indicated in Figure 2. When a hair is touched, it exerts pressure on receptors near its root. Thus hairs, though for the most part dead structures, are important in sensing touch. Certain animals make especially good use of hairs as sensing devices. A cat, for example, uses its whiskers to sense whether its entire body will fit through a small opening.

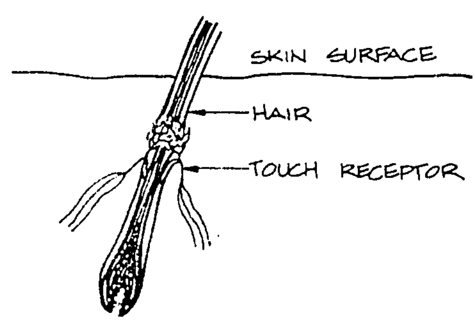


FIGURE 2: A hair and associated receptors.

The receptors for warmth and cold sense the temperatures of the receptors themselves. The cold receptors are stimulated at temperatures between about 12 °C and 35 °C, while the warmth receptors are stimulated between about 25 °C and 45 °C. Up to a temperature of about 33 °C, the cold receptors send more nerve impulses to the brain than the warmth receptors, and we tend to feel cold. Above this temperature, the opposite occurs.

Both the warmth and cold receptors are far more sensitive to abrupt changes in temperature than to a steady temperature, the cold receptors responding to a drop in temperature and the warmth receptors to a rise. Following an abrupt change in temperature a receptor is strongly stimulated at first; but it begins to adapt to the new temperature in a short time, if the temperature remains constant afterward.

For example, when you first step into a hot bath the water feels very hot. Within a half-minute or so, your warmth receptors adapt to the change in temperature and you feel pleasantly warm. Notice that the adaptation is not complete; in other words, although your warmth receptors become less sensitive and send progressively fewer nerve impulses, the impulses do not stop. The water continues to feel warm.

Most of our other senses also adapt to one extent or another to a steady, continuous stimulus. This adaptation to a sensation that does not change is of some advantage to us, because it frees us of such distractions as being continually reminded by our buttocks that we are sitting, while we are trying to concentrate on the book we are reading.

One sensation that persists is pain, as you may know from experience if you have ever had a toothache. This lack of adaptation to pain is also advantageous: it does not permit us to ignore conditions that may threaten our health.

Both pain and pressure receptors also exist within our bodies. These receptors are sensitive to the stretching of the organs they are embedded in. Migraine headaches are caused by pain receptors in arterial walls. The pain receptors are stimulated when arteries widen (dilate). We also feel pressure or pain when large amounts of gas are produced in the intestines. These sensations are produced by receptors in the intestinal walls.

Whether a particular sensation is pleasant or unpleasant is determined by our brains; it can depend upon the situation. A tickle may be either pleasant or unpleasant. The feeling of cold water can be very pleasant on a hot day, yet painful at other times. Pain itself is not a pleasant sensation but the brain may seem to reduce the feeling of pain, for instance, during a time of emotional or physical stress such as an athletic contest. Actually, the pain remains but we are responding to other stimuli.

What are the five traditional senses? What other senses do we posess?

What is the kinesthetic sense?

What are five components of the sense of touch?

Give an example of adaptation involving a sense. How is adaptation useful?

Vocabulary:

adaptation--the process by which a sense receptor reduces the number of nerve impulses it sends, after a stimulus (such as heat or touch) has been present for a time.

cutaneous (kyoo-TAY-nee-us)--pertaining to the skin.

kinesthetic sense (KIN-es-THET-ik)--the sense of orientation, position and movement of the body. It includes the functions of several kinds of receptors throughout the body.

SECTION 37: TASTE AND SMELL

37-1 The Sense of Taste

How do we detect taste?

In preceding sections we have described a variety of receptors that sense different kinds of things--light, pressure, sound, temperature, etc. Another class of receptors are known as chemoreceptors because they respond to the presence of particular chemical substances, or to changes in the concentration of particular substances. One kind of chemoreceptor was discussed in the Respiration Unit--cells in the respiratory center of the brain that monitor the H^+ concentration in the cerebrospinal fluid. When the H^+ concentration becomes too high, the chemoreceptors cause the respiratory center of the brain to send signals to the muscles used in breathing which, in turn, increase the rate of respiration. The net effect is to remove CO_2 from the blood more rapidly and return the pH to normal.

Other chemoreceptors are involved in two of the five traditional senses: taste and smell. Figure 1 shows the location of some of the chemoreceptors responsible for our sense of taste. There are approximately 10,000 taste buds on the surface of a person's tongue, and each taste bud contains from 5 to 18 chemoreceptors. Taste buds, in lesser numbers, are also located on the soft palate and the epiglottis and on the walls of the pharynx and larynx. As we grow older, some of the taste buds become inactive and we become less sensitive to taste. This may be why older people become more tolerant to "hot" foods such as pepper.

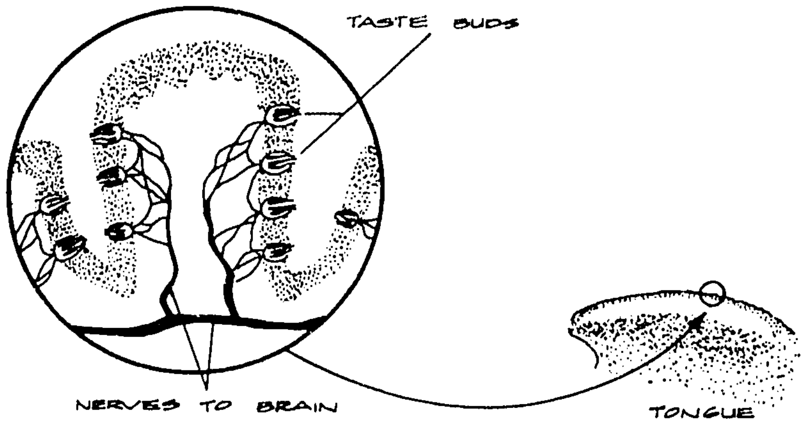


FIGURE 1: A small area of the tongue showing location of the taste buds.

Taste buds are stimulated by substances dissolved in the fluids of the mouth. In order for a person to perceive the taste of a substance it must be soluble in either water or fat. The mechanism by which these dissolved chemicals interact with the taste buds is not known. One theory for which there is some evidence is that the molecules of the substance bind themselves to specific proteins in the chemoreceptors in taste buds. The process of binding may be similar to the way in which an enzyme binds to a substrate, or an antigen and antibody form a complex.

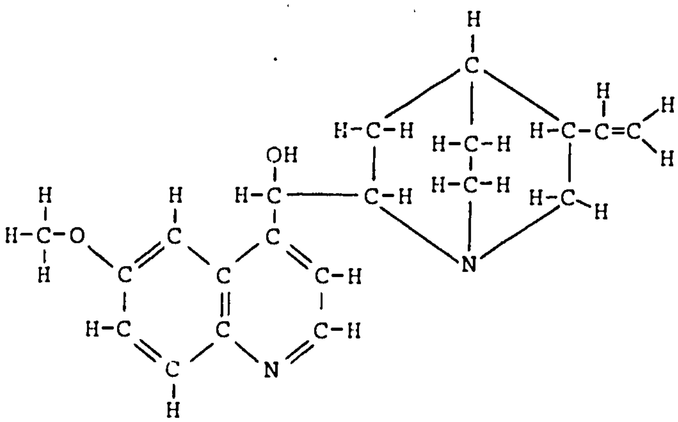
There are four basic tastes: sweet, sour, salty and bitter. Although all taste buds appear to have the same structure when examined microscopically, some respond more strongly to one taste than to others. For example, a taste bud may respond slightly to salt, strongly to sugar and not at all to bitter or sour substances. No taste buds have been found to respond to all four types of stimuli.

Sour tastes are associated with acids; the degree of sourness is proportional to the concentration of H^+ ions. Salty tastes are also produced by ions, but in this case it is mainly the negatively charged ions that stimulate the taste buds. If you add NaCl (table salt) to your food, the degree of saltiness is largely proportional to the concentration of Cl^- ions. For this reason, KCl (potassium chloride) serves as a salt substitute for people on low-sodium diets.

Bitterness is the taste to which we are most sensitive. The number of molecules necessary to produce a taste of bitterness is much lower than the number necessary to evoke salty, sweet or sour tastes. For example, we can detect a bitter taste in a 0.000008 (8×10^{-6}) molar quinine solution. When you have completed Laboratory Activity 37, you can compare this value with the concentrations of sucrose, saccharin and NaCl that you are able to detect.

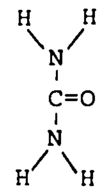
Figure 2 on the following page shows the structural formulas of quinine and some other substances that taste bitter. There is no obvious structural likeness among the kinds of molecules and ions that evoke a bitter taste.

There is a variety of substances that taste sweet, including sugars, some alcohols, glycerol and lead salts. Sugars, alcohols and glycerol all have something in common, as you can see from the structural formulas shown on the following page (Figure 3). Each of these compounds contain one or more -OH (hydroxyl) groups. But the hydroxyl group does not seem to be the complete answer to what constitutes sweetness. For example, ethyl alcohol is not sweet and some sweet compounds contain no hydroxyl group. (Note the structure of saccharin.) The nature of "sweetness" as well as bitterness remains a puzzle.

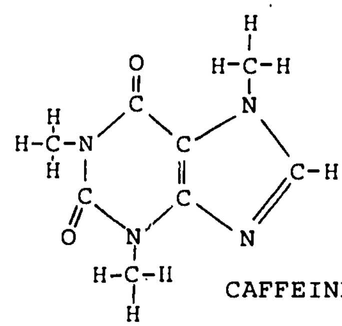


QUININE

Mg^{++} MAGNESIUM ION

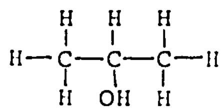


UREA

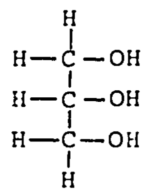


CAFFEINE

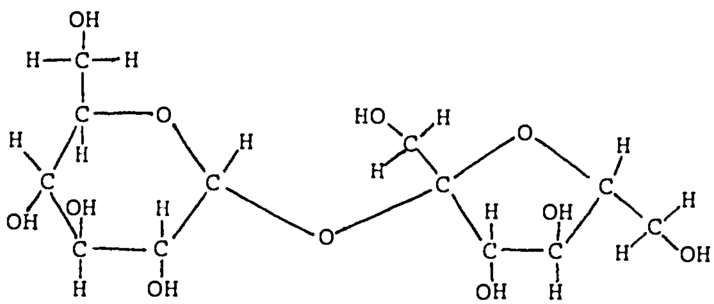
FIGURE 2: Some bitter-tasting substances.



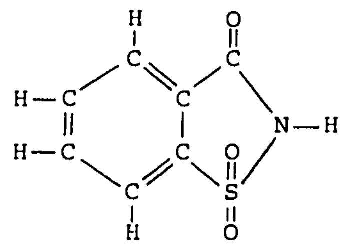
ISOPROPYL ALCOHOL



GLYCEROL



SUCROSE ($C_{12}H_{22}O_{11}$)



SACCHARIN

FIGURE 3: Some sweet-tasting substances.

While we can easily characterize a taste as salty or bitter, it is sometimes hard for us to compare two foods and say that one is more salty or more bitter than the other. If we were given two slices of toast, each with a different brand of margarine, we would have difficulty deciding which spread was more salty. In fact, for us to distinguish that the margarines have different salt levels, there must be at least a 30 per cent difference between the two concentrations of salt molecules. Apparently our sense of taste is not very quantitative. This is in contrast to our sense of sight which can detect very slight differences in brightness.

37-2 The Sense of Smell

How do we detect odors?

Humans are capable of distinguishing between 2000 and 4000 different odors. The receptors responsible for sensing this impressive number of odors lie on the surface of the mucous membrane lining the upper portion of the nasal cavity. They are called olfactory receptors. The olfactory receptors include the dendrites of neurons of the olfactory nerves (Figure 4 on the following page).

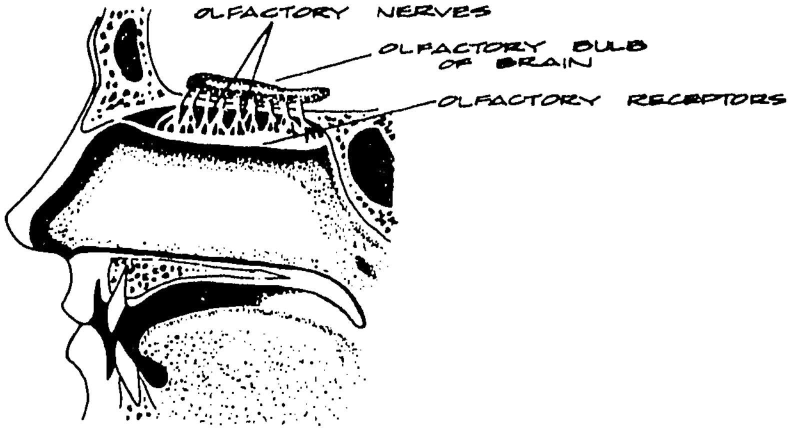
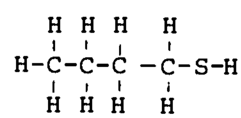


FIGURE 4: Part of the olfactory apparatus.

The upper portion of the nasal cavity is poorly ventilated, so most of the air passing through the nose and down the trachea to the lungs does not come in contact with the olfactory receptors. In order for us to smell a substance the molecules must either diffuse up to the receptors or be drawn up and across them. You may have noticed that when you sniff, your sense of smell is more acute. When you sniff, you pull air up and over the olfactory receptors.

On a microscopic level there appears to be no difference between one olfactory receptor and the next, which raises the question of how we sense thousands of different odors. One current theory suggests that many odors are mixtures of a limited number of "primary" odors. However, up until now, attempts to identify these "primary" odors have been unsuccessful.

It is known that in order for us to detect an odor, the substance from which the odor originates must be volatile; that is, it must release molecules into the air. Ether and ethanol are examples of volatile compounds; NaCl and glucose are examples of compounds that are not volatile. Not all volatile substances can be detected by our sense of smell. For example, water is a volatile substance, yet we cannot smell pure water.



butyl mercaptan

In order for us to detect an odor, molecules of a substance must enter the nasal cavity. They must reach the upper part of that cavity in sufficient numbers to be detected and dissolve in the mucus that coats the receptors. Then the receptors generate nerve impulses and we perceive an odor. Some substances are especially volatile and we are more likely to smell these. Consider, for example, our sensitivity to butyl mercaptan (better recognized as essence of skunk). We can sense .000000000001 (1×10^{-12}) mole of butyl mercaptan in a liter of air! A number of factors influence the release of molecules into the air. One of these is temperature. Substances tend to be more volatile at higher temperatures. Consequently, foods are usually more aromatic (or odorous) when they are cooking.

Our response to odors is also affected by variables other than concentration of molecules and temperature. If you have a head cold, your nasal cavity and the mucous membranes in your nose are likely to be congested and your sense of smell diminished. Smoking may decrease a person's sensitivity. A hungry person is more sensitive to odors than a person who has just eaten, and women generally possess a more acute sense of smell than men. This is especially true of women just before and during a menstrual period, and during pregnancy.

Like the sense of taste, the human sense of smell is very sensitive to the presence of odors, but surprisingly indiscriminate when it comes to the intensity of the odor. In other words, only a very small number of molecules need be present for us to smell something, but a large difference in concentration is necessary for us to differentiate between intensities of a given smell. You might sense a pizza in the vicinity but you would have difficulty deciding whether you smelled four or five pizzas without looking.

What are taste buds? How are they related to chemoreceptors?

What are the four basic tastes? To which are we most sensitive? What kind of ions are responsible for causing a sour taste? a salty taste?

Why must a substance be volatile in order for an odor to originate from it?

Vocabulary:

olfactory (all-FAK-tuh-ree)--of or pertaining to the sense of smell.

volatile (VAHL-ut-ul)--readily diffusing into the air; vaporizing at a relatively low temperature.

UNIT REVIEW SET:

1. a. List at least three functions of the hypothalmus.

   b. List at least two functions of the medulla.

2. a. Which parts of the body have the largest representation on the motor cortex?

   b. How is this useful?

3. a. Draw a diagram of a neuron and label the dendrites, axon, and terminals.

   b. On the diagram, indicate with an arrow the direction in which an impulse travels.

4. What is the anatomical distinction between the central nervous system and the peripheral nervous system?

5. How does a nerve impulse cross the gap between one neuron and the next?

6. a. List the four different normal brain-wave patterns.

   b. Under what conditions are each of these waveforms likely to be observed?

7. a. What factors may contribute to an epileptic seizure?

   b. How is epilepsy treated?

8. Compare the autonomic nervous system and the central nervous system in terms of body location and function.

9. a. Describe biofeedback training.

   b. Give an example of its use in treating a medical disorder.

10. a. Give at least three examples of reflexes.

    b. Give at least two reasons why reflexes are important.

11. What is CSF and where is it found?

12. a. What three substances are commonly analyzed for in CSF?

    b. What is the significance of the presence of each?

13. Which brain disease is associated with hypertension?

14. a. What is cerebral thrombosis?

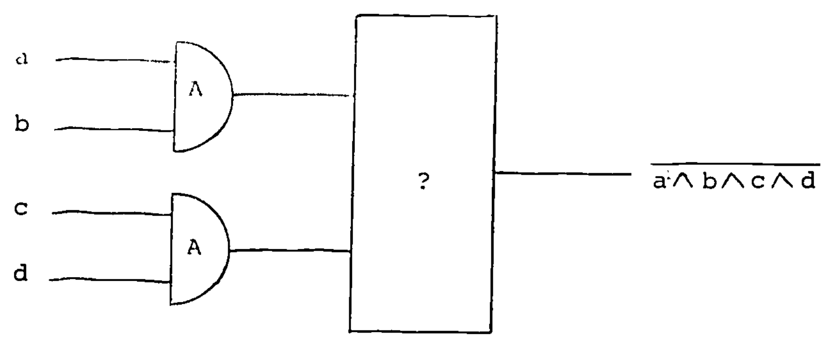
b. What is the relationship between atherosclerosis and cerebral thrombosis?

15. List at least two findings that suggest the possibility of a brain tumor.

16. How can an eye examination be used in the diagnosis of brain tumors or other brain disorders?

17. How are X-rays, angiograms and echoencephalograms used to diagnose brain disorders?

18. Suppose that you are given the circuit shown below along with a 2-OR, a 2-NOR and a 2-NAND gate. Which of these gates would you use to complete the circuit in such a way as to obtain the same output as a 4-NAND gate?



Use the following information on strep throat, bronchitis and bacterial pneumonia to answer Questions 19 through 23.

Findings:

d: fever

q: culture of throat swab positive for bacteria

h: cough

p: severe sore throat

Diseases:

Strep throat: always involves a severe sore throat and a positive throat swab culture, may or may not involve a fever and never involves a cough.

Bacterial pneumonia: always involves a fever, may or may not involve a cough, and never involves a positive throat swab culture or a severe sore throat.

Bronchitis: always involves a cough, may or may not involve a fever, and never involves a positive throat swab culture or a severe sore throat.

19. Write the simplified truth table for each of the three diseases given above.

20. Combine the truth tables in your answer to Question 19 to give a diagnostic truth table for all three diseases.

21. Write the logic statement for each of the three diseases.

22. Design a diagnostic circuit for each of the three diseases. Remember to use a final INVERT gate for the diagnostic output in each case.

23. Combine the three circuits you designed in Question 22 to give a complete circuit diagram for a diagnostic computer.

24. If you feed a set of findings into a diagnostic computer and the output indicates a diagnosis of "disease X," does this mean that the patient definitely has this disease? Explain your answer.

25. Classify the source of each of the following drugs as plant or animal or neither: thyroxin, digitalis, aspirin, insulin, kaolin, morphine, quinine.

26. Some kinds of bacteria can form structures called spores. These structures are alive but inactive--they do not grow, do not reproduce and their metabolic rate is very slow. Would bacterial spores be destroyed by penicillin? Explain.

In Questions 27 through 31, indicate the kind of drug that appears to be called for. For example, if a drug is needed to kill pain, an analgesic would probably be prescribed.

27. A drug is needed to increase the diameter of blood vessels in a patient with a slow rate of circulation. What class of drugs might be prescribed?

28. What class of drugs would be used to make a person unconscious prior to surgery?

29. What class of drugs might be prescribed to induce a bowel movement in a patient?

30. What class of drugs might be prescribed to decrease the activity of neurons in a patient?

31. What class of drugs might be used to treat a patient with a bacterial infection?

32. List at least seven factors a physician should consider before prescribing a drug.

33. From the following list of antibacterial agents, choose the one(s) which work by (a) causing bacteria to lose water by osmosis, (b) causing damage to bacterial proteins and (c) making the tooth surface more resistant to attack.

fluoride

high concentrations of salt or sugar

oxidizing agents

formaldehyde

34. List at least four different ways that an antibiotic might destroy a microbe.

35. a. What is a placebo?

b. List at least two uses of placebos in medicine.

36. What are the two major medical problems associated with chronic use of large doses of alcohol?

37. What is the difference between addiction and habituation?

38. List at least one medically useful pharmacological property of opiates and one of cocaine.

39. Compare tolerance, addiction and withdrawal for the opiates, cocaine and marijuana.

40. a. Describe a transverse wave.

b. Describe a longitudinal wave.

c. Are sound waves transverse or longitudinal?

41. Group the waves caused by the following as standing or traveling waves: vibrating vocal cords, voice, vibrating strings of a guitar, laser, vibrating air column in a trombone, sounds of music.

42. Define hearing threshold.

43. How do the signals sent to the brain for a loud sound differ from those sent for a quiet one?

44. a. What are two categories of hearing loss?

b. Compare the two categories, giving causes and sound frequencies affected.

45. a. What is articulation?

b. Give examples of articulatory movements.

46. Which two independent resonators in your body produce the sounds of speech?

47. What is the vowel quadrilateral?

48. If the frequency of a wave is 700 cps and the wavelength is 1.8 meters, what is the wave speed?

49. What is the speed of light in a vacuum?

50. a. To which wavelengths of light is the eye sensitive?

b. Which frequencies?

51. In what basic way is light similar to sound?

52. Describe two differences between light and sound.

53. Under what conditions will waves from two different sources of the same signal arrive at a point in phase? Out of phase?

54. How is the wavelength of light related to the size of objects visible with a light microscope?

55. a. What is meant by the phrase, "monochromatic green?"

b. If something looks green, does this mean that we are receiving monochromatic green light from it?

56. What light-bending mechanism is essential to our visual system?

57. If $\lambda = 45°$ and $\beta = 30°$, n = ?

58. If $\lambda = 70°$ and $\beta = 30°$, n = ?

59. If $n_x = 2.0$ and $c_x = 1.5 \times 10^8$ meters/sec, what is c_{vacuum}?

60. The greater the index of refraction is for a medium, the (faster, slower) the speed of light in the medium.

61. For a convex lens and a real image the relationship between focal length, image distance and object distance is given by the formula $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$. Use this formula to justify the statement "For a lens having a constant focal length, the closer an object is to the lens, the farther away from the lens an image is formed."

62. State two differences between a real image and a virtual image.

63. Under what conditions will a convex lens form a real image? A virtual image?

64. A certain watch glass has a depth of .6 cm and a width of 12 cm.

a. Use the formula to calculate the radius of curvature of the lens.

$$R = \frac{\left(\frac{w}{2}\right)^2 + d^2}{2d}$$

b. A convex lens is formed with two of these watch glasses and filled with water ($n \approx 1.3$). Use the formula $f = \frac{R}{2(n-1)}$ to calculate the focal length.

65. Describe how the radius of curvature affects the focal length of a convex lens.

66. Describe how the difference in indices of refraction of the lens and the surrounding environment affects the focal length of a lens.

67. At which boundary is a light ray entering the eye bent the most? Why?

68. a. For the eye, which variable in the formula $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$ remains constant at all times?

b. Of the two remaining variables which one is controlled by our eyes?

69. Describe the process of accommodation.

70. We have two major kinds of receptors on the retina, rods and cones. For each of the following phrases write either R for rods or C for cones depending on which it is associated with.

a. color vision
b. night vision
c. black and white vision
d. most sensitive to light
e. rhodopsin
f. B, G and R receptors
g. vitamin A
h. a biochemical that is destroyed by light
i. carrots

71. Draw a sketch of the eye and label the following parts: cornea, aqueous humor, lens, vitreous humor, ciliary muscles, retina, iris, pupil and sclera.

72. Explain why an eyeball that is too short results in hyperopia.

73. Explain why an eyeball that is too long results in myopia.

74. Match the terms on the left with the phrases on the right.

A.	Myopia	a.	"Lazy eye"
B.	Hyperopia	b.	Opacity of lens
C.	Glaucoma	c.	Bad alignment of eyes usually due to weakness of one or more eye muscles
D.	Presbyopia	d.	Farsightedness
E.	Cataracts	e.	Nearsightedness
F.	Optic atrophy	f.	Ocular hypertension in vitreous humor
G.	Detached retina	g.	Decline of ability of lens to accommodate due to age
H.	Strabismus	h.	Wasting away of retina and/or optic nerve
I.	Amblyopia	i.	Not uncommon result of trauma to eye
J.	Astigmatism	j.	Irregular curvature of cornea
K.	Conjunctivitis	k.	A pimple-like infection of one of the glands of the eyelid
L.	Trachoma	l.	Affects about one eighth of the world's population
M.	Sty	m.	Inflammation of the eye and eyelids.

75. Answer the following true (T) or false (F).

a. Glaucoma can be corrected with glasses.

b. Hyperopia is sometimes associated with short eyeballs.

c. Astigmatism is corrected surgically.

d. Amblyopia is often seen in association with strabismus.

e. The Snellen test is a diagnostic test.

f. An E on the $\frac{20}{40}$ line of the Snellen chart is larger than an E on the $\frac{20}{100}$ line.

g. $\frac{20}{20}$ vision is average vision.

h. Hyperopia is often revealed by the Snellen test.

i. Astigmatism may cause poor performance on the Snellen test.

j. Conjunctivitis is contagious.

k. Sties are not contagious.

l. Trachoma is associated with unsanitary conditions.

76. What common refractive error will not be detected by the Snellen test?

77. Name three eye dysfunctions that are "refractive errors."

78. Which senses comprise the kinesthetic sense?

79. Define the term "adaptation" as applied to the senses, and give an example.

80. a. What is meant by a volatile substance?

b. Why must a substance be volatile in order to produce an odor?

81. What units are associated with current, resistance and potential difference?

82. What three conditions are necessary for electrons to flow?

83. How does the diameter, length, and temperature of a wire affect its resistance?

84. What is the difference between an insulator and conductor?

85. Draw the symbols for connected wires, unconnected wires, a voltage source, a light bulb, a resistor and a switch.

86. a. What happens to the current when the voltage is increased?

b. What happens to the current when the resistance is increased?

87. Provide the formula for Ohm's Law:

a. in terms of current, voltage, and resistance.

b. in terms of I, V and R

88. How can a rheostat be used to alter a current?

89. a. What is the difference between alternating current and direct current?

b. What is the advantage of AC?

90. What is meant by a "grounded" electrical device?

91. Under what conditions can a person receive an electrical shock?

92. How do fuses help prevent fires in buildings?

SECTION A: AN INTRODUCTION TO CURRENT ELECTRICITY

A-1 The Electronic Future

I rubbed my eyes. I had been dozing--but how long? And where was I? Everything seemed so strange. The city looked different. Where were the people? Where was the traffic? Why was it so quiet?

I stood up and stretched and looked at the all-glass building nearby. Neon lights blinked on and off. The sign read, "AUTOMATED HOSPITAL 3." The words puzzled me. I had a vague nervous feeling. A page from a newspaper floated by and I grabbed it. It was dated May 3, 1997!

I knew it couldn't be true, so I walked into the hospital to find out what was going on. Electric doors slid open just like in a supermarket, and I walked over to the admission desk. Where were the clerks? There was not a soul there--just a bunch of electric typewriters, and two of them were typing away.

"Please sit down on the striped chair," a high-pitched metallic voice said. The voice came from a speaker on the wall behind the typewriters. Sure enough, in the corridor was a neatly upholstered, green-and-white striped chair. I laughed because the whole thing seemed so ridiculous. Then I sat down on the chair, not knowing what else to do.

I stopped laughing when a seat belt suddenly swung around and clamped me to the chair and the chair began to move down the long hospital corridor. Actually the chair was clamped to the floor and the floor was moving. And it was moving fast.

The chair carried me past a series of rooms in quick succession, each with a brilliantly lit sign--X RAYS, LASER SURGERY, ELECTROCARDIOGRAPHY, AUTOMATED URINALYSIS, ELECTRON MICROSCOPY. Then I noticed that the chair had a panel with numbered switches on it and I pressed one to see what would happen. The chair slowed down, turned left down another corridor, and took me into a room marked ELECTRONIC THERAPY. Then I heard the weird metallic voice again: *"Quiet please. My patients are receiving therapy."*

The room was dimly lit, but as my eyes adapted I could see patients in beds. The chair moved slowly now as it transported me between the beds. I noted a patient with electrodes on her head, and next to her a TV screen showing her brain waves in four colors. Another patient was hooked up to a high-frequency sound generator and was being bombarded with sound waves. I saw a third patient, a teen-aged boy, sit up and open his eyes. I was relieved. I wanted to speak to someone.

But he wasn't getting out of bed. He pressed a pink button on the side of his bed and the room was transformed to a warm pink color. As he put on his earphones and lay down again, I heard strange electronic music. It sounded like a police-car siren in slow motion.

I had had enough of this, so I pressed another switch on the panel of my chair. The chair took off again with a lurch forward and then screeched to a stop at the door.

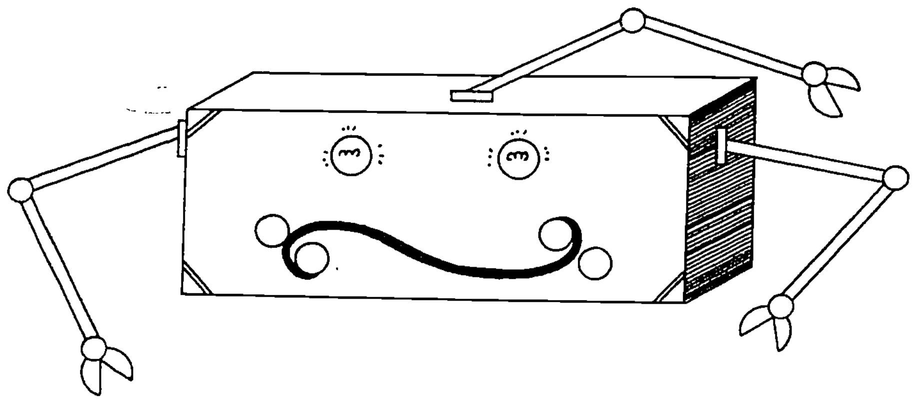
ZAP! I felt a slight tingle move through my body. *"Nothing to worry about."* It was that tinny voice again. *"You have just been decontaminated."*

Back out in the corridor. The chair was moving fast now. I could just make out the signs on the rooms as we flew by--HEART-SOUND ANALYSIS, RADIOACTIVE ISOTOPES INSTRUMENTATION, AUTOMATED BLOOD ANALYSIS, AUDIOGRAPHY, COMPUTER-ASSISTED LITERATURE RETRIEVAL--and there were others that made less sense to me.

Then we slowed down. The bright sign on the door read: BRAIN CENTER. The chair carried me into the room and I realized what it was--a computer room. And huge. It had dozens of computers but no operators. The computers were buzzing and humming, lights went on and off, computer tapes whirred.

We stopped in front of a gigantic computer of a type I had never seen before.

It had two red bulbs that looked like eyes, a roll of paper tape that looked like a mouth and three long, dangly things that looked like arms.



"*I want to talk to you,*" it said.

The voice was familiar. It was that same tinny, metallic sound that I had heard before.

"*Your name and Social Security number, please. Type it over there.*" All three metallic arms pointed at a typewriter.

I figured I might as well, so I sat down at the typewriter and did as directed.

"*Roll up your sleeves, please.*"

"Now, wait a minute!" I said. An electrical charge passed from the chair to my body and I felt a slight electrical shock. "*Don't make me do that again,*" it said.

I saw the two red bulbs turn brighter and the paper tape move mechanically from left to right. I rolled up my sleeves meekly.

Before I realized what was happening the computer's arms went into action. One drew a blood sample from my left arm. One drew a blood sample from my right arm. And one drew my wallet from my jacket pocket, counted out twenty-five dollars and returned the wallet.

"*Thank you,*" it said. "*I'll have the results for you in three days.*"

The chair whirled around and I found myself going back down the corridor toward the entrance.

A-2 Electricity in the Modern World

Is the automated hospital myth or reality?

Electricity affects each of our lives, perhaps hundreds of times every day. Often we are not aware of the presence of electricity, although we continually benefit from its use. For example, an electric spark helps to make a car run; electricity is necessary for television, telephone communication, lighting our homes, pin-ball machines and high-fidelity music systems. In business and industry, electricity has essentially unlimited uses. And, in the human body, our muscles move in response to electrical signals transmitted along the nervous system from the brain.

Clearly, electricity is a very useful and valuable kind of energy. Its principal value is that it can be controlled easily in many ways for many purposes.

For this reason, electricity has had a tremendous impact on the field of health care. Although the automated hospital described in Section A-1 may seem like part of a fantasy world, the fact is that all of the medical electrical devices mentioned in the story (except for the three-armed computer) are in use today, helping to provide better health care. And the new automated analytical equipment has opened up challenging fields for those interested in health careers.

Remarkably enough, these devices may only be a small indication of what is to come. The use of electrical devices in medicine has begun fairly recently. Many of the important medical instruments in use today could not be developed until the invention of the transistor in 1948 and the advance of computer technology during the 1960's. Many new applications of electricity in medicine can be expected during the coming years. In fact, by 1997, our medical technology may make the automated hospital in the story look pretty old-fashioned.

In Sections A through E some of the fundamentals of electricity will be studied: how it behaves and why. In addition, we will discuss some of the applications of electricity in medicine, how electricity is produced in the body, and some important aspects of electrical safety.

A-3 What is Electricity?

Electricity may seem difficult to understand, because it is not something that can be seen. We are very much aware of its effect, however, whether the effect is a flash of lightning, warm air from an electric heater or music from the radio. Generally, electricity may be described as a form of energy, the effects of which are produced by a movement of charged particles. In the Respiration Unit, we found that positively and negatively charged objects are attracted to one another. Objects with the same charge tend to repel each other. This behavior is an important aspect of all electrical phenomena.

Most electrical devices depend upon the movement of electrons which, as you may remember, are one of the tiny bits of matter that make up the atom. Each electron is negatively charged. However, positively charged particles are also involved in many electrical systems. For example, in the body, charged ions such as sodium (Na^+) and potassium (K^+) are related to electrical function of the nervous system and the heartbeat.

A-4 Current

What is electric current, and how is it measured?

Electric current is no more than the movement of charged particles. In a wire, the current is due to moving electrons, each of which has a negative charge. It is often useful to compare electric current to the flow of water in a pipe. For example, the amount of water flowing through a pipe might be expressed in "liters per second" or "gallons per minute." Electric current is usually measured in units of amperes, which can be related to the number of electrons moving through a section of the wire per unit time.

One ampere is equivalent to the movement past a point of 6.24×10^{18} electrons per second. This means that a light bulb carrying one ampere of current has 6.24×10^{18} electrons entering and leaving the light bulb during each second. Note that the electrons are not used up. The number of electrons that enter the light bulb is equal to the number that leave.

Table 1 lists the amount of electric current associated with a variety of common electrical phenomena. Note the large variation in the amount of current flow.

TABLE 1: CURRENT ASSOCIATED WITH VARIOUS ELECTRICAL SYSTEMS

System	Current in amperes
nerve cells	10-11 (maximum)
flashlight	0.2
electric light bulb	0.1 to 1
oven	10
electric eel	100 (maximum)
electric street car	200
electric arc welding	500
lightning	10,000 (maximum)
industrial electric furnace	100,000

A-5 Voltage

What causes the flow of current? What is meant by "potential difference?"

The movement of electrons in a wire does not just happen. The electrons must be attracted to a region of positive charge, such as the positive terminal of a battery. A battery is a commonly-used device which can give energy to the electrons in an electrical system. The electrical energy of the moving electrons may then be converted into other forms of energy such as heat and light (as in a light bulb) or sound (as in a loudspeaker).

In order to understand what happens when a battery provides this energy, we can once again compare electric current to the flow of water. You may recall from the Nutrition Unit that water has higher potential energy at the top of a hill than at the bottom of a hill. Gravitational attraction causes the water to move to a position of lower potential energy (see Figure 1). As the water flows downhill, potential energy is converted into kinetic energy. If a pump is used to return the water to the top of the hill, the pump restores the gravitational potential energy of the water, and the cycle can continue indefinitely.

Thus a continuous flow of water is possible if three conditions are met:

1. A gravitational potential energy difference must exist between the water at the top and the bottom of the hill.

2. A source of energy (the pump) is needed to raise the potential energy of the water from a low to a high level.

3. There must be no breaks or gaps in the path of the water as it circulates around the system.

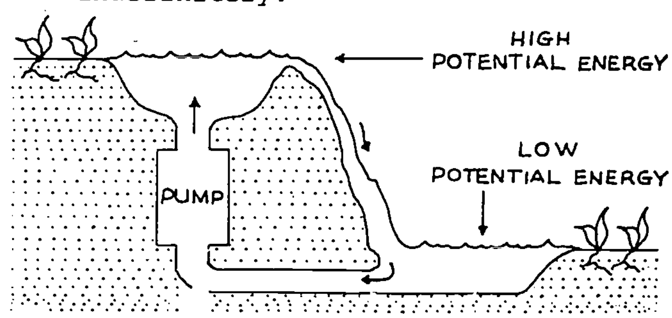


FIGURE 1: Water flow and potential energy. Water loses potential energy as it flows downhill and gains potential energy as it is pumped uphill.

A battery works on electrons the way that the pump works on water. In a battery, chemical energy is used to maintain a surplus of electrons at one terminal (which is therefore negatively charged) and a deficiency of electrons at the other terminal (net positive charge). If the ends of a wire are attached to the two terminals, free electrons in the wire are attracted toward the positively charged terminal. This electrical attraction is similar to the gravitational attraction which causes water to flow downhill. The electrons at the negative terminal have higher potential energy than at the positive terminal (see Figure 2). By moving toward the positive terminal, the electrons approach a condition of lower potential energy.

The energy given up by the electrons is converted into other forms of energy, such as light, heat or sound.

As in the water example, three conditions must be met if a continuous flow of electrons is to occur.

1. An electrical potential energy difference (usually called simply "potential difference") must exist between electrons at the two terminals of the battery.

2. A source of energy (the battery) is needed to raise the potential energy of the electrons from a low to a high level.

3. There must be a continuous path along which the electrons can move. For example, if a wire is disconnected from one of the terminals, the flow of current will stop.

A system through which electrons can flow is generally referred to as an electric circuit. A continous loop of moving electrons, such as described in this example, is called a closed circuit. If a gap is present which stops current flow, the system is said to be open circuit.

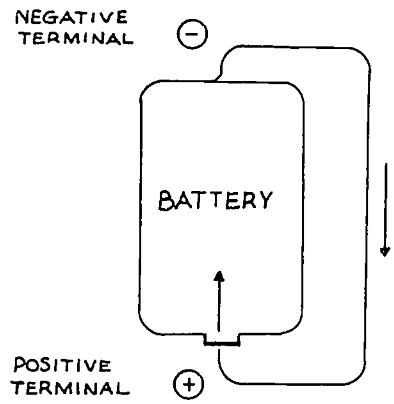


FIGURE 2: Electron flow and potential energy.

Electrons lose potential energy as they flow through the wire toward the positive terminal. They gain potential energy inside the battery as they move toward the negative terminal. The arrows indicate the direction of electron flow.

Potential difference is commonly referred to as voltage. To be more exact, voltage may be described as a measure of the potential difference between two points. The higher the measured voltage is between two points, the greater must be the potential difference (and the flow of current if the points are connected). The unit of potential difference is the volt, which is defined in terms of the amount of energy needed to move charges between the two points. The higher the voltage is, the greater the amount of energy needed.

It is important to keep in mind that potential difference is always measured between two points in a circuit. If a battery is rated at 1.5 volts, it means that there is a potential difference of 1.5 volts between two points, the positive and negative terminals. It is meaningless to talk about voltage at a single point.

To summarize, a battery uses its chemical energy to establish a potential difference between its two terminals. The magnitude of this potential difference is measured in volts. If a wire is connected to the two terminals, the potential difference causes electrons to flow in the direction which lowers their potential energy. That is, the electrons lose potential energy as they leave the negative terminal, and pass through the wire. The electrons entering the positive terminal gain potential energy as a result of the energy released by chemical reactions inside the battery.

Table II (on the following page) lists the voltages associated with a number of electrical systems. Note the wide range of voltages.

TABLE II: Voltage Associated with Various Electrical Systems

System	Potential Difference in Volts
electrocardiogram measurement	0.001
nerve cell (inside and outside)	0.090
flashlight (two dry-cell batteries)	3.0
the BIP	5, 12 or 24
most home electrical devices	120
stove or clothes-dryer	240
electric eel	550 (maximum)
electric street car	15,000
power station	200,000
lightning bolt	100,000,000 (average)

How may electricity be defined?

How are "amperes" defined? How are amperes similar to the units "liters per minute?"

Explain the difference between current and amperes.

What conditions are needed for electrons to flow?

Why is it incorrect to refer to a voltage flowing through a wire?

Vocabulary:

ampere (AM-peer)--the common unit of electric current; equivalent to the movement past a point of 6.24×10^{18} electrons per second.

electric circuit--a system through which electrons can flow.

electric current--the movement of charged particles (also see ampere).

potential difference--the difference in potential energy of a quantity of charge at two points in an electrical system.

voltage--potential difference; also a measure of potential difference.

volt--the common unit of potential difference, defined in terms of the amount of energy needed to move a quantity of charge between two points.

SECTION B: RESISTANCE IN CONDUCTORS AND INSULATORS

B-1 Resistance

What limits the flow of electrons through a wire?

In a wire, some of the electrons in the metal atoms are loosely bound to the atomic nuclei. A potential difference applied to the ends of the wire causes these electrons to migrate from atom to atom, giving a current. Each metal atom that loses a negatively charged electron becomes a positively charged ion. The electrons are not completely free to move, however. Since the electrons and nuclei are oppositely charged, there is always some attraction between the ions and the moving electrons (Figure 1). This means that the structure of the metal tends to "resist" the movement of electrons. The opposition to the flow of current is known as resistance.

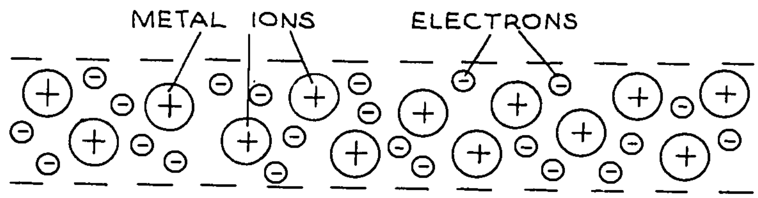


FIGURE 1: A schematic drawing showing how electrons and metal ions are arranged in a wire.

The unit of resistance is the ohm which is defined in terms of the amount of potential difference that is needed to cause the flow of a specified current. More exactly, the resistance of a wire is said to be equal to one ohm when a potential difference of one volt causes a current of one ampere to flow through the wire. The greater the resistance in a circuit, the more the circuit resists the movement of electrons and therefore, the greater the voltage must be in order for the same current to flow. Note that ohms can be expressed in terms of volts per ampere. This relationship has very important consequences which are discussed more thoroughly in Section C.

The resistance of a wire is affected by a number of factors, such as thickness and length. The situation in a wire may be compared to the flow of water through a pipe. Forcing water to flow at a fixed rate becomes more and more difficult when the pipe is made narrower. In narrower pipes, there is more opposition to the flow of water and a greater pressure is required.

A similar situation exists for electric current in wires, as is indicated in Table 1. The table shows how the resistance of a wire is related to the thickness, length and temperature of the wire. For example, a long, thin wire resists the flow of current more than one that is short and thick. Note that temperature, which has little effect on the rate of flow of water through a pipe, has an important effect on electrical resistance. The resistance of a light-bulb filament (which is made from a very thin, high-resistance wire) when lit brightly is 10 to 15 times greater than its resistance at room temperature.

TABLE 1: RESISTANCE IN WIRES

	Low Resistance	High Resistance
Diameter	wide	narrow
Length	short	long
Temperature	low	high

B-2 Conductors and Insulators

Does current flow through all substances?

Resistance also depends upon the type of material through which the current flows. Wires are usually made of materials with very low resistance, such as copper or aluminum. The low resistance allows electrons to flow along a wire from a battery to a light bulb without losing very much energy. Then, when the electrons meet the high resistance of the light bulb, the energy of the electrons is converted into light and heat (Figure 2).

Materials such as copper or aluminum, which readily permit the flow of current, are called conductors. Most metals fall into this category, and so it may be said that metals conduct electricity well. Ionic solutions can also serve as good conductors. In a solution of sodium chloride in water, the charged ions (Na^+ and Cl^-) are free to migrate through the solution in the presence of a potential difference. Consequently, it is also possible for small electric currents to flow inside the body (since the body contains many charged ions). These currents are for the heartbeat, respiration, the nervous system, etc.

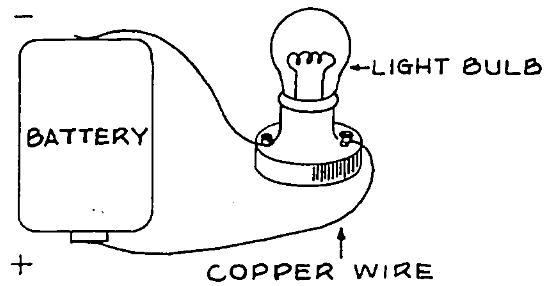


FIGURE 2: A simple circuit for lighting a bulb.

Substances with high resistance, such as rubber, glass and air, are called insulators. These materials have practically no free electrons, and consequently are very poor conductors of electric current. However, insulators are very important since they prevent the flow of current to where it is not wanted or needed. Wires are generally surrounded with an insulation of rubber or plastic which protects us from the current flowing through the wire. The insulation also prevents the wire from becoming corroded.

Note, however, that all substances conduct electricity to some extent under the proper conditions. For example, current can flow through gases--this occurs in neon signs. In a thunderstorm, a large potential difference may be established between two clouds, or between a cloud and the earth. This can cause an extremely large current to flow through the air, which is seen as lightning. Voltages of this magnitude are uncommon in most electrical systems, so that normally, current is not conducted through an insulator such as air.

Semiconductors are a third class of substances that lie in between conductors and insulators in terms of their electrical properties. Examples include silicon and germanium, which are much poorer conductors than metals such as copper and aluminum. Nevertheless, semiconductors revolutionized the electronics industry in the 1950's, because they have special properties that permitted electrical components to be miniaturized. Components containing semiconductors are referred to as "semiconducting" or "solid-state" devices.

These devices can either conduct or insulate, depending upon other factors in the circuit. The operation of the diode (a simple semiconducting device) can serve as an example of this property. The diode is made from a tiny semiconducting crystal that has two connecting wires (Figure 3). Certain diodes conduct current only if the voltage across the diode is greater than a specified value. When the voltage is less than this value, the diode functions as an insulator. With the use of diodes and other components in various combinations, circuits may be designed that have many applications and capabilities.

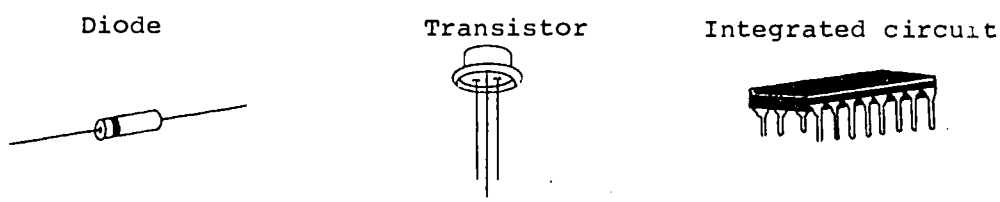


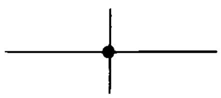
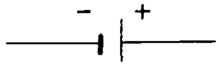
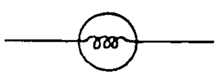
FIGURE 3: Semiconducting devices.

The most famous of the semiconducting devices is the transistor (Figure 3), which first made possible the miniaturization of large circuits. Since the mid 1960's, even transistors have been miniaturized. By means of increasingly sophisticated manufacturing processes, integrated circuits (Figure 3) have been developed that contain literally thousands of transistors, diodes and other components in a tiny semiconducting wafer. Integrated circuits are now used in television sets, hand-held calculators, computers and many types of electronic instrumentation.

B-3 Electrical Symbols

What is a  ?

In order to communicate about electric circuits, a set of symbols has been developed. These symbols show how components are connected together in a circuit. Only six symbols are given here, but they are sufficient for the treatment of electricity in this course.

SYMBOL	MEANING
	The lines represent two wires or other conductors used in conventional circuits. The spot (●) indicates that the wires are connected.
	This symbol refe[illegible] two wires that are not connected.
	A voltage source, such as a battery. The - and + signs indicate the cathode and anode (that is, the negative and positive terminals).
	A light bulb connected to two wires or other conductors.
	A component that provides resistance. This symbol usually refers to devices known as resistors, which can be designed to provide any desired resistance.
	This symbol represents a switch. In an actual circuit, the switch prevents the flow of current when it is open. The circuit may be turned "on" by closing the switch.

Letter symbols representing voltage, current and resistance are also used. These are summarized in Table 2. Note that the symbol for resistance is different from the symbol used for ohms (the units of resistance). The symbols used for current and amperes (units of current) are also different.

TABLE 2: SYMBOLS USED FOR ELECTRICAL PROPERTIES AND THEIR UNITS

	Letter Symbol
Current	I
Voltage	V
Resistance	R

	Letter Symbol
amperes	A
volts	V
ohms	Ω

The circuit shown in Figure 4 (on the following page) is a representation of the battery, light bulb and wires shown in Figure 2. Note that the voltage of the battery is indicated next to its symbol.

What is resistance? What are the units used for measuring resistance?

How is resistance affected by the diameter, length and temperature of a wire?

Explain the difference between conductors and insulators. How are they used in electric circuits?

What kinds of substances are good conductors? poor conductors?

List at least three applications of semiconductors.

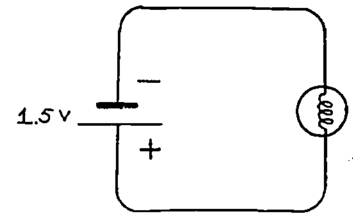


FIGURE 4: A diagram of a circuit containing a battery, light bulb and connecting wires.

VOCABULARY:

conductor--any substance that readily permits the flow of electric current.

insulator--any substance that does not conduct electric current under normal conditions.

ohm--the unit of electrical resistance, symbol Ω; expressed in terms of volts per ampere.

resistance--opposition to the flow of electrical current, measured in ohms; a measure of the opposition to current flow caused by a circuit component.

resistor--a device designed to provide a specified electrical resistance.

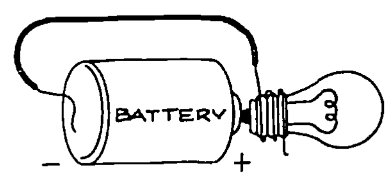
semiconductor--a substance that is intermediate between conductors and insulators in terms of its ability to permit the flow of electrical current.

PROBLEM SET B:

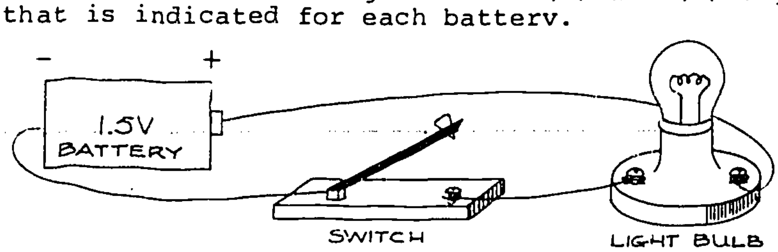
1. In Sections A and B, electricity has been compared to the flow of water. Although this analogy is not exact, there are enough similarities to make this a useful comparison. Below are two columns of terms. The left-hand column refers to water flowing through a pipe, the right-hand column to the movement of electrons in a wire. Match each term in the electricity column with the corresponding term in the water column.

a.	water	switch	e.	liters per second	amperes
b.	pipe	resistance	f.	pump	electrons
c.	water flow	current	g.	valve	wire
d.	gravitational potential energy difference	battery	h.	friction in pipes	voltage

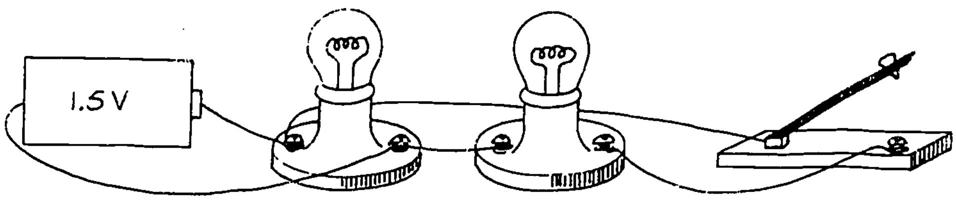
2. The figure at right shows a simple electric circuit with a battery, wire and a light bulb. List at least three kinds of energy that are associated with this circuit.



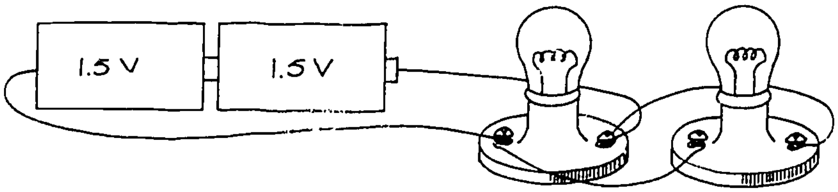
3. Draw a schematic diagram for each of the following circuits. Label the voltage sources in your schematic diagrams with (+) and (-) signs, and the appropriate voltage that is indicated for each battery.



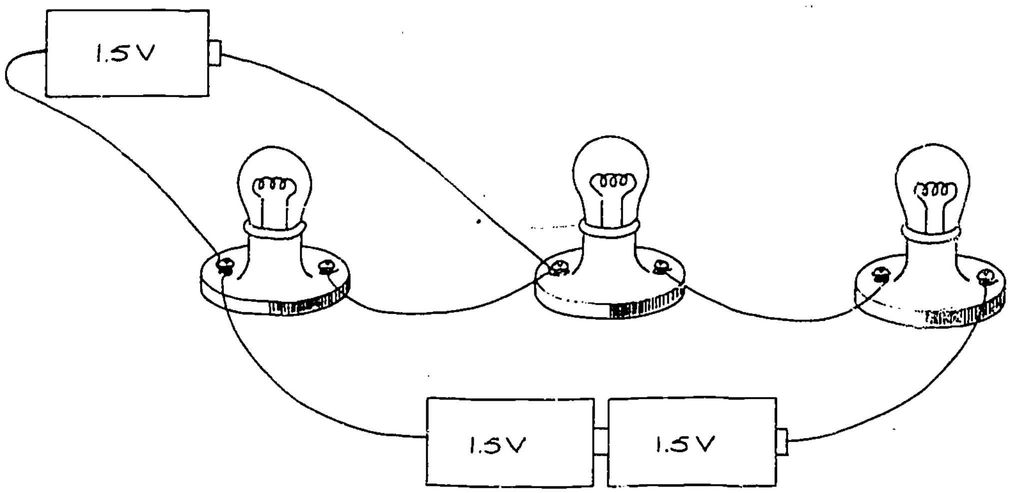
b.



c.



d.



4. Electrical appliances such as a toaster or an iron operate less effectively than normally when they are used at the end of a long extension cord.

a. Explain briefly why this is so.

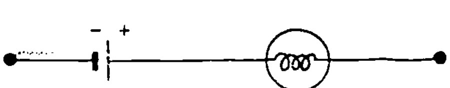
b. How might the performance of the appliance be improved without using a shorter cord?

5. How many electrons flow past a point per second in an average lightning bolt, assuming that the flow of current is about 10,000 amperes?

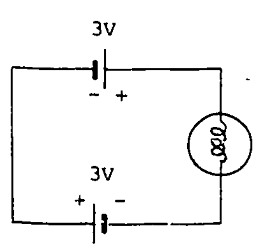
6. Explain the difference between current and amperes.

7. A number of circuits are diagrammed below. For each circuit, decide whether or not the light bulb should be lit. In your answer sheet, simply indicate either "on" or "off," and give a short explanation for your answer. Also indicate the potential difference (voltage) across the light bulb.

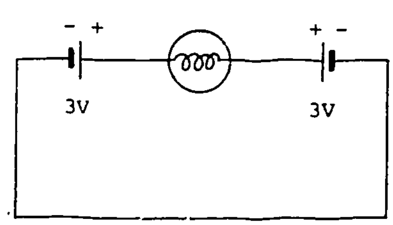
a.



b.



c.



SECTION C: OHM'S LAW

C-1 Controlling the Flow of Current

How is current affected by a change in voltage or resistance?

In general, the amount of energy released by a circuit component such as a light bulb is directly dependent on the amount of current flowing. If the current is increased, the light bulb burns more brightly. Or, if too much current flows through the filament, the light bulb burns out. Similarly, if too much current flows in the wiring of a house, the wires can heat up and cause a fire. Clearly, it is essential to control the flow of current, so that circuits can be operated safely and efficiently.

Aside from current, we have discussed two other variables that are present in any circuit: voltage and resistance. Both of these variables have an important influence on the current flow in a circuit, and consequently it is important to understand how current is affected by voltage and resistance.

Since electrons acquire their energy from a voltage source, let us first examine how current depends on voltage. An increase in voltage causes an increase in current, since at higher voltages more energy is available to force electrons through the circuit. As an example, consider the simple circuit shown in Figure 1A. The battery causes a particular current to flow which makes the light bulb glow. The amount of current and the intensity of the light stay the same as long as the circuit is left alone. When a second battery is placed in the circuit as shown in Figure 1B, the current is increased and the light bulb glows more brightly.

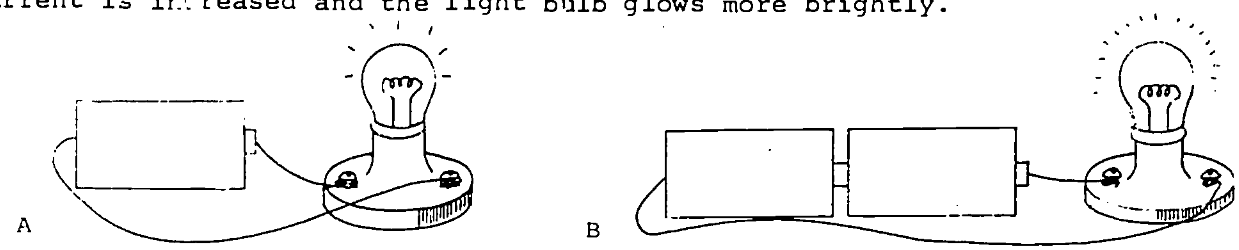


FIGURE 1: The light shown in A can be made to glow more brightly by increasing the current flowing through it. Increasing the voltage by adding an additional battery B increases the current.

A similar circuit is diagrammed in Figure 2. As shown in A, a potential difference of 5 volts causes a current of 0.1 ampere to flow. When the voltage is doubled as indicated in B, the current is also doubled.

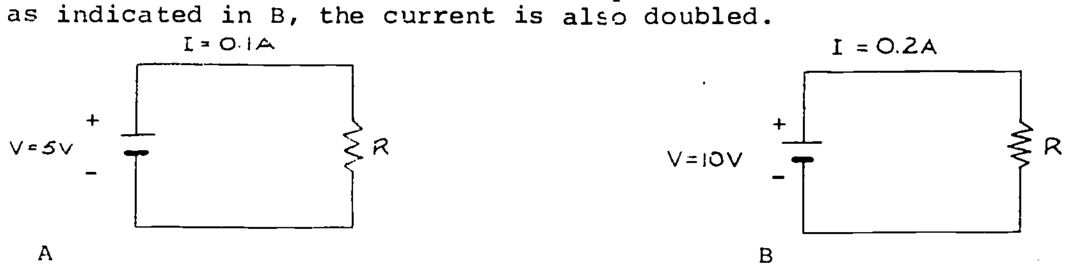


FIGURE 2: An increase in voltage causes a proportionate increase in the current in a circuit, as long as the resistance remains constant.

The dependence of current on voltage can be described mathematically as follows.

current is proportional to voltage (for a constant resistance) (1)

or current = k(voltage) where k is a constant

This means that the amount that the current increases is in direct proportion to the increase in voltage, as long as the resistance in the circuit remains constant. When the voltage is multiplied by a certain factor, the current is multiplied by the same factor.

This relationship may be understood if it is remembered that doubling the voltage is equivalent to doubling the potential energy difference. Since twice as much energy is available, twice as much current can flow. The effect of doubling the voltage is to double the amount of current flowing in the circuit.

Resistance also has an important but different effect on the current flowing in a circuit. Increasing the resistance causes the current to decrease, as long as the voltage doesn't change. For example, two light bulbs, when connected in series to a battery, do not glow as brightly as when one light bulb is connected to the same battery. Two light bulbs provide a higher resistance than one light bulb. Consequently, less current flows, and the bulbs do not glow as brightly.

As shown in Figure 3, increasing the resistance by a factor of two reduces the current to <u>one-half</u> of its original value, if the voltage remains constant. The relationship between current and resistance can be represented as follows.

$$\text{current is proportional to } \frac{1}{\text{resistance}} \quad \text{(for a constant voltage)} \qquad (2)$$

This expression tells us that an increase in resistance causes less current to flow; a decrease in resistance permits more current to flow. When the resistance is multiplied by a certain factor, the current is divided by the same factor. Such a relationship is known as an inverse proportion.

A B

FIGURE 3: As shown in A, a resistance of 10 ohms allows a current of 0.8 ampere to flow. When the resistance is doubled to 20 ohms (B) and the voltage is kept constant, the current is halved to 0.4 ampere.

C-2 Ohm's Law

How are values for current, voltage and resistance calculated?

The amount of current flowing through a circuit is dependent on both the resistance and the voltage present in the circuit. In order to calculate the value of the current, we need an expression that relates current to both resistance and voltage. This may be done by combining expressions (1) and (2).

The combined equation is called Ohm's Law, and may be stated as follows.

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} \qquad (3)$$

Using the symbols I, V and R for these three variables, Equation (3) may be written as

$$I = \frac{V}{R}$$

Note that if the equation is rearranged as $R = \frac{V}{I}$, it may be seen that the units for resistance must be equivalent to volts per ampere. This explains why as stated in Section B, the ohm has been defined as the resistance which permits a current of one ampere to flow in the presence of a potential difference of one volt.

Ohm's Law makes it possible to calculate a value for resistance, voltage or current as long as two of these three variables are known. For example, if the voltage in a circuit is 10 volts, and the resistance is 20 ohms, then the current is given by

$$I = \frac{V}{R}$$

$$I = \frac{10 \text{ volts}}{20 \text{ ohms}} = 0.5 \text{ ampere}$$

Values for voltage and resistance may be found in a similar manner. For example, to calculate the voltage needed to provide a current of 0.01 ampere with resistance of 20,000 ohms, the Ohm's Law equation may first be rearranged before it is solved for V.

$$V = IR$$
$$= (0.01 \text{ ampere})(20{,}000 \text{ ohms})$$
$$= 200 \text{ volts}$$

Ohm's Law does not take into account changes in resistance that are due to temperature changes. Consequently, if we wish to know the amount of current flowing through a light bulb, the resistance of the bulb must be measured while the current is flowing--that is, while the bulb is hot.

C-3 Using Ohm's Law

How can Ohm's Law be used in circuit analysis?

Ohm's Law can help us to understand the operation of virtually any circuit. As an example, we can calculate the amount of current flowing through the circuit shown in Figure 4. When resistors are connected in series, as in Figure 4, the total resistance in the circuit is the sum of the separate resistances. In this case, the total resistance is 150 Ω, and the voltage is 15 V. These values can be used in the Ohm's Law equation to provide a value for the current.

$$I = \frac{V}{R} = \frac{15 \text{ V}}{150\ \Omega} = 0.1 \text{ A}$$

Thus, 0.1 A flows in the circuit. It is important to recognize that this current flows at all points in the circuit at the same time. The current in the voltage source has the same value as the current in the wires or in the resistors.

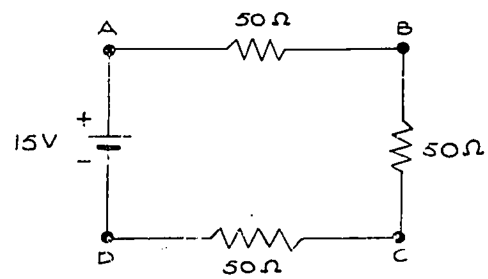


FIGURE 4: A circuit with three 50-Ω resistors connected in series to a 15-V voltage source.

The voltage, however, has different values when it is measured at different points in the circuit. Remember that voltage must always be measured between two points in a circuit. For example, the potential difference between points A and D (Figure 4) must be equal to the voltage of the voltage source, which is 15 V.

What is the potential difference between points A and B? This question may be answered in two ways. Since the same current is flowing at all points in the circuit, the heat energy released by the electrons must be divided equally between the three resistors (because they have equal resistances--50 Ω each). Thus, the potential difference across each resistor must be 5 V. This change in potential is often called a voltage drop, since the potential energy of the electrons "drops" 5 V across each resistor.

The potential difference between points A and B may also be determined using Ohm's Law. Since a current 0.1 A is flowing through a resistance of 50 Ω, the voltage drop across the resistor must be equal to

$$V = IR = (0.1 \text{ A})\ (50\ \Omega) = 5 \text{ V}$$

Note that the sum of all the voltage drops around the circuit (that is 5 V + 5 V + 5 V) must be equal to the voltage produced by the voltage source (15 V).

C-4 Rheostats

How may current be altered?

The dependence of current on resistance and voltage is extremely important in electric circuits. For example, by varying the voltage drop across a light bulb, the intensity of the light is also changed. As the potential difference increases, the current also increases, which allows more energy to be released.

The potential difference across a component can be easily controlled with a device called a rheostat--a device whose resistance may be varied as desired. The simplest form of rheostat is a high-resistance wire with a sliding contact, which is shown in Figure 5. The resistance between points A and B depends upon the position of the sliding contact. If the total resistance of the wire is 100 ohms, then with the contact at the midpoint of the wire, the resistance between A and B is 50 ohms. By sliding the contact, any resistance between 0 and 100 ohms may be achieved.

When connected to a circuit, a rheostat may be used to vary the current. In Figure 6 below, a rheostat is connected to a voltage source and a light bulb. With a constant voltage, the intensity of the light depends upon the amount of current, which can be varied by adjusting the resistance with the rheostat. The light is brightest with the rheostat set at 0 ohms, and dimmest when the setting is 100 ohms. This kind of circuitry may also be used for controlling the speed of an electric motor, or the volume of a loud speaker.

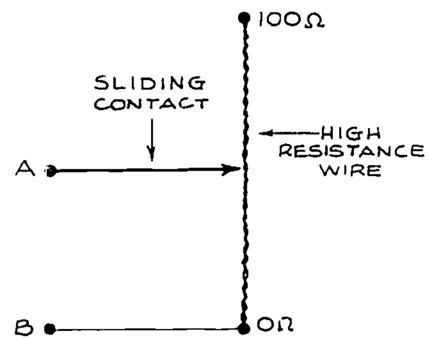


FIGURE 5: A simple rheostat. The resistance between points A and B may be varied between 0 and 100 ohms.

How does current depend on voltage? On resistance?

What is the relationship between voltage, current and resistance described in Ohm's Law?

How are rheostats used to alter the flow of current?

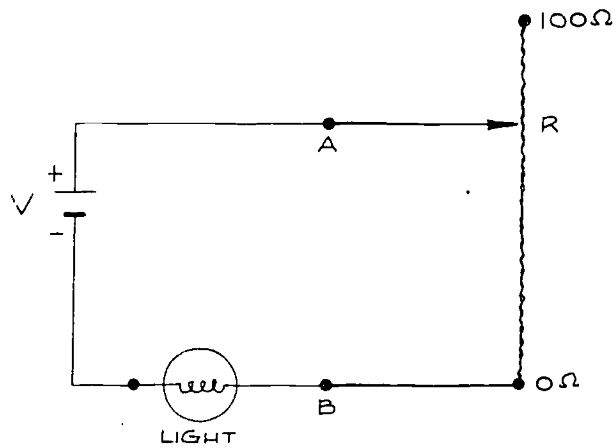


FIGURE 6: A rheostat used to vary the intensity of a light bulb.

Vocabulary:

Ohm's Law--the mathematical relationship which states that the current flowing through a circuit is directly proportional to the applied voltage, and inversely proportional to the resistance of the circuit. Usually expressed as $V = IR$.

rheostat (REE-oh-stat)--a variable resistor, used for changing the amount of current flowing in a circuit.

voltage drop--potential difference, in volts, between two points in a circuit.

PROBLEM SET C:

1. The amount of current flowing in any electrical circuit depends on two things. What are they?

2. What happens to the current in a circuit when

   a. the resistance is increased without changing the voltage?

   b. the voltage is increased without changing the resistance?

   c. when the resistance is increased by a factor of two?

   d. when the voltage is decreased by a factor of four?

3. A resistance of 12 ohms is connected across a 3-volt battery.

a. Draw the circuit diagram.

b. What is the current in the circuit?

4. What is the resistance of a lamp that operates on a 120-volt line and carries a current of 3 amperes?

5. What voltage is needed to produce a current of 2.5 amperes in a 44-ohm toaster?

6. The following data are measured for a certain electrical device.

current	0.28	0.46	0.98	1.42	1.68	amperes
voltage	6.9	11.5	24.3	35.8	41.7	volts

a. Graph the data, using current for the horizontal coordinates, and draw a "best" straight line through the points.

b. Use your knowledge of slope and Ohm's Law to determine the resistance in the circuit.

c. What is the current in the circuit if the voltage is set at 1.5 volts?

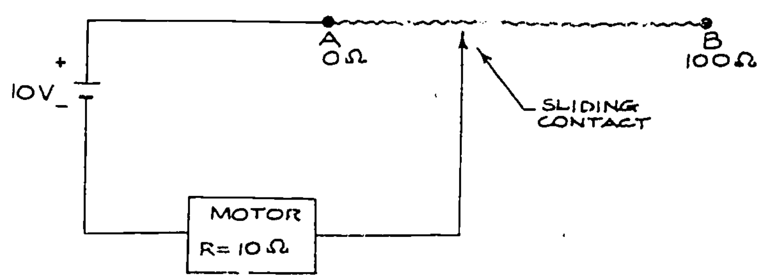
7. A uniform high-resistance wire, 10 meters long, is connected to the terminals of a 12-volt battery. If the resistance of the wire is 24 ohms per meter,

a. what is the total resistance of the wire?

b. what is the current in the wire?

c. how long must the wire be to permit a current of .0[illegible] ampere?

8. An electric motor is shown connected in the circuit diagram below. The speed at which the motor turns is directly dependent on the amount of current flowing through the circuit; the greater the current, the faster the motor turns. A uniform high-resistance wire, the resistance of which may be varied between 0 and 100 ohms by moving the sliding contact, is also shown.



a. In which position of the sliding contact will the motor turn the fastest?

b. What is the total resistance in the circuit when the motor is turning most rapidly? (The resistance of the motor must be added to that of the high resistance wire to obtain the correct result.)

c. What is the current when the motor is turning fastest?

d. What is the current when the motor is turning slowest?

e. What is the current when the sliding contact is set halfway between A and B?

f. What is the voltage drop across the motor when the motor is turning fastest?

g. What is the voltage drop across the high-resistance wire when the motor is turning fastest?

h. What is the voltage drop across the high-resistance wire when the motor is turning slowest?

SECTION D: ELECTRICITY IN THE BODY

D-1 The Electrical Nature of the Nervous System

How are voltages and currents produced in the body? What is the role of electricity in the body?

In Sections A through C, we have discussed electrical devices such as batteries, light bulbs, loudspeakers and computers. Although these devices are extremely useful, electricity plays a role of even greater importance in the human body. In the body, the chief role of electricity is in the transmission of nerve impulses. Since the nervous system controls heartbeat, breathing, and body movement and since the nervous system is involved in all thought processes, electricity is involved in virtually everything we do.

How is electricity conducted through our bodies? In our body fluids are many ions that are free to move about. Among the most common are Na^+, K^+, and Cl^-. If a voltage is applied to the body, ions such as these move in response to the voltage and create electrical currents.

Normally, however, these ions function in a different way. Rather than simply responding to voltages applied to the outside of the body, ions are used by the nervous system to produce voltages inside the body. To understand how this can occur, let us examine the functioning of a single nerve cell.

Like all other cells, a nerve cell is covered with a thin membrane which is permeable to water and certain ions. The cell is capable of producing a potential difference across this membrane. It does this by using chemical reactions (active transport) to regulate the concentration of ions on either side of the membrane. The result is that the inside of the cell is negatively charged with respect to the outside.

The inside surface of the membrane contains many organic molecules that are negatively charged. The outside of the membrane, on the other hand, has a positive charge which is due to an excess of positively charged ions (see Figure A). You might expect that the positive ions would migrate through the membrane since (1) they are attracted by the negative charge on the inside, and (2) they tend to diffuse to where their concentration is low. However, in nerve cells, this separation of charge is maintained by active transport reactions. The nerve cell membrane is similar to a tiny battery, since it uses chemical reactions to maintain a region of surplus charges. The potential difference across the membrane of a resting nerve cell is approximately 70 millivolts. (A millivolt equals 10^{-3} volts.) A membrane that is maintaining this kind of charge separation is said to be "polarized."

When a nerve cell is stimulated (as, for example, when your skin is touched) the polarized condition of the nerve cell changes (B in figure on the following page). The membrane becomes very permeable to positive ions, which rush into the cell, both because they have a natural tendency to diffuse to a region of lower concentration and because they are attracted by the negative charges on the inside of the cell. Positive ions keep entering the cell until the inside is positive and the outside is negative (C in the figure on the following page). Then, soon afterward, the nerve cell re-establishes its original balance of charge (D in figure on the following page).

This reversal of charge is not confined to one location on the nerve cell. Instead, it moves along the membrane at fairly high speeds from one end of the cell to the other. Some nerve impulses move at speeds greater than 100 meters per second. When the impulse reaches the end of the cell, the membrane releases chemicals that either stimulate another nerve cell, cause a gland to secrete or cause a muscle to contract, depending on where the nerve goes. A nerve impulse is thus an electrochemical change which carries a message as it travels along the cell membrane. Large combinations of nerve impulses are used each time we move a muscle or use any of our senses such as hearing, tasting or seeing.

Nerve impulses are also used by the node located in the heart which controls the heart rate. The sinoatrial node is composed of a special kind of tissue that has some of the properties of both nerve and muscle. This neuromuscular tissue produces electrical impulses which initate the contraction of the heart muscle. Although the voltage of the node tissue is produced in the same fashion as in nerve cells, the potential difference is somewhat higher--approximately 90 millivolts.

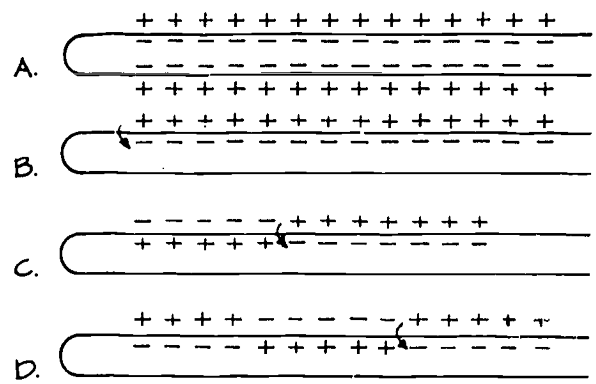


Diagram of a nerve impulse. (A) The resting nerve cell is polarized; the inside of the membrane is negatively charged with respect to the outside. (B) When the cell is stimulated, positive ions rush through the membrane. (C) The charge on the two sides of the membrane becomes reversed. (D) The membrane quickly returns to its original state.

Note that there are important differences between the flow of current in wire and in a nerve. The current in a nerve travels across a membrane, and not along the length of the nerve. (The nerve impulse, however, moves along the length of the nerve. The impulse corresponds to depolarization along the length of the nerve.) The charged particles are ions and not electrons. And, although nerve impulses travel very quickly, electricity in a wire moves more than a million times as fast.

Also note that our bodies do not derive energy directly from the current in the way that an electrical device uses the energy of moving electrons. The nerve impulse is only a signal that moves along the length of the nerve cell. When it reaches the end of the cell, it starts a sequence of chemical reactions that stimulate either another nerve cell or a muscle. If another nerve cell is stimulated, then the impulse continues in the new cell, and the signal moves farther along. But if the impulse stimulates a muscle cell, then a new sequence of chemical reactions begins, and these chemical reactions--in the muscle cell, not in the nerve cell--are the source of energy which the body puts to use. Thus, a nerve impulse is not an energy source, but a signal that "turns on" an energy source.

To summarize, voltage in the body is a result of the accumulation and separation of charged particles. This typically occurs in nerve cells, where the distribution of charges is controlled by chemical reactions in the cell membrane. The movement of these charges into or out of any region constitutes an electrical current. Thus, as a result of many ion transfers which occur in neural, muscle and neuromuscular tissue, the body is full of varying voltages and currents.

The voltages produced in the body can be detected by electrodes attached to the skin. The voltages are very weak by the time they reach the skin's surface--only a few millivolts at most. However, the signals detected by the electrodes can be amplified and recorded with special equipment. As discussed in Unit III, Circulation, the record of the electrical activity of the heart is called an electrocardiogram and is used to detect abnormalities in the heart action. Similar equipment can be used to detect abnormalities in the electrical activity of muscle and brain tissue.

D-2 Current That Kills

How is death caused by an electric shock?

A current of about ten amperes flows through an electric iron while it is heating. A kitchen blender as it struggles to blend may draw three or four amperes. A 60-watt light bulb gets by on about half an ampere. Yet a current of only a tenth of an ampere flowing through the body of a human being is enough to bring on a fatal ventricular fibrillation.

Ventricular fibrillation is a disorganized spasm of the heart muscle. The quivering heart muscle is not effective in pumping blood, and death comes quickly unless "defibrillation" can be accomplished. Interestingly, although one electric shock can kill, another can save. A defibrillator makes use of a "countershock" --a carefully controlled, brief electric discharge that returns the heart to its proper rhythm.

Heart failure resulting from ventricular fibrillation is the most common cause of death from electric shock. However, death may also result from respiratory failure. A large-enough current passing through the respiratory center in the brain can disrupt breathing and result in death by suffocation unless artificial respiration is used to revive the victim.

An electric shock can affect nerve tissue anywhere in the body. A current can disrupt the resting state of large numbers of nerves causing wild and disordered combinations of nerve impulses. When these impulses reach the muscles at the ends of the nerves, the muscles contract uncontrollably. This is one reason why electric shock is so dangerous. If an electrically "hot" object is grabbed with a hand, the current flowing through the hand can make it impossible to let go of the object. Large currents can also cause severe burns, although such burns, by themselves, are rarely fatal.

The effects of various currents flowing through the body are difficult to establish with any certainty. The effects of an electric shock differ from person to person depending upon the physical condition of the victim and the duration of the current flow. Consequently, the current values provided in the following table are, at best, estimates based on available evidence.

EFFECT OF A CURRENT FLOWING FROM ONE HAND TO THE OTHER

CURRENT IN MILLIAMPERES	OBSERVED EFFECT
1	tingling sensation
16	limit above which subject cannot let go
50	pain and possible fainting when applied for one second
100	ventricular fibrillation when applied for one second

How does a nerve impulse differ from the flow of current in a wire?

What role does electricity play in controlling the heart beat?

What are the two most common causes of death from electric shock?

SECTION E: ELECTRICAL SAFETY IN THE HOME

E-1: House Voltage Supplies

How is electricity supplied to the home? What is meant by a "grounded" connection?

Although electricity can be of great benefit to each of us, it can also be very dangerous when used improperly. If the wiring in a house or electrical appliance is faulty, electricity can start fires or cause severe shocks. In the United States during a recent year (1973), there were 171,000 electrical fires, which caused $332 million in damage. In fact, more fires are caused by electricity than by any other single cause. Since electrical accidents are often a result of poor safety measures, it is important to understand how electricity is supplied to buildings such as your home, school or hospital.

Until this point we have discussed only the flow of current in one direction. Such a current is known as direct current and is abbreviated DC. In the home, a different type of current is used; it is called alternating current, abbreviated AC. Alternating current refers to electrons flowing first in one direction, then in the reverse direction, then forward again, and so on. The changes in direction result from the way the electricity is produced at the generating station. The advantages of alternating current over direct current will be discussed shortly.

As you may have guessed, an alternating current in a wire cannot occur unless the voltage is also changing. A typical electrical outlet in the home provides an alternating voltage which in turn produces the alternating current.

Just as a battery has two terminals, so an electrical outlet must have at least two connecting points. Inside an electrical outlet, the two contact points are connected by wires to two power lines which provide the building with electricity. One of these power lines is commonly connected to the earth, usually by contact with a metal rod that has extensive contact with the ground. This power line is said to be grounded, since it is at the same electrical potential as the earth. In most circuits, voltages are measured with respect to "ground;" consequently, anything connected directly to ground would be at a potential of zero volts. In circuit diagrams, ground potential is indicated with the symbol, ⏚ .

The potential of the other line in an electrical outlet alternates between being greater than ground potential and less than ground potential. The effective value of this alternating potential in most buildings is 120 volts.

If an alternating voltage of this sort is connected across a resistance, it produces an alternating current. As the potential difference alternates between positive and negative, the current moves first in one direction and then in the other.

Certain devices such as an electric stove work just as well with alternating current as with direct current. For other applications, the AC may be easily converted to DC when it is required. Almost all instrumentation, as well as radios, television and computers use direct current.

Having the current surging back and forth many times a second, with the voltage alternating above and below ground potential, may seem unnecessarily complicated. However, alternating current has one distinct advantage over direct current. The voltage supplied with the alternating current may be adjusted to other values more easily than is the case with DC. For example, power lines may leave a generating station with a voltage of 200,000 V or more. Near a town being supplied by the system, the voltage is reduced to perhaps 7000 volts for safer and easier transmission around town. Then near each group of homes to be served, the voltage is reduced again to 120 volts.

E-2 Electrical Safety

How can the hazard of electric shock be avoided? How can faulty electrical wiring cause a fire?

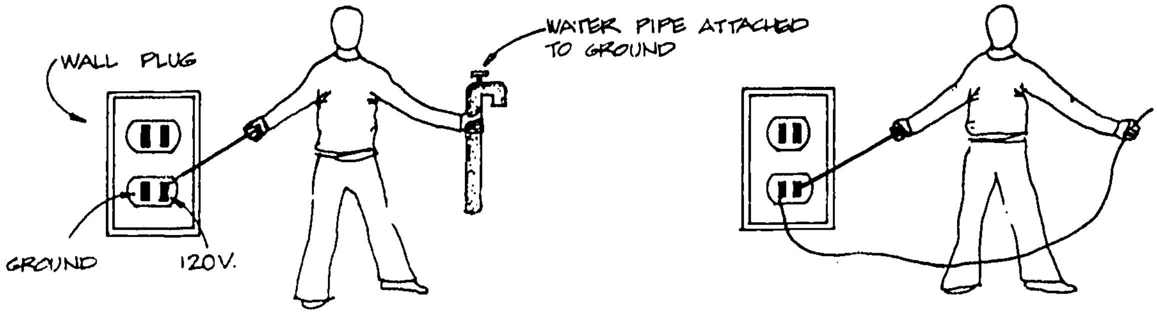
Electric shock can be most unpleasant and occasionally fatal. Fortunately, it can usually be avoided if sensible safety precautions are used. Knowledge of electricity can help you to avoid becoming part of a dangerous electrical circuit.

As with any electrical device, the flow of current through the body requires the application of a potential difference between two points on the body. In the home this is likely to occur in either of two ways:

1. by being connected to both of the two contacts in an electrical outlet or,

2. by being connected to the ungrounded wire of an electrical device, and a conducting surface in contact with the ground such as a water pipe or wet concrete.

Both of these possibilities are diagrammed on the following page. In both cases, the potential difference across the body is 120 volts.



The severity of any electric shock depends on the amount of current that flows. What determines the amount of current? Ohm's Law tells us that the current depends in part on the resistance in the circuit. The inside of our bodies conducts current very well, and consequently, we need help from some source of resistance. Fortunately, each of us is covered with a layer of skin, which is a comparatively poor conductor.

The amount of resistance provided by the skin depends partly on the surface condition. A dry skin with its natural film of oil is a much better insulator than sweaty skin. Sweat, which contains sodium and chloride ions, is a rather good conductor. (This fact, incidentally, underlies the operation of the lie detector.)

The skin resistance also depends on the area of contact with the voltage source. The larger the area of contact, the greater the flow of current. This can make a substance such as fresh water, which has a rather high resistance, electrically dangerous. A person standing in a bathtub filled with water has a large area of contact between the skin and the water. The water is connected to the ground through the drainpipe. If a person standing in water reaches out and touches a 120-volt line (for example in a defective light switch or radio), a dangerous amount of current would flow through his body and into the ground via the water and the pipe.

As another example, imagine that you are standing on a wooden floor while wearing dry shoes and socks. You would probably not feel the current flowing through your body when a 120-volt line is touched. The high resistance of the footwear and floor would limit the flow of current through your body to a safe level. If this high resistance is removed, the picture changes radically. If your shoes and socks are removed,and the wooden floor is replaced with a wet concrete slab, then the only protective resistance remaining would be your skin. In such a situation, your skin would probably not provide enough protection to prevent a severe shock.

Clearly, the skin cannot always provide enough resistance to pro[illegible]. When working with electrical systems it is wise to place a layer of resistance between the skin and the voltage source. For example, rubber gloves provide good protection when handling electrical wiring. Rubber is a very poor conductor, and therefore the gloves provide enough resistnace to keep the current at a safe level.

Voltage also has an important effect on the current flow in a circuit. For example, it is unlikely that the 12-volt battery in a car would deliver a dangerous shock. Unless the skin is punctured, the relatively small voltage would not produce enough current to cause harm. However, in the home where the voltage of a wall outlet is 120 volts, it is important to have protective resistance between the body and the electric current.

Old electrical wiring in a home can be the cause of dangerous accidents. If the insulation around a wire is worn or frayed, the wire can come into contact with a person and cause a shock. Or, the wire can contact a piece of metal such as the case of a toaster, making the toaster dangerous to touch. Another of the potential hazards from such a situation is known as a "short circuit." A short circuit occurs when the two wires leading from an electrical outlet come into direct contact. In such a case, there is almost no resistance in the circuit, and a very large current flows. The energy from the moving electrons can create a large spark or seriously overheat the wires, thus causing a fire. In order to prevent such situations, our homes are equipped with devices that shut off the electricity if the current flowing in a wire is too high.

One such device is a <u>fuse</u>. A fuse contains a special wire that melts in the presence of a large current. The melted wire creates a gap in the circuit which prevents any further current flow. The fuse may be replaced and will not " blow" again if the problem has been corrected. Modern buildings more often use circuit breakers, which are not destroyed when they "break" the circuit. These can be re-set rather than thrown away.

How do alternating current and direct current differ?

How is an electrical device grounded?

What safety precautions can be taken to prevent a dangerous shock?

How does a fuse on a circuit breaker prevent electrical fires?

VOCABULARY:

alternating current--an electric current that reverses direction at regular intervals; abbreviated AC.

circuit breaker--a switch that automatically shuts off when the flow of current in a circuit exceeds a safe level; circuit breakers may be re-set after correcting the electrical problem.

direct current--an electric current that flows only in one direction; abbreviated DC.

fuse--a device that contains a special wire that melts when the flow of current exceeds a safe level; the fuse must be replaced in order to continue the operation of the circuit.

ground--any part of an electric circuit that is connected by a conductor to the earth; the potential (zero volts) relative to which voltages in a circuit are measured.

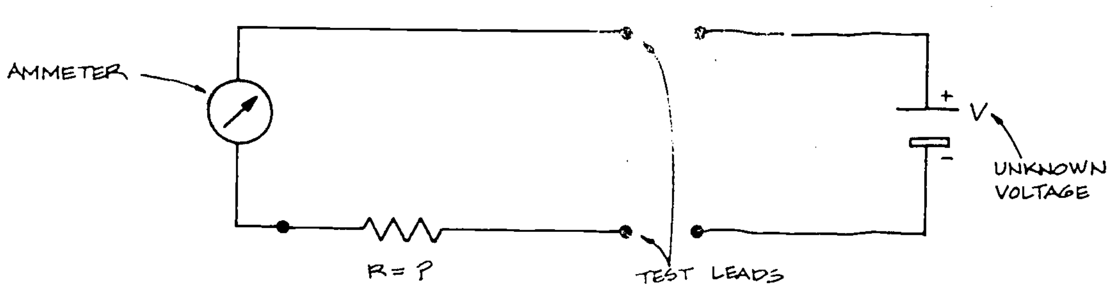
PROBLEM SET E:

1. A D-size flashlight battery, rated at 1.5 volts, is capable of producing a current of 500 milliamperes in a flashlight bulb. If this same current passes through the body of a human, the result could be fatal. Yet flashlihgt batteries are safe to handle. Explain why this is so.

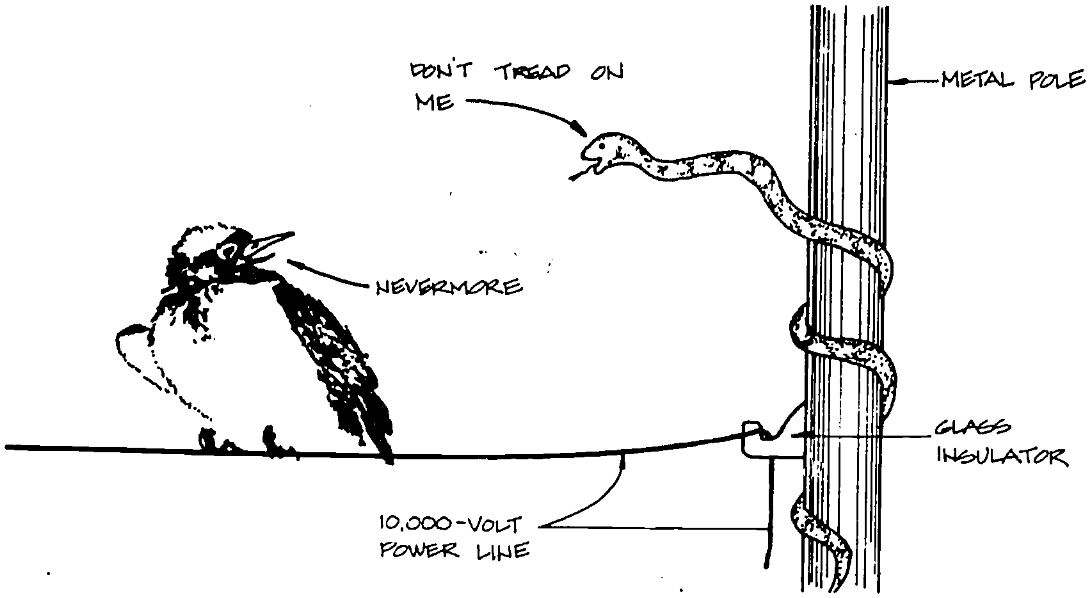
2. An ammeter (a device with which current may be measured) has a dial which reads from 0 to 100 milliamperes. By attaching a resistor to one of the test leads and then attaching the test leads to an unknown voltage, it is possible to use the ammeter to measure the unknown voltage. (See the diagram below.)

a. What resistor would be needed to provide a range of measurement from 0 to 100 volts?

b. What resistor would be needed to provide a range of measurement from 0 to 1 volt?



3. As shown in the figure, a bird is perched on a 10,000-volt power line that is supported by a glass insulator attached to a metal pole. The pole is anchored in the ground.



a. How does the bird avoid a lethal electric shock, even though it is touching the metal of the high-voltage wire?

b. What will happen when the snake grabs the bird?

4. Ima Nome, standing in a puddle of water in her basement, reaches out to switch on a light bulb. Unfortunately, the light switch is defective, and Ima's hand comes in contact with a 120-volt line.

a. Is Ima likely to receive a dangerous shock? Explain.

b. Assuming that the resistance to the flow of current through Ima's body is about 6000 ohms, what current flows through her body?

c. Is the current calculated in b likely to be fatal? Explain.

d. What current would flow through Ima's body if she had been wearing rubber gloves? Assume that the resistance provided by the gloves is 10^{17} ohms.

e. Assuming that Ima had no way of knowing that the switch was defective, how could she have best protected herself from a shock?

5. Fred was driving his car a little too fast one afternoon when he skidded off the road into a pole that supported high-voltage wires. One of the wires came crashing down and landed on the roof of his car. The wire had an electric potential of about 5000 volts different from that of the earth. At first, Fred was surprised that he hadn't been electrocuted, for he certainly had been in contact with metal parts of the car that the wire was touching. He decided that he had just been lucky.

a. Why didn't Fred receive a shock when the wire landed on the roof of his car?

b. What could happen when Fred opens the door and steps out of the car? Explain your answer.