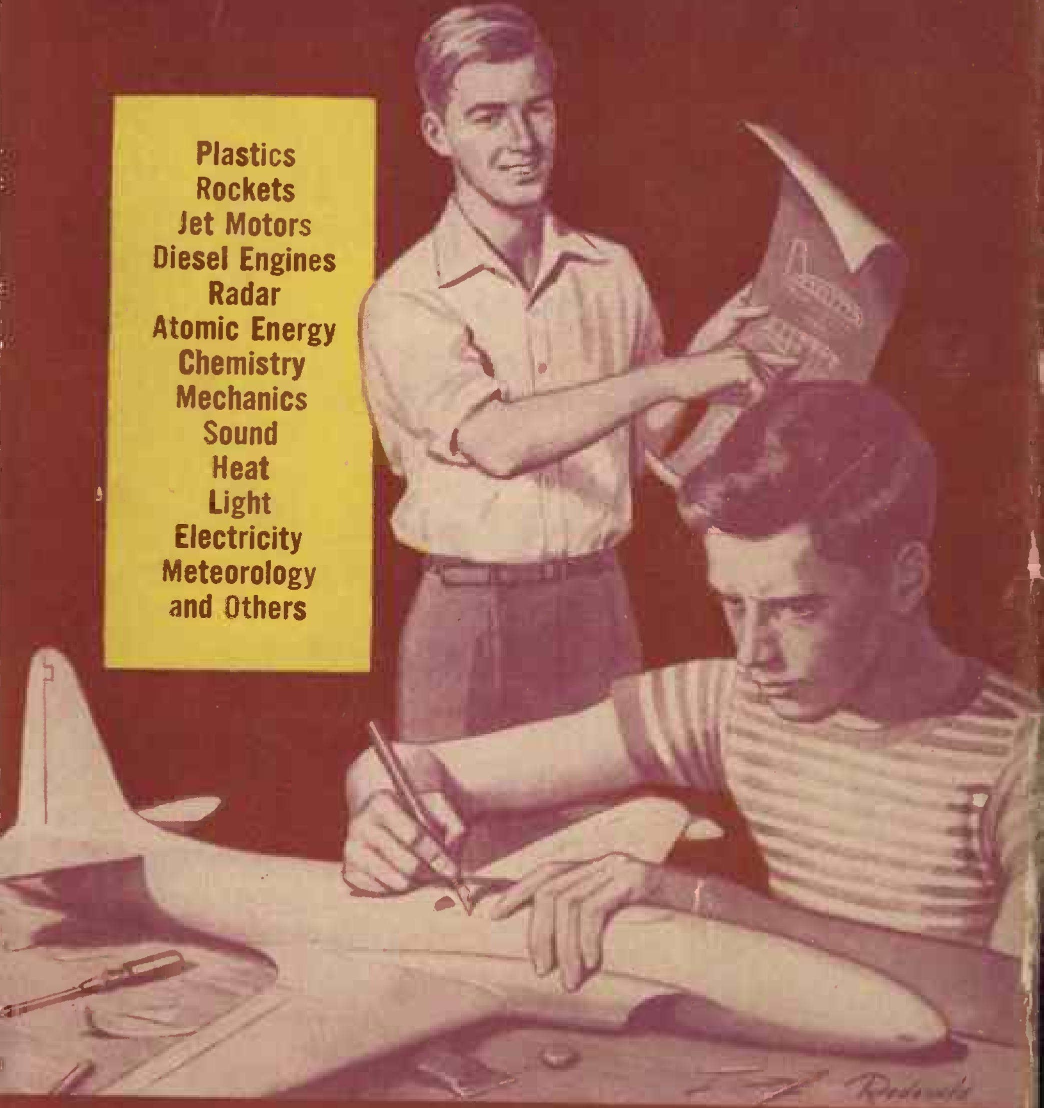
BOYS' BOOK of SCIENCE and CONSTRUCTION

by ALFRED P. MORGAN

Plastics
Rockets
Jet Motors
Diesel Engines
Radar
Atomic Energy
Chemistry
Mechanics
Sound
Heat
Light
Electricity
Meteorology
and Others



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by ALFRED P. MORGAN

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LOTHROP, LEE AND SHEPARD CO., INC.
NEW YORK

BOYS' BOOK OF SCIENCE AND CONSTRUCTION

BY

ALFRED P. MORGAN

AUTHOR OF THE BOY ELECTRICIAN

ILLUSTRATIONS AND WORKING DRAWINGS
By THE AUTHOR

REVISED EDITION

LOTHROP, LEE & SHEPARD CO.

NEW YORK

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BOYS' HOME BOOK OF SCIENCE AND CONSTRUCTION

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BOYS' BOOK OF SCIENCE AND CONSTRUCTION

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BOYS' BOOK OF SCIENCE AND CONSTRUCTION

CHAPTER I

A CHANCE FOR ADVENTURE

I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore and diverting myself in now and then finding a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.—Sir Isaac Newton.

Deep in the heart of almost every boy lies an instinct for adventure, a love of the unknown and a desire to know the secrets of things. Whether a farm boy, city lad, millionaire's son, or newsboy, the hankering after strange ventures takes all, some only in imagination but others in reality, to the far corners of the four winds. They want to know the stars and the seas as travelers, not as astronomers or geographers; and the birds and live things as hunters, not as scientists.

In all ages there have been pioneers and adventurers. These have been men who have gone out on new and strange journeys and through their work have benefited the people of the world. Thus, Columbus discovered America and the early English settlers colonized New England and Virginia. In the same way, inhabitants of this country pushed West and made new homes beyond the Alleghenies and the Rockies.

There you have the whole thing in a nutshell. *These old pioneers left everything behind them in order to push forward into the unexplored wilderness beyond.*

The young reader of this page cannot leave home to go to Africa or some other far-away place in order to find a frontier whence he may push into the great unknown beyond. It is not even necessary. There is, right at home, a wonderful borderland which needs exploring, and the boy who passes along the frontier which exists on the edge of a land called *Science* has an opportunity for adventure which far surpasses almost anything else of the sort that he might desire.

Every boy probably knows a little bit about electricity, mechanics, chemistry, astronomy, etc. Some of you probably know so little that it does not seriously interest you, for it is not until you begin to approach the boundary line on the other side of which lies the Land of Science that you will become interested. Here is opportunity for real adventure.

Exploring the Land of Science

This Land of Science, as I have called it, is well worth some of your spare minutes. It is really a huge wilderness into which countless men have gone in exploration. The knowledge which they have brought back with them is one of our most precious possessions. This land is so huge that no man can even imagine going to its farthermost border.

The entrance to this great territory is right at hand, and is in such a strange place that you would hardly look for it there. It is wherever your toys, or those things which you use for amusement may happen to be. The very top which you spin on the sidewalk is a portion of the Land of Science which is just being explored and which promises many interesting adventures.

Have any of you ever heard of the *gyroscope?* It is really a sort of top. Every top exhibits *gyroscopic* action. That is why it stands up when spinning and falls down as it stops. A gyroscope is a top which is supported at both ends. You will per-

haps understand better by referring to the illustration in Figure 2 which shows a gyroscope spinning. If the wheel in the centre of the gyroscope is set to spinning by pulling a string, which has been wrapped around the shaft in the same manner as for spinning your top, the apparatus will exhibit many strange properties which it did not possess before the wheel

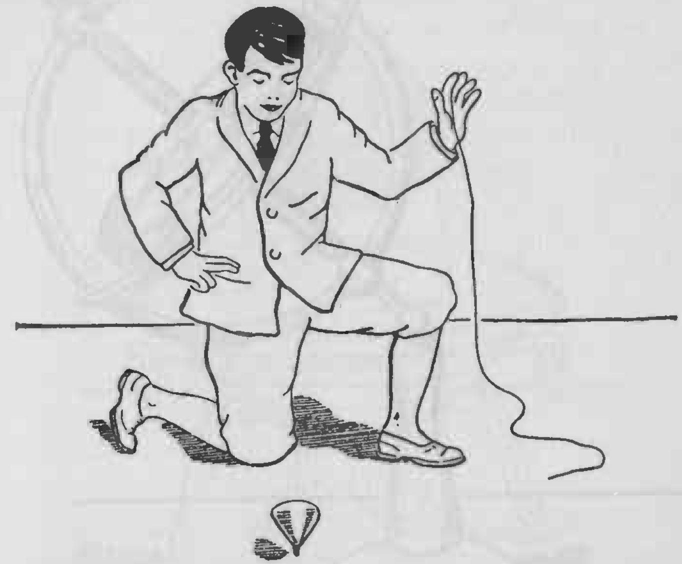


Fig. 1. — The top which you spin on the sidewalk is a portion of the Land of Science. A top stands upright on its point while spinning, by reason of its *gyroscopic* action.

started to spin. For example, if you pick it up in your hand by means of the framework and give it a sudden twist, you will find that it resists you and tries to twist back just as if it were alive.

Some explorer noticed this peculiar property of a spinning gyroscope to resist any attempt suddenly to change its position and tried to put it to good use.

As a result, gyroscopes now balance and steer airplanes and ships. It used to be necessary for a steersman or pilot to constantly shift the wheel of an airplane or ship so as to counteract the effect of the waves, currents, and winds, and keep the craft

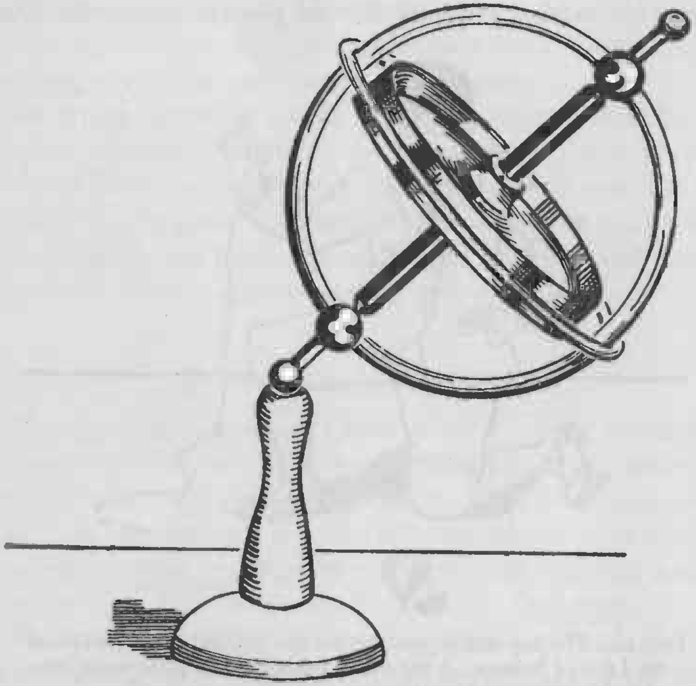


FIG. 2. — The gyroscope was once only a toy. Scientists and inventors who played with it learned how to use a gyroscope for balancing and steering ships and airplanes.

true to her course. Gyroscopes now tirelessly perform this duty far more accurately than men could. The gyroscopes used for this purpose are kept continuously spinning by means of an electric motor. They are mounted on very delicate pivots. After the ship's course is set, any slight tendency to turn to the right

or left, even an almost imperceptible bit, affects the gyroscope, and the latter by means of its resisting action, immediately sets into operation an electrical device which turns the rudder in the proper direction and corrects the course. This is only one

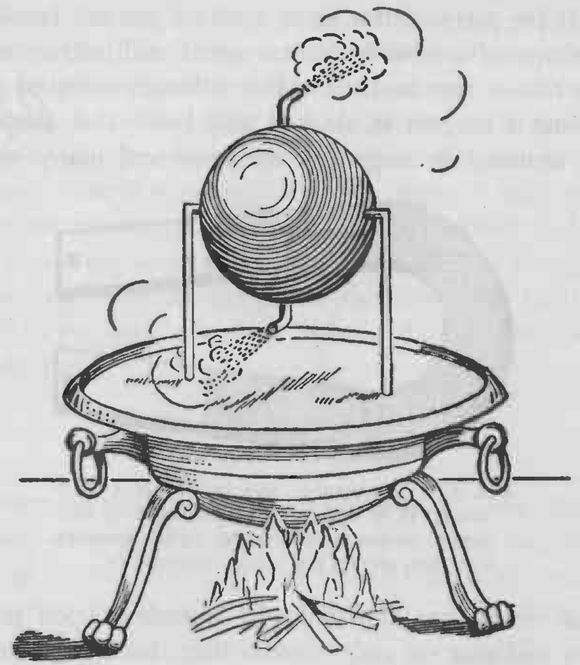


FIG. 3. — The Greek toy called an Eolipile was the forerunner of the modern steam engine. It consisted of a shallow vessel of water closed by a tight-fitting lid and connected to a hollow ball by tubes. When heat was applied and the water boiled, steam escaping from the jets caused the ball to revolve.

of the many useful purposes of the gyroscope which have been discovered during the past few years.

Two thousand years ago the steam-engine was a toy. The ancient Greeks used to play with a toy in which a jet of steam caused a wheel to rotate. They never dreamed that this simple device was the germ of something which would replace slaves and finally make possible the great factories, railroads, steamships, and other such things of our day.

Another toy which is on the borderland between you and science is the permanent magnet most of you are familiar with in the shape of a steel horseshoe which will attract nails and tacks or bits of iron and steel. But although many of you may know what a magnet is, do you also know that telephone-receivers, automobile magnetos, dynamos and many wonderful

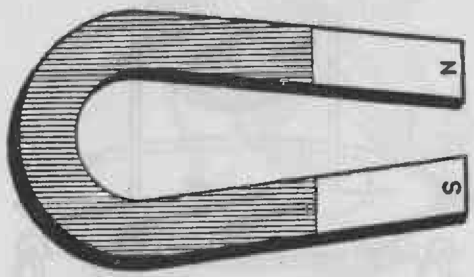


FIG. 4.—The magnet was once only a plaything. It is now an essential part of telephone receivers, magnetos, radio speakers, electrical meters and other instruments.

electrical instruments are entirely dependent upon permanent magnets and that we only possess them because some pioneer went adventuring and used his powers of observation and reasoning to bring them back from the Land of Science?

Some one had to observe intelligently those things to cause the Greek toy to become a steam-locomotive and the permanent magnet a telephone-receiver.

Oftentimes an apparently trivial thing which you may notice about some of those objects which surround you, especially your playthings, and for which there does not seem to be any useful application at present, may some day develop into a new invention which will prove useful to all humanity.

Don't despise the small ideas. They may prove of inestimable worth in an opportune moment.

If you build a toy steam-turbine, a telegraph set, or an electric motor, it is not the actual work which will prove of the most benefit to you, but rather your observance of the principles of those devices and the things which take place in your mind after you finish them and set them in operation.

Therefore, in telling you how to make batteries, steam-engines, chemicals, water-motors, barometers, and the many other things described in the following pages, I have not only presented the constructional details but have tried to be your guide in observing some of the apparently trivial things about the apparatus which should prove valuable clues to the trail that leads to the wonderland of Science if you have a mind to go adventuring.

Experimenting

For every mystery there is an explanation. We are sometimes a very long time in finding the explanation, but the more we know about the true meanings and properties of things, the more mysteries we are able to explain—and as soon as we can explain a mystery, *it ceases to be one.*

Whenever we want to find the answer to a mystery or anything which we do not know, there are two good ways of proceeding. One is to ask some one who does know or else to read what learned men may have discovered and written about it. The other is to *arrange an experiment and find out the answer ourselves.*

An experiment is not a conjuring trick, for the purpose of amusement, but is a *question which we ask of Nature,* and Nature is always ready to give a correct answer provided the question is properly asked by arranging the proper experiment.

Sometimes you must have good sharp eyes to get the right answer, but above all you must have a good "thinker," and a good "eye in the mind."

Experimenting will not only train your powers of observation but also your ability to reason correctly. Therefore, in the following pages you will not only find instructions for building various interesting devices, but also the method of performing many simple experiments which will be of the utmost worth to you in learning to use your own reasoning powers and in explaining the mystery of some of the wonderful happenings which occur every day around about you.

Theories

One of the first things that an experienced scientist, who wishes to solve a mystery or make an invention, does, is to form a *theory*. His *theory* is the probable explanation or principle existing in his mind which he thinks is the answer to his problem.

He then sets to work to prove his theory by means of experiments. The results of these experiments often make it necessary to discard the old theory and adopt a new one time and time again. Or, as has often been the case, one man's lifetime is not long enough to prove a theory and the work has had to be passed on to others.

Many thousands of theories, attempting to explain the wonders of science have been thrown away as only useful for the time being because they have ultimately been disproved. On the other hand, many others have resisted every attempt to disprove them and stand to-day in the light of Nature's laws or truths.

One of the advantages of a true theory is that it not only explains what has happened but *what will happen.*

The Science of Physics

This whirling old ball upon which we live, moves in a wonderful universe filled with many strange substances and amazing happenings.

When we first wake in the morning, we see light, then objects, hear sounds and become conscious that we are touching things. As the day progresses, our senses bring us into contact with innumerable substances and the many different manifestations of heat, light, electricity, chemistry, etc. Our familiarity with such things has led us to take them more or less for granted without stopping to think why various things happen, how they take place and how they may be related to one another.

But if my young reader stops for a minute to think seriously of the world around him, he is probably first amazed and then bewildered by the complexity of it all. Thousands of phenomena of all sorts, seemingly hopelessly entangled, confront him.

But one of the most persistent beliefs of mankind has always been that these things are not the intricate tangle that they seem, but that this is a harmonious, orderly universe with a well-defined principle back of every phenomenon. And so the brilliant and untiring minds of scientists have been patiently at work since the beginning of time, trying to unravel these mysteries. Progress has been slow, and made only step by step.

When we take advantage of all this painstaking work which has been done for us, and actually begin to sort things out, we find that instead of being hopelessly entangled, as they seemed at first, matters proceed with amazing smoothness, and our knowledge soon arranges itself into perfect order. Our knowledge has become *Science,* for science is simply classified or systematized knowledge.

In recent times, human learning has become so extensive and so complex that the truths which have been ascertained have had to be divided into groups. We, therefore, have the science of electricity or *classified knowledge of electricity,* the science of chemistry or *classified knowledge of chemistry,* and many other sciences covering the different groups of knowledge which mankind has painstakingly labored to acquire.

But no matter how many of these various sciences of *electricity, heat, light,* etc., and their branches there are, it soon becomes apparent that they have much in common and are all concerned with matter and energy. They all are actually part of the science of *physics.* Physics is the science that treats of matter, especially in its relations to energy.

Matter

If you were asked to define the word *matter,* you would probably stop and think for a moment and then say that matter is "stuff." This would be a poor sort of answer but the reason that you probably could not give a better one is not because you do not recognize matter when you see it or feel it, but rather because you do not really know what it is when you have recognized it. And in all fairness to you, it should be explained that just exactly what matter *really is,* it is impossible to say.

In order, however, that we shall have some uniform understanding, let us consider matter to be something which occupies space and possesses weight. Thus, wood, air, iron, water, etc., are matter and fill space. They can be weighed in pounds or measured in quarts or inches.

It may seem to you, upon first thought, that everything is matter; but light, heat, electricity, magnetism, etc., cannot be considered to fill so many quarts or to weigh so many pounds. They are therefore not matter.

If you apply this understanding of matter to some of the things which you see around about you, you will begin to realize that there is practically an endless number of forms of matter. Two hundred and fifty thousand would probably be a modest estimate of the number of things having properties that clearly differentiate them from every other thing.

All of these many forms of matter may exist in three states —solid, liquid or in the form of gas. Water is one of the most common forms of matter known to us in these three states. When it is frozen into ice, it is a solid, when melted, it is a liquid, and when vaporized, it is an invisible gas.

Air may be made so cold that it becomes a liquid like water or even a solid like ice. Gaseous air or gaseous water are just as real and as much matter as liquid air or liquid water. But gaseous water and air are invisible and are good examples of why we should not persist in thinking that anything which we cannot see or cannot feel is not real. If you put your hand out against the wall, you can feel it, but when you look at the wall, you cannot see that the space between is filled with matter which is just as real as that of which the wall is made. But this is a fact. It is filled with air.

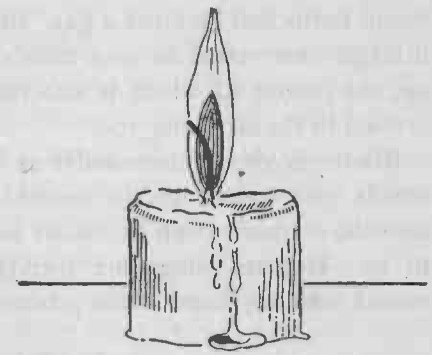


FIG. 5.— When a candle burns it disappears but the *matter* of which it was made still exists somewhere. Matter is indestructible.

There is a great fundamental law governing matter in all its varied forms which up to the present time has been absolutely iron-clad and unbreakable. This law is known as the *law* *of conservation of mass* and states that no particle of matter, even though it may be exceedingly small, can be created or destroyed by man or nature.

Consider such an apparently insignificant thing as a small chip of wood. You can crush it, burn it with fire, or consume it with acids and employ every apparently annihilating means or agency and yet the matter out of which that bit of wood is composed will still exist somewhere.

When you burn a candle it disappears. The wax or tallow is first in a solid state. It melts and becomes a liquid. The liquid burns and becomes a gas. Before the candle was burned, it might have rested on your table or desk. After it has burned up, the matter of which it was composed still exists, floating around in the air about you.

Matter is also as uncreatable as it is indestructible. In other words, you cannot create something out of nothing. If the creation or destruction of matter is taking place, it is unknown to us. Human beings are merely unwitting spectators and cannot take any hand in the process.

The Ether

All of you have no doubt been always more or less familiar with matter, but when we come to the subject of the ether it is probably a little strange because you have never had any evidence of its existence. In order for most of us to be aware of, or to believe in the existence of anything, we must be able to see it, hear it, taste it, smell it, weigh it, or feel it. In other words, it must be evident to our physical senses. When you are told that you cannot see the ether, or taste it, or feel it, or discern it with any of the physical senses, you may perhaps be inclined to doubt its reality.

You have already been warned against depending entirely upon the physical senses, and the fact of the matter is, that

while the ether is not evident to the eye, or touch, or nose, etc., it is visible to the "eye of the mind" which is much less likely to make mistakes than our physical organ of vision.

Many scientists once accepted the existence of the ether, not as a vague dream but as a reality, in order to explain the evidence that light and heat consist of *waves*.

The evidence that light and heat are *waves* could be readily given but it would lead away from the subject we are now considering.

If light and heat are waves, you will probably want to ask, waves *in what?* They must exist in *something*. This *something* cannot be any of those forms of matter which we are familiar with, for throughout the 93,000,000 miles which exist between our world and the sun there is space. There is no such thing as a real emptiness, however, and, according to the ether theory, this seeming space must be *filled* and filled to the brim with the *ether*. In every corner of the universe, wherever a star shines, in the centre of the earth or in a bar of iron, in our own bodies, the ether must exist. Everything must lie in a vast pool of the ether, not only surrounded by it but soaking it up as a sponge lies soaking in a pail of water.

Light and heat waves are supposed to take place in the ether and this is the something through which travels the light and heat, whether coming streaming down to us from the sun over the inconceivable distance of over ninety million miles or from a lamp a few feet or inches away from our eyes.

A word must be said in conclusion regarding the ether and the nature of light. The existence of the ether and the wavelike nature of light are both theoretical. In certain experiments light acts more as if made of tiny particles than waves. This has led to the "Quantum" theory which presumes light to be particles called *photons*. Neither theory has been proven. You can probably better understand the simpler wave theory.

Energy

Just as there is no such thing as emptiness, so there is no such thing as perfect rest. A bar of iron or a block of wood is not the solid it seems, but is made up of an enormous number of extremely small pieces, too small to be seen with the eye or the most powerful microscope, and which we will call for the present *particles.* These little particles are not at rest but are in a state of perpetual motion.

Now this restless motion is not the same at all times but is continually changing from one speed to another and the same kind of reasoning which leads us to believe in the ether leads us to believe that these *particles* can move faster or slower only because of some *cause.* This cause or power which changes the speed of the little quivering particles is called *energy.*

Just as there are different *forms* of matter, so there are different *forms* of energy. In the following list, remember that these are not *different energies* but *different forms* of the same energy.

1. Kinetic Energy
2. Gravitation Energy
3. Heat
4. Energy of Elasticity
5. Cohesion Energy
6. Chemical Energy
7. Electrical Energy
8. Magnetic Energy
9. Radiant Energy

We shall learn to recognize these different forms of energy later on. The principal thing to remember now is that one of these different forms may be converted directly or indirectly into any of the other forms.

A good example of the *conversion* of one form of energy into another is the *chemical* energy of burning coal which supplies *heat* energy to water in a steam-boiler. The steam passes into an engine producing *mechanical* energy, which in turn drives a dynamo creating *electrical* energy. This *electrical* energy may be finally converted into the *radiant* energy of an electric lamp.

Therefore wherever we find energy, there must have been some other energy. The great underlying law or principle of energy is very similar to that of matter. It is called the *conservation of energy* and states that energy can neither be created or destroyed.

CHAPTER II

CHEMISTRY

The Kitchen a Chemical Laboratory

THOSE things around about us, with which we are most familiar usually occasion the least thought and are regarded with the least wonder. We have, no farther away than in our own homes, a great many of the most interesting phases of science and by far the larger number of these take place in the *kitchen,* for you should realize that a kitchen is nothing more or less than a *domestic chemical laboratory.* A great many volumes would be required to embrace the present-day knowledge of chemistry, and this whole book would be necessary in order to give you the simple principles of it. Since no more than a single chapter can here be devoted to one subject, our experiments in chemistry will be confined practically to those common substances which are to be found in any well-equipped pantry and medicine-chest. The water, salt, and vinegar on the dining-table or the alcohol and iodine in the medicine-closet are no less chemicals because we eat them or apply them to our bodies to repair an injury than those substances with the long-sounding names to be found on the chemist's shelf. And that which takes place in the kitchen when yeast is put in the bread-dough is just as interesting a chemical process as the manufacture of some wonderful compound in a great factory.

Not only do many chemical processes daily take place in our kitchens, but we also have there the final result and benefit of a

great many elaborate chemical actions which have taken place elsewhere. The gas burning under the teakettle is undergoing a chemical change, but one of small importance in comparison with the things which have happened in the production of that gas.

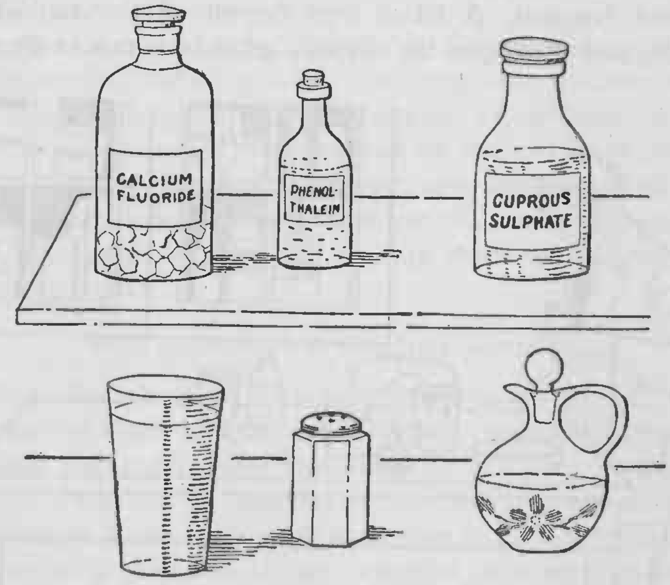


FIG. 6. — The water, salt and vinegar on a dining table are no less chemicals because we eat them than those substances with the long sounding names to be found in a chemist's laboratory.

If we consider some of these things, we shall find that it is possible to learn a great deal about chemistry with a kitchen table, some bottles, glass tubing, and a few substances right at hand.

When you study chemistry, however, you are investigating a particular branch of knowledge and it is well first to understand exactly what the science of chemistry concerns.

Chemical Changes

When air moves in a breeze or wind, and water moves in rain or tides, the air and water remain air and water. Their constitution is not changed by their motion whether fast or slow or however frequent. A bit of iron thrown off the roof of a building and striking on the sidewalk below is no new or altered

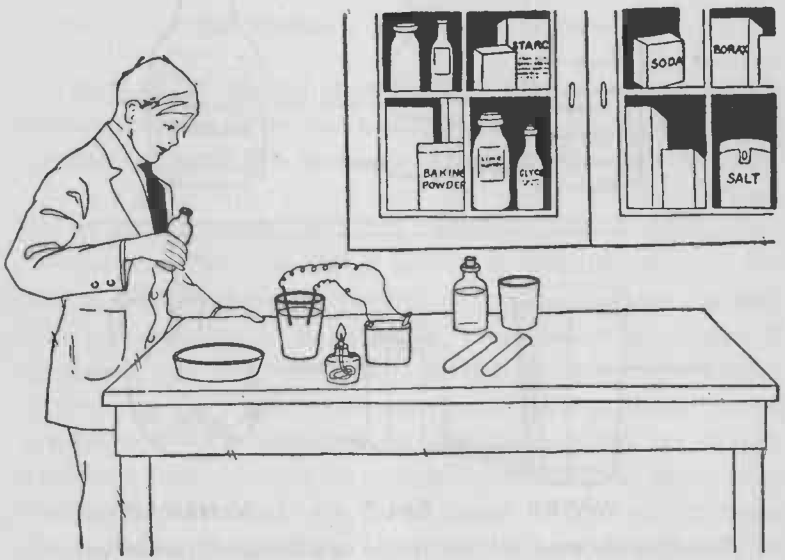


FIG. 7.—It is possible to learn a great deal about chemistry with nothing more than a kitchen table, some bottles, glass tubing and a few other substances right at hand.

thing but still a bit of iron. If broken into bits or reduced to filings, each small piece is still metallic iron. The molten iron in the foundry and the finished casting of a steam-engine are the same in substance, only differing in respect to temperature and shape.

But when a piece of clean iron is exposed to air and mois-

ture, it becomes covered with a brownish earthy coating which bears no outward resemblance to the original iron. The iron becomes *rusty,* at first only on the surface, but if allowed to remain in the air long enough the metal completely disappears and becomes entirely changed to the reddish-brown rust so that no iron, as such, is left.

A piece of coal, burning in the kitchen stove, soon vanishes, leaving nothing but a few ashes. Dead vegetable or animal matter, buried in the ground, decays and after a time disappears.

Changes of this sort in the iron and the coal and the vegetable matter involve alterations in the intimate constitution of the bodies which undergo them. What are the causes of these remarkable changes? What can we learn about them by experiment and study?

What the Science of Chemistry Comprises

Those changes which do not affect the composition of substances, as when iron is simply melted, are called *physical* changes and come under that branch of science known as *physics.* Iron rust is, however, not iron but *iron* and *oxygen.* The change which takes place when iron is allowed to rust or coal to burn gives rise to the formation of a *new substance* with new properties and is a *chemical* change, dealt with in the realm of chemistry.

Compounds and Elements

We have already learned that the number of different weighable, space-filling things in our world would probably reach the astonishing total of over two hundred and fifty thousand. Most of these substances are known as *compounds* because they are made up of more than one substance.

Ordinary water may be broken down into two invisible gases called *oxygen* and *hydrogen.* Common table salt may be decomposed into a silvery metal that floats on water, called *sodium,* and a greenish yellow gas called *chlorine.* In fact, almost every one of this one quarter of a million substances may be broken down into the simpler bodies of which they are composed. These simpler bodies such as the *oxygen* and the *hydrogen* of the water and the *sodium* and the *chlorine* of the salt have so far resisted all attempts to be decomposed themselves, and some ninety-six in all constitute what the chemist calls the *elements* of matter. Some of these elements may exist free or combined, as *iron, sulphur, copper,* etc., while others such as *calcium, fluorine,* etc., are always combined with some other substance and you never find them alone in Nature. Some elements are literally as common as dirt, while others are a thousand times scarcer than gold.

The important thing to remember is that these ninety odd elements unite in different ways and in different quantities to constitute all the *matter* that there is, whether here on earth or on the sun, moon, and stars.

Molecules and Atoms

If we take a bag of salt and a sharp knife we can easily divide it in half. We can keep on sub-dividing it until we have only a single grain of salt left. And we could split the grain of salt in half and keep on dividing its pieces into halves if we had eyes and instruments fine enough, until away down in the scale of fineness we arrived at a piece so small, that if it were broken in two, we should no longer have two pieces of salt resulting, but instead two pieces of two different elements, namely a piece of metallic *sodium* and a bit of the gas *chlorine.*

This small piece of salt, so infinitesimal that if it were broken in half, it would no longer be salt is called a *molecule* of salt. A grain of salt is therefore simply a large quantity of molecules of salt.

The little pieces or particles of sodium and chlorine which resulted when the molecule was broken, are called *atoms.* Molecules are made of atoms. There are as many different atoms as there are elements. Instead, therefore, of considering a compound to be a substance composed of elements, the chemist

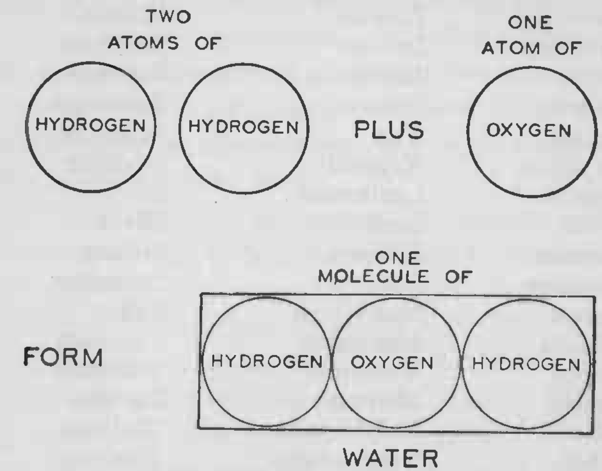


FIG. 8. — Diagram to illustrate that two atoms of hydrogen join company with one atom of oxygen to form a molecule of water.

considers it to be a substance, the *molecules* of which are made up of particles or *atoms* of the elements.

We can therefore reconsider a bit some of our first definitions which were given by way of explanation and call:

A molecule, the smallest piece of a substance that can exist without being divided into atoms,

An atom, the smallest particle of an *element* that exists in any molecule,

An element, a substance whose molecule contains only one kind of an atom, and

A compound, a substance whose molecule contains two or more kinds of atoms.

Atoms of the Elements

Actinium	Helium	Prototactinium
Alabamium	Holmium	Radium
Aluminum	Hydrogen	Radon
Americium	Illinium	Rhenium
Antimony	Indium	Rhodium
Argon	Iodine	Ruthenium
Arsenic	Iridium	Samarium
Barium	Iron	Scandium
Beryllium	Krypton	Selenium
Bismuth	Lanthanum	Silicon
Boron	Lead	Silver
Bromine	Lithium	Sodium
Cadmium	Lutecium	Strontium
Cesium	Magnesium	Sulfur
Calcium	Manganese	Tantalum
Carbon	Masurium	Tellurium
Cerium	Mercury	Terbium
Chlorine	Molybdenum	Thallium
Cobalt	Neodymium	Thorium
Columbium	Neon	Thulium
Copper	Neptunium	Tifanium
Curium	Nickel	Tin
Dysprosium	Nitrogen	Titanium
Erbium	Osmium	Tungsten
Europium	Oxygen	Uranium
Fluorine	Palladium	Vanadium
Gadolinium	Phosphorus	Virginium
Gallium	Platinum	Xenon
Germanium	Plutonium	Ytterbium
Glucinum	Polonium	Yttrium
Gold	Potassium	Zinc
Hafnium	Praseodymium	Zirconium

Atoms have been called the bricks of the universe, for out of them everything is built. The different names by which the

principal atoms are known to the chemist are given in the table above. You will find a great many old and well-known friends, such as oxygen, hydrogen, copper, iron, gold, nickel, radium, etc., among them. Others may not be quite so familiar because they are extremely scarce or, as is often the case, are quite common but disguised. Thus, *caesium* is fifteen times and *radium* thousands of times rarer than gold. Some others such as *krypton* and *samarium* are so scarce that they cannot be bought. Calcium and silicon are common elements which are usually disguised. They are silvery metals, yet we see them most often in the form of lime and sand.

Some chemicals, such as calcium and sodium, are very sociable and do not like to be alone but always join company with certain other elements as soon as possible. Such elements are said to have a strong *chemical affinity* for each other.

Another property of the elements is that they always like a certain definite amount of company and have the habit of associating with each other in definite numbers.

An atom of oxygen does not like to be alone, but tries to join company with another atom of oxygen.

Hydrogen is a lonely atom which travels around by itself, but if it joins company with an atom of oxygen much prefers that another one of its fellows be included in the group. Two atoms of hydrogen and one atom of oxygen in company with each other form a *molecule of water*.

It will be well to know something about how the different atoms group together to form the molecules of various substances, for the mere addition or subtraction of a single atom from a group results in a molecule of a substance having entirely different chemical properties. Although this is not exactly the way a chemist considers atoms and molecules, just for our own purposes, we will represent an atom as a little ball with its name on the side and a molecule as a box containing two or more atoms. We can then easily show how water is composed of two atoms of *hydrogen* joining with one atom of *oxygen* or how a molecule of salt is formed of an atom of *chlorine* and one of *sodium*.

Something About the Chemicals We Breathe

We are everywhere surrounded by an invisible gas which we call

Air. This is perhaps the most common substance with which we come into contact and, as human beings, we have an especial

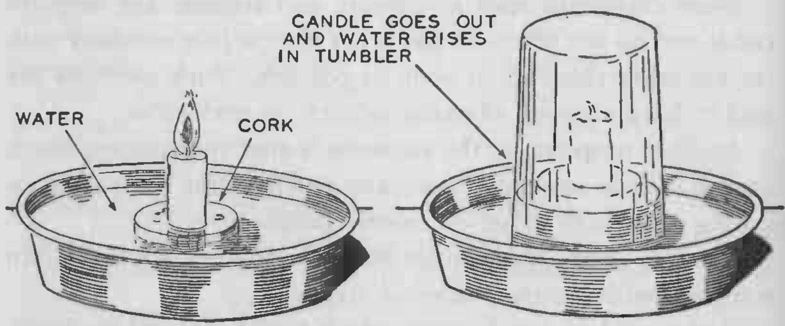


FIG. 9. — This simple apparatus will give a valuable clue regarding the composition of air. The candle will burn for a short time and then go out. The water will rise in the tumbler and there will be much *less* air enclosed in the tumbler.

interest in the composition of air because our living depends upon it.

When in motion, air is wind and we can easily recognize it by its effect on things. It raises dust, moves trees, and can be felt flowing against us. When air is not in motion, we cannot feel it, but it nevertheless exists in the stillest places. We often speak of bottles, boxes, etc., as being empty when in reality they are *full of air*. The presence of air in an "empty" bottle

can be shown by trying to pour water into a bottle having a narrow neck. The water will not run in easily. The bottle which we called empty, is in reality filled with air, and it is this air which prevents the water from entering easily.

Pure air is tasteless and odorless. Small quantities are colorless, but when in large masses, as in the sky on a cloudless day, it appears blue.

However, the real question which we are interested in is, of *what* is air composed. We can get a valuable clue by trying a simple experiment.

Place the lighted stump of a candle on a flat cork or block of wood floating in a shallow pan of water. Then set an inverted tumbler, jelly-glass, or fruit-jar over the candle.

The candle will burn for a short time and then go out. If you allow the jar to cool off you will find that the water has risen part way into it and there is much less air in the jar than in the beginning.

Why did the candle go out and what happened to part of the air which was in the jar? Something necessary for the candle flame to exist must have become exhausted and something originally in the air must have disappeared in order for the water to rise and take its place. How does the air remaining in the jar differ from that which was there before the candle went out?

This something is *oxygen* and that which remains in the jar is principally *nitrogen*. Air is largely a mixture of these two gases.

Oxygen is a transparent, colorless gas which cannot be distinguished by its appearance from atmospheric air. It is probably the most widely distributed element in Nature. It exists in very large quantities. It forms nearly one-half of the solid crust of the earth, about eight-ninths of the water and approximately one-fifth of the air. It enters largely into the composition of all plants and animals and is absolutely necessary to all animal and vegetable life.

When things *burn,* they *combine with oxygen.* When a stick burns, the carbon and hydrogen, etc., in the wood combine with oxygen. The compounds which are formed by the union of oxygen with other elements are called *oxides.*

The reason that the lighted candle, under the jar, went out is because the oxygen in the air became used up. The disappearance of the oxygen created a partial vacuum and drew the water in.

Nitrogen is also a transparent, colorless, odorless, and tasteless gas. Like oxygen, it is widely diffused in nature and constitutes an important part of all animal and vegetable life. But in its chemical behavior towards other substances, it is remarkably unlike oxygen. Oxygen has a strong chemical *affinity,* that is, it is active and aggressive and tries to combine with other substances, while nitrogen, at least when in the condition in which it exists in air, is quite inactive and indifferent as regards entering into combination with other bodies.

It extinguishes flames and destroys life. Animals, plants, and fire cannot live in an atmosphere of pure nitrogen. It is not poisonous, however, for if it were, it could not be breathed in such large quantities as exist in air. Animals, plants, and fires are killed in an atmosphere of nitrogen simply from want of oxygen.

The other substances in air besides oxygen and nitrogen are so small that they are almost negligible from the ordinary standpoint.

Argon is one of the principal of these. This substance is also a gas. There is only about one-hundredth part as much argon as there is nitrogen in the air. Besides argon, there are also found other much rarer gases and particles of dust. Some of the dust is *living* dust and some *inorganic.* The part which is in-

organic consists of coal dust, tiny shreds of cotton, refuse from the streets, etc. The living dust consists of bacteria, pollen, spores of fungi, etc.

Pure country air contains about three parts in ten thousand of a gas called *carbon dioxide.* The other gases which we have named have all been elements, but carbon dioxide is a *compound.* We shall learn more about this gas later. In the cities, there are from six to seven parts of carbon dioxide in every ten thousand of air, while in the air of a crowded audience room there may be nearly ten times as much.

At each breath we draw air into our lungs at the rate of about fourteen cubic feet an hour. The oxygen of this air is partly taken up by the blood, the remainder passing out again with the exhaled breath. The nitrogen is unaffected.

The exhaled air contains considerable carbon dioxide, which is formed when oxygen combines with carbon. This is another example of the strong affinity of oxygen. When it enters the lungs, it combines with some of the carbon of the body. Two atoms of *oxygen* join hands with one atom of *carbon* to form a molecule of *carbon dioxide.*

The Simple Chemistry of Water and the Gases of Which It Is Composed

Another natural substance, quite as common as air, is

Water. The great quantity of water which occurs in nature makes it one of the most familiar chemical substances. Three-fourths of the earth's surface is covered with it. The bodies of both animals and plants, and many minerals contain large amounts. A man has been described as consisting of about twelve pounds of ashes and eight buckets of water. A watermelon is ninety-six to ninety-eight per cent water. A world without water, would not only be a world without life, but would be utterly different from anything that we know. If we were to attempt to learn all there is to be known about this wonderful liquid we should have to study nearly everything there is on the earth, because the question of water comes into very nearly everything.

When you drink a glass of water, you have swallowed something that is probably older than anything else in the world. It existed before there was a blade of grass and before there was a living creature on the earth. Since it is such an important substance and the one which chemists use most, the few facts and experiments which we have space for here should be studied attentively.

At the ordinary temperature of the air, pure water is a transparent liquid without taste or smell. When in thin layers, it appears to be colorless, but large masses of it are blue.

Below 0 degrees on the Centigrade thermometer and 32 degrees on the Fahrenheit, water becomes solid and we call it ice. Above 100 degrees Centigrade or 212 degrees Fahrenheit, it becomes a gas or water vapor.

We have already learned that water may be broken down into two gases, *oxygen* and *hydrogen*. This can be accomplished by chemical means, but is more easily performed with the aid of electricity.

If an electric current is caused to flow through water, the force by which the component gases are held together will be overcome.

You can perform this experiment yourself. Figure 10 illustrates a very simple arrangement for proving that water is oxygen and hydrogen gas. It consists of a bottle with the bottom broken out and provided with a cork fitted snugly into the neck. Two carbon rods from old flashlight batteries pass through the cork. The carbon rods are connected to copper wires leading to two dry cells.

If the bottle is inverted and filled with water to which a small amount of *sulfuric acid* has been added, the current from the battery will *decompose* the water. Pure water is not a conductor of electricity and the sulfuric acid is added to form an *electrolyte* or a liquid which will conduct electricity.

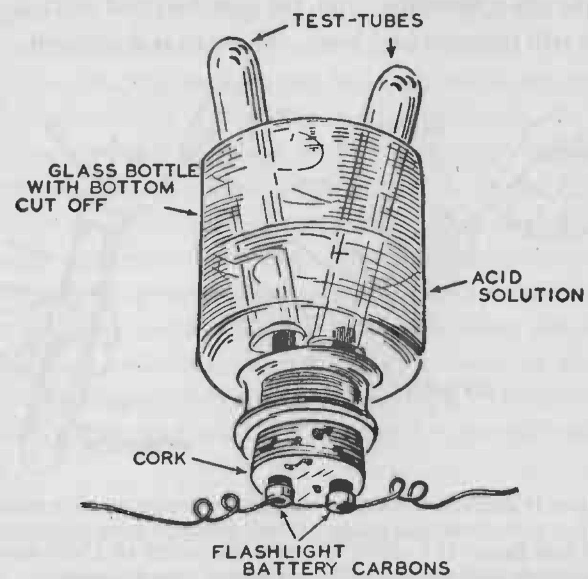


FIG. 10.—A simple apparatus for proving that water is composed of oxygen and hydrogen. It consists of a bottle with the bottom broken out and provided with a cork fitted snugly into the neck. Two carbon rods connected to two dry cells pass through the cork. When current passes through the acid solution in the bottle, the water is decomposed into oxygen and hydrogen.

As soon as the battery is connected, you will notice small bubbles start to rise from the platinum wires. They will rise more rapidly from the wires connected to the negative pole of the battery.

You can collect the gas by filling two test-tubes full of some of the water containing a little sulfuric acid and inverting one over each wire. As the gas rises in the tubes, it will displace the water and collect in the top. It will be found that twice as much gas collects in one tube as in the other. If the test-tube containing the larger volume of gas be closed with the thumb, turned mouth-uppermost, and the gas touched with a lighted match, it will take fire and burn. This gas is *hydrogen.*

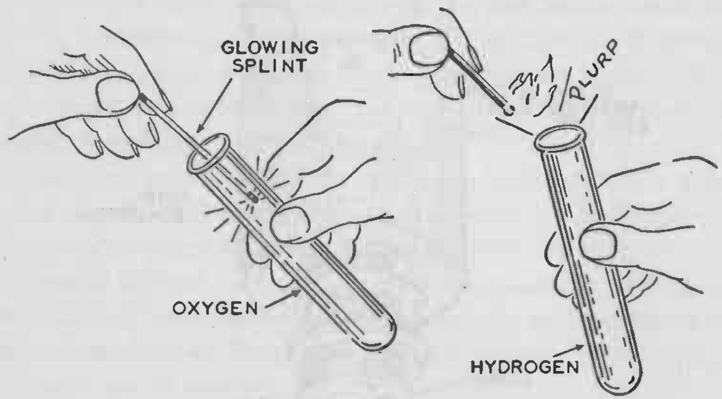


FIG. 11. — If a splinter of wood retaining a glowing spark is immersed in a test-tube containing oxygen, it will instantly burn brilliantly and burst into flame. If a match is held to the mouth of a test-tube containing hydrogen, the gas will burn with a "plurp" sound.

Hydrogen is a transparent, colorless and tasteless gas. It is odorless when pure. Animals die from suffocation when immersed in it from want of oxygen as they do in an atmosphere of nitrogen.

It is one of the lightest substances known, being 14½ times lighter than air. That is why a balloon is filled with hydrogen. Being lighter than the surrounding air, it floats. Water weighs about 11,160 times and mercury 151,700 times more than hydrogen.

The exceeding lightness of this gas can be illustrated by filling soap-bubbles with it as described in Chapter IV. They will rise rapidly through the air, and, if touched with a lighted match, will burst into flame.

The tube containing the smaller amount of gas is filled with *oxygen.*

Oxygen will not ignite and burn as hydrogen, but if the tube is held with the mouth uppermost and a splinter of wood retaining but a single glowing spark be immersed in the gas it will instantly burn more brightly and burst into flame.

It is thus proved that out of water may be made two volumes of hydrogen and one volume of oxygen.

Although water is chemically composed of these two gases,

Natural waters contain other substances which are *impurities.* Rain-water is the purest natural water, but contains nitrogen, oxygen, and carbon dioxide dissolved from the air. The gases which are *dissolved* in water may be seen by allowing a glass of drinking-water to stand overnight. In the morning, the sides of the glass will be found to be covered with small bubbles.

The foreign matters or impurities which water may contain may be divided into two kinds, dissolved matter and that which we call *suspended* matter. No water is free from either of these varieties of impurity. Distilled water is always employed in chemical laboratories, but it is impossible to keep it pure for any length of time, for even ordinary glass dissolves in water to an extent very noticeable to the chemist.

For all ordinary purposes, the suspended matter which water contains, may be removed by *filtering* or straining. In the chemical laboratory, this is accomplished by passing the water through a sort of blotting paper, the pores of which are so small that they allow the water to trickle through but hold back the suspended matter just as you may sort stones from sand through a piece of screen. The water which we drink is usually filtered on a large scale by being passed through huge beds of sand before being pumped into the reservoirs.

Impurities which are *dissolved* in water cannot be removed by ordinary *filtration,* but are eliminated by a process called *distillation.* This merely consists of boiling the water so as to change it into steam or vapor. The vapor is collected and cooled

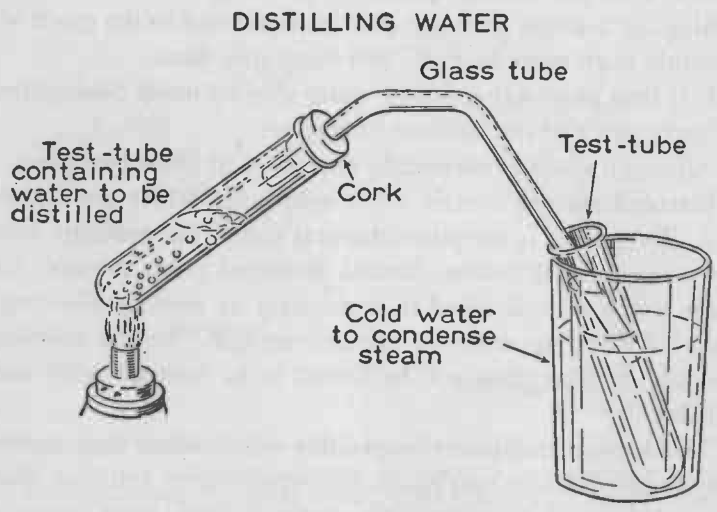


FIG. 12. — A simple distilling apparatus. Steam formed by boiling water in the left hand test-tube passes through the glass tube and is condensed into pure distilled water in the right hand tube.

or *condensed* so that it changes back into water again. The impurities remain behind and the result is distilled water.

The experimenter may readily improvise a simple distilling apparatus from two large test-tubes arranged as in Figure 12. One tube is provided with a cork through which a piece of bent glass tubing passes. The other end of the tube is inserted in the second test-tube, which is partly immersed in a glass of water so as to keep it cool and condense the steam.

Dissolve some salt in a cup of water and taste it. It will have the well-known salty taste with which you are familiar. Place some of this salt water in the first test-tube. In order to make the experiment a little more spectacular and better prove to yourself that distillation actually removes all of the impurities in water, add a few drops of ink so that the water is discolored. Then heat the test tube with an alcohol lamp or a Bunsen burner until it boils gently. Place the heat below the tube where the water will boil very gently and not rapidly enough to boil over into the glass tube. The steam which is formed will pass through the glass tube and be condensed, drop by drop into clean, pure, distilled water in the second test-tube. The color of the ink does not appear in the distilled water. Taste some of the distilled water when it has cooled and you will also find that it has none of the salty flavor. The salt and the ink have remained behind in the first test-tube or "retort."

Hard and soft waters. Well-water and that from springs, coming into contact with rocks and minerals in the earth dissolve some of these substances and therefore often contain compounds of the elements *calcium* and *magnesium* and are then said to be *hard.*

Ordinary soap dissolves readily in *soft* water, that is, water which does not contain calcium and magnesium. When soap is put into hard water, however, a new soap compound is formed which is insoluble and it is therefore difficult to wash with hard water.

Boiling hard water causes the calcium and magnesium along with the mud held in the water in suspension to *precipitate* or solidify and form what is known as "scale." If you boil hard water in a teakettle, the scale will form on the sides and bottom and after a long while become so thick that you can chip it off.

This same thing happens in boiler-tubes and causes a great deal of trouble. The scale forms on the inside of the tubes and is such a poor conductor of heat that it runs the coal consumption away up. Eventually the scale ruins the tubes. There are all sorts of compounds sold to prevent boiler scale, most of them designed to act on the water chemically and produce a scale that is lighter and porous, so that it is more easily removed by mechanical means.

A great many power plants avoid boiler scale by using in their boilers rain-water from the roofs. The exhaust steam

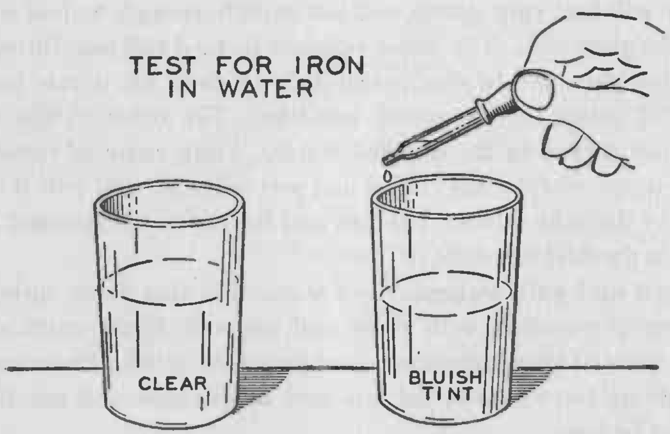


FIG. 13.—You can test water to see whether or not it contains any iron by adding a few drops of a solution of sodium ferrocyanide. If the water contains iron it will assume a bluish tint.

from the engines is then condensed back into water so that it can be used over again.

The water in some localities contains iron. If the percentage of iron is very high, it is very troublesome, especially when used for laundry work. It produces brownish streaks on clothing which show when ironed.

You can test your water supply and tell whether it has iron in it by means of a little *sodium ferrocyanide* which you can purchase at a drug-store.

Dissolve a small amount of the chemical in a tumbler of water which you wish to test. If the water shows a bluish tint, either at once or after standing a short time, iron is *present.*

The importance of water in chemistry. There are a great many interesting things known about water and an endless number of experiments which you might perform, but space does not permit mentioning them here. The important thing to remember is that water is the most frequently used substance employed by the chemist. In some cases, it does not play a chemical part, but is only a sort of mechanical adjunct for bringing other chemicals together through its property of dissolving many substances. In other words, when two or more chemicals desire to meet, water introduces them to each other.

Some Experiments with Common Table Salt

The salt-shaker in front of you on the dining-table contains a chemical substance which is so common and inexpensive that we hardly realize what an important and valuable thing it is. That which we know as *salt,* common table salt, is *sodium chloride* to the chemist. It is a substance which we cannot do without. When it is scarce, we prize it and when it is lacking, men will brave almost any danger to get it. It is an important item in the process of digestion. Its exact function there is not known, but it is probable that the *hydrochloric acid* which we have in our stomachs is prepared from the salt which we eat by the chemical factory each of us has in his body.

Aside from the importance of salt to the stomachs of men and animals, it has a great value as the raw material for some great chemical industries.

Common salt, which we have learned is a substance whose molecules are composed of one atom of a soft, silvery metal called *sodium* and an atom of gas called *chlorine,* forms more than two-thirds of the solid matter dissolved in sea-water, and sea-water contains nearly four per cent of solid matter in solution. Salt is therefore a very abundant substance.

Salt itself, as such, is not of great value to the chemist, but the two elements, *sodium* and *chlorine,* of which it is composed are very useful when in combination with other chemicals and

A METAL THAT DISSOLVES IN WATER

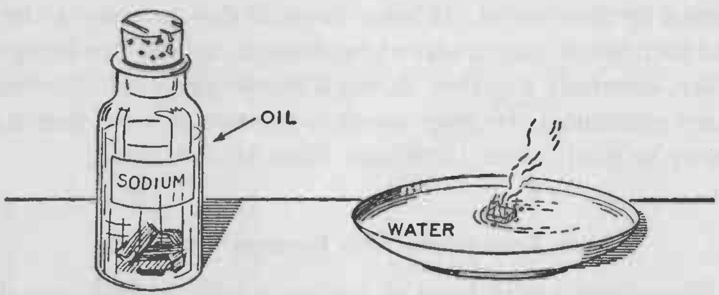


FIG. 14. — Sodium is a silvery metal which floats on water. As soon as it comes into contact with air or water, sodium burns. It is kept under oil to protect it from water and air.

it is very valuable as a raw material or source for obtaining these substances.

We will consider the chlorine by itself later on and devote our attention now to

Sodium, which has been already mentioned as a soft, silvery *metal.* Sodium is one of the elements but is never found in nature except combined with other substances. It cannot exist in contact with air or water but immediately takes fire and burns up. For that reason, it is always kept under oil in the laboratory. Although it is a metal, it is far from resembling ordinary metals in most respects. It is as soft as wax at ordinary temperatures and is lighter than water so that a piece of sodium floats like a block of wood.

When metallic sodium comes into contact with water a curious thing happens. It runs rapidly around over the surface of the water and exhibits such a strong *affinity* or tendency to unite with the oxygen atoms in the water molecules that it tears the molecules apart and sets some of the hydrogen free. The heat caused by the chemical combination is so great that the hydrogen starts to burn.

The metal swims rapidly about on the water until it is entirely consumed and converted into *sodium hydroxide,* or as it is more commonly called, *caustic soda.* A molecule of caustic soda is composed of three atoms, one each of *sodium, oxygen,* and *hydrogen.* The oxygen and hydrogen atoms in the caustic

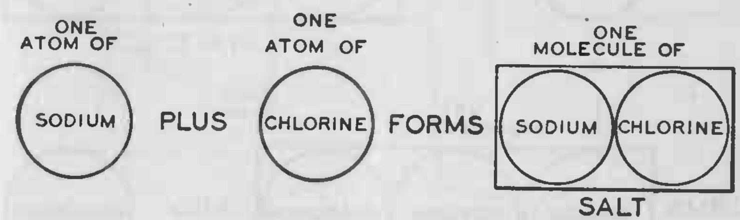


FIG. 15. — A diagram showing that one atom of sodium plus one atom of chlorine forms a molecule of sodium chloride.

soda molecule produced when sodium comes into contact with water are furnished by the water molecules.

Caustic soda is manufactured in large quantities for use in the production of soap, paper pulp, and many other chemical industries.

The commercial method of producing caustic soda is not one using metallic sodium in the manner described, but employs electricity to produce it directly from salt.

Just how this is done can best be explained by means of a simple experiment.

Fill a glass tumbler with a strong solution of salt water. Then obtain two short pieces of copper wire and two pieces of pencil lead. You will also require a battery giving three to four volts. Three ordinary flashlight batteries will serve the purpose. Twist one piece of wire around each piece of pencil lead so as to make a good electrical connection. Connect the other end of each wire to a terminal of the battery.

Place the pencil leads in the salt-water solution. The two leads should be about an inch or so apart. It is important to

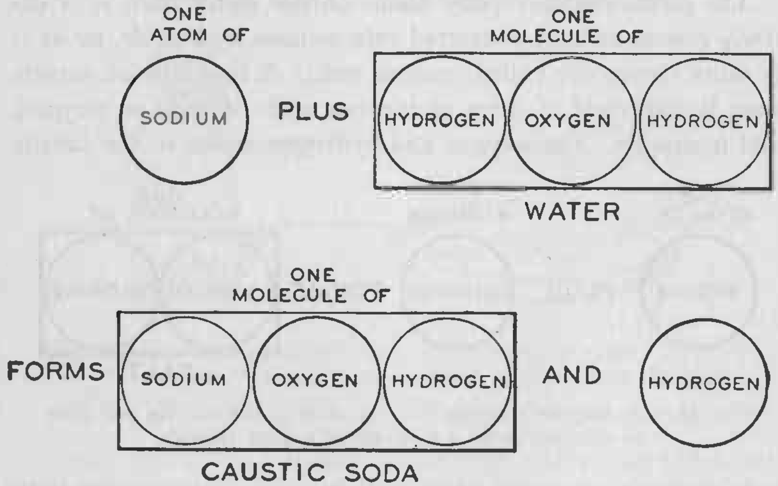


FIG. 16. — When sodium comes into contact with water, hydrogen and caustic soda are formed.

keep the copper wires out of the solution, only the pencil leads being immersed.

In a short time you will be able to notice that tiny bubbles are collecting on the pencil leads. These soon join together into larger bubbles and float up to the surface. The bubbles arising from one lead are the gas *chlorine,* and those from the other *hydrogen.*

The same thing has happened that took place when we passed a current of electricity through the acidulated water. The en-

ergy of the electricity has overcome the force with which some of the elements were held together.

Here is exactly what is taking place. The lead connected to the positive pole of the battery started gathering all the chlorine atoms in the salt while the negative lead gathers the sodium atoms. Thus the electricity produces a sorting-out

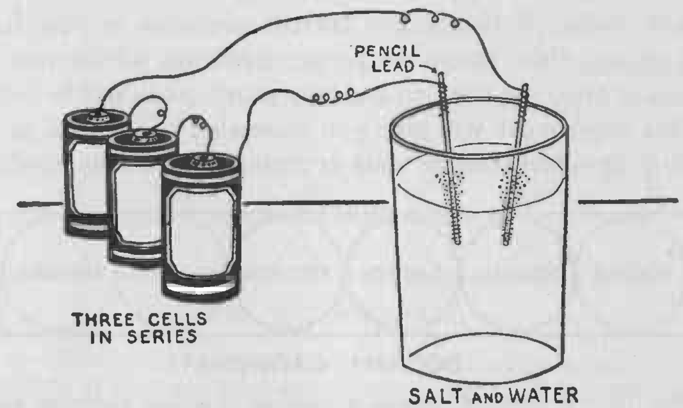


FIG. 17. — Experimental apparatus for decomposing a solution of salt water and showing how caustic soda, etc., are manufactured commercially.

process by which the chlorine is gathered at one point and the sodium at another.

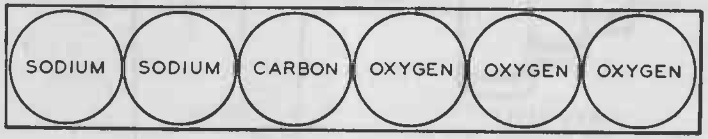
But perhaps you will ask where the hydrogen comes from and why we can't see the sodium. Both questions may be answered together.

When the little sodium atoms are separated from their old partners the chlorine atoms, they become very lonesome and being possessed of a strong chemical affinity, look for fresh partners. We already know how well sodium likes oxygen, and so it should not be surprising to learn that the sodium atoms therefore proceed to tear the water molecules apart.

Oxygen likes hydrogen, but sodium does not like the company of more than one hydrogen atom at the same time. Since a water molecule contains two hydrogen atoms, one of them is forced out of the group by the sodium and goes bubbling up to the surface, along with some other of its fellows that have been likewise displaced.

Thus caustic soda is formed, but being dissolved in the water, it is invisible. If the electric current continues to pass for a long enough time, under the proper condition, all the salt will disappear from the solution and only caustic soda will be left.

This experiment will give you somewhat of an idea of the method by which caustic soda is manufactured commercially.



SODIUM CARBONATE

FIG. 18. — If we could examine a molecule of sodium carbonate we would find that it is made up of the little atoms shown in the diagram above.

In the chemical factories, the chlorine is not allowed to go to waste, however, but is caught and led into chambers where it comes into contact with *lime,* with which it combines to form a powder which is used as a disinfectant and also to bleach cotton and woolen fabrics.

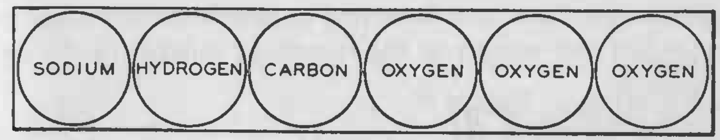
The principal use for caustic soda is in the manufacture of soap. In the soap-works are enormous tanks of boiling fats. To this fat is added some caustic soap solution and the mixture kept boiling for some time, the process finally resulting in *soap.*

Other sodium chemicals. One who has not studied chemistry would hardly think that one of the essential elements of soap and salt would be a silvery metal. Yet this same metallic

sodium lies equally well hidden in a number of other common substances.

Sodium carbonate or Washing Soda is used in large quantities for the manufacture of glass and soap and also for cleansing. If we could examine a molecule of this substance we should find that it is made up of two sodium atoms, one atom of carbon, and three atoms of oxygen.

If one of the sodium atoms in a molecule of sodium carbonate is removed and its place filled by an atom of hydrogen, we get an entirely different substance known as,



SODIUM BICARBONATE

FIG. 19. — If one of the sodium atoms in a molecule of sodium carbonate is replaced by an atom of hydrogen we get an entirely different substance called sodium bicarbonate or baking soda.

Sodium bicarbonate which is used in the manufacture of baking powder and in medicine. Most baking powder is composed of *sodium bicarbonate* and *cream of tartar.* When these two chemicals are dry and are mixed together nothing happens, but just as soon as they are moistened, carbon dioxide is generated. The little bubbles of carbon dioxide blow the cake or biscuit full of little holes and make it light and porous.

If you put about a half-teaspoonful of baking powder into a small pill-bottle and then add a little water, carbon dioxide will be generated so rapidly that if you put the cork in the bottle it will be blown out again with a loud pop.

Hypo is the common name applied to what the chemist calls *sodium thiosulphite,* familiar to those experimenters who have ever taken pictures and done their own developing and printing.

Water glass, often used for preserving eggs and for fireproofing wood and other materials is a compound of sodium, oxygen, and the element *silicon,* which you will find in a chemistry book under the name *sodium metasilicate.*

Something about an element, which, like interesting persons, is not always the same. It is highly prized as a gem, yet we burn it in the stove. We also eat it and shoot it in guns. Its name is carbon.

Before you have been interested in chemistry very long, you cannot help but wonder at the surprising number of different

FIG. 20. — Put about one-half teaspoonful of baking powder in a small bottle and add a little water. Carbon dioxide will be generated so rapidly that if you put the cork in the bottle, it will be blown out again with a loud pop.

forms the same element may take through the mere associations of its atoms. There is an old saying that "people are known by the company which they keep." This is especially true in chemistry, because when you have a crowd of little atoms combined

together in a molecule, all that is necessary to change the whole complexion and actions of the crowd is to add or subtract a single atom.

One of the still stranger things about these often queer little atoms, is that the same ones sometimes go about with entirely different clothes on, disguised, so to speak, and if it were not for the chemist, we should never be able to recognize them.

Who would ever think of a lady wearing a lump of coal or a piece of pencil lead in a ring on her hand? Yet the diamond

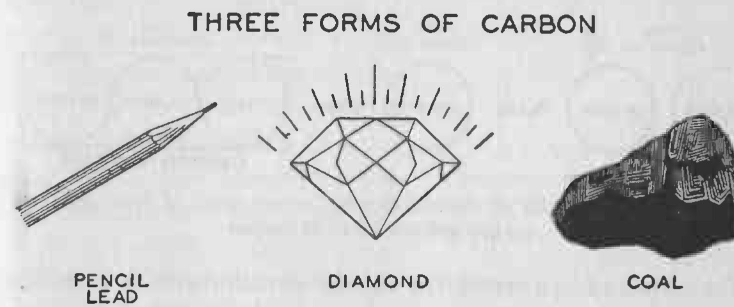


FIG. 21. — Here are three substances, pencil lead, a diamond, and a lump of coal. Each is a different form of carbon.

on her finger is nothing more than a lump of *pure carbon,* and coal and pencil lead are carbon also. Here you have three things, a diamond, a lead pencil, and a lump of coal, all made of the same stuff with nothing else added or subtracted but yet all entirely different in appearance from each other.

It should, therefore, be no wonder to you to find carbon almost everywhere, disguised to every one except the chemist.

Carbon is an extremely important and abundant element which we *eat* in enormous quantities. Of all the many different chemical compounds which are known, over one-half of them contain carbon. All meat, vegetables, fruit, in fact everything which we term *organic,* or things which have life, contain it. In the mineral kingdom, the various forms of coal, graphite, petroleum, limestone, chalk, marble, etc., contain carbon in large proportion. All animal life is dependent upon the carbon compounds which are eaten in the form of meat and vegetable matter and all plant life is dependent upon the presence of the carbon (carbon dioxide), which exists in the atmosphere.

Carbon Dioxide is, as we have seen, the gas formed when carbon burns or unites with oxygen. When the oxygen in the air is drawn into the lungs, it combines with some of the carbon

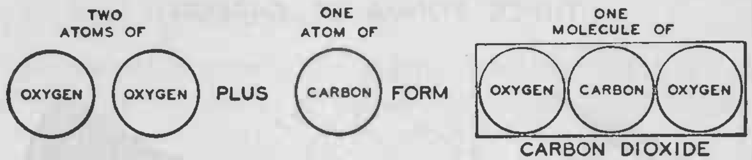


FIG. 22.—A molecule of carbon dioxide is composed of two atoms of oxygen and one atom of carbon.

in the body and as a result, the exhaled breath contains considerable carbon dioxide. Two oxygen atoms have joined company with one carbon atom.

You can show the presence of carbon dioxide in the breath by a simple experiment. Stir some slaked lime into a tumbler of water and after it has settled a while so that the water is clear, pour off the clear water into another tumbler through a piece of clean white blotting-paper. The clear liquid is called *lime-water.*

Lime is a silvery metal called *calcium,* which has joined company with an atom of oxygen. In chemical language it is called *calcium oxide.* When we put lime or calcium oxide into water it forms a new compound called *calcium hydroxide.* Calcium hydrate is used for painting chicken-coops, cellars, fences, etc., and then we call it *whitewash.*

Lime-water is a solution of calcium *hydroxide.* If you dip a

glass tube into the tumbler of lime-water and blow through the tube for a few minutes, the water will become milky. What has happened? Carbon dioxide is very friendly to calcium and upon being introduced by the breath, these two friendly substances form a partnership resulting in a new compound, *calcium carbonate,* which is white in color and insoluble in water and so makes the latter appear milky.

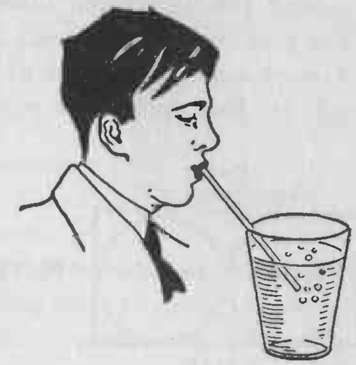


FIG. 23.—You can show the presence of carbon dioxide in the breath by blowing into lime-water.

The Diamond is the hardest substance which we know of. It will scratch any surface. It is not attacked by the strongest chemicals and has no interest in either acids or alkalies; they do not affect it. The diamond appears to be the form which carbon takes when it wants to be left severely alone chemically. But like every other seemingly impregnable thing there is a weak point somewhere and the weak point of the diamond is oxygen. For although the diamond is not affected by other chemicals, if you heat it to redness and dip it into a jar containing oxygen, it will *burn* with a bright flame *just like a piece of coal.* Examination of the fumes from a burning diamond prove it to be carbon and nothing else, because the fumes are *carbon dioxide.* If you lead some of it into lime-water, down will come the white carbonate of lime.

If a diamond is heated to a very high temperature in air, it turns to *graphite.*

Graphite is a form of carbon but unlike the diamond, it is very soft and opaque and is a good conductor of heat and electricity. Remember that it is just as much carbon as the diamond, but that there is simply a difference in the arrangement of its atoms in their molecule.

Lead pencils are not made of lead at all, but of graphite. The graphite is mixed with a small amount of clay, squeezed through a die in the form of a small rod, and then baked. The rods are then enclosed in wood and you have a pencil.

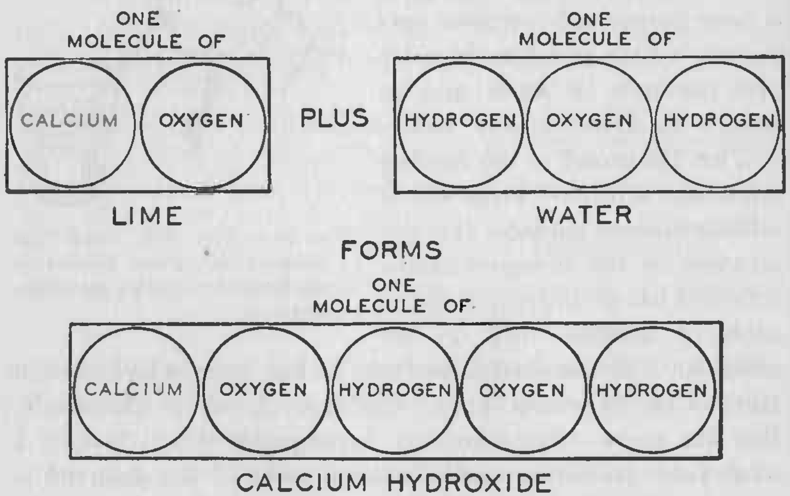


FIG. 24.— A diagram which explains how calcium hydroxide is formed from lime and water.

Graphite is so soft and slippery that it makes an excellent lubricant for machinery. One of the most common forms of graphite is *stove-polish.*

Coal is one of the forms of carbon with which we are the most familiar and perhaps also the most valuable of all.

It is about four-fifths carbon, the balance being hydrogen and various mineral substances. The strong affinity or desire to combine, between carbon and oxygen, is one reason why coal is so valuable. If we put it in a fire it starts to burn or

combine with the oxygen in the air, producing the heat energy which we make use of for cooking, warmth, and power.

But the coal which is put in the stove or under a steam-boiler is changed into carbon dioxide and ashes without doing any of the several wonderful things which it is capable of.

An experiment with coal, which is the basis of a tremendous industry may be performed by filling a hard glass test-tube about one-third full of *soft* or *bituminous coal.* The coal usually burned in our home stoves and furnaces is *hard* or *anthracite coal.* You can probably find some fragments of soft coal along a railroad track or at a power-house. Fit the open end of the test-tube with a cork and glass tube as shown in the illustration. Heat the powdered coal in the tube with an alcohol lamp or a Bunsen burner and soon a gas will commence to be given off and pass out through the glass tube. This gas will burn with a yellow flame if ignited with a match where it issues from the glass tube. This gas is a mixture of several compounds of carbon and hydrogen. It is in fact, *illuminating gas,* and the experiment you have just performed illustrates the principle of one of the methods of making illuminating gas.

Illuminating gas made in this manner is sometimes called coal-gas and is made on a large scale commercially in very much the same manner as you have done it, by heating soft coal in huge retorts. The gas is stored in tanks and then distributed through pipes in the streets for heating and illuminating.

A great many chemical processes result in the production of what are known as *by-products.* The chemist starts out to produce a certain substance but produces a number of other valuable chemicals as well.

The manufacture of coal-gas is a very profitable industry because of the large number of valuable by-products which result.

If you should continue to heat the coal in your test-tube until no more gas is given off, the substance which remains behind would be coke.

Coke is a valuable fuel which is used in large quantities in the iron and steel industry. Before the coal-gas is stored in the huge tanks from which it goes out into the pipes in the streets to the consumer, it is *washed* by passing it through water

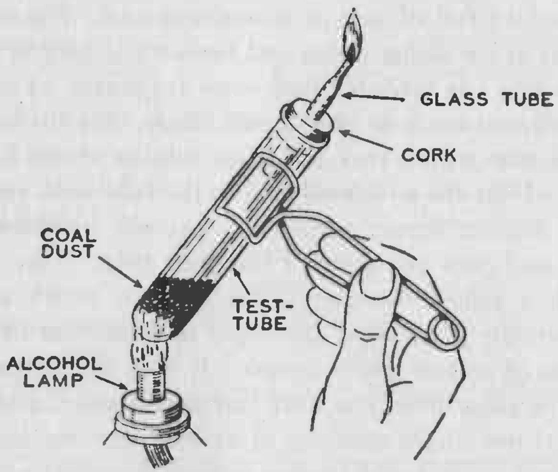


FIG. 25. — An experiment showing how illuminating gas, coke and coal-tar are produced by heating soft coal.

in the form of bubbles. This washing process frees the gas from various impurities. The water becomes charged with these substances and is called gas-liquor. It contains principally *ammonia* and *coal-tar*. The ammonia is abstracted from the gas-liquor and used for many purposes, one of the principal being the preparation of fertilizers.

The coal-tar produced in this manner is the foundation of many great industries and the source of wonderful chemical compounds. When the tar is distilled in much the same manner

as you distilled water, only on a larger scale, several different kinds of tars, oils, and pitches result.

And now here is the most wonderful part of it all. The molecules of the sticky tars and pitches may be "cracked" and "split" into hundreds of wonderful compounds which you would never imagine could have their beginning in a lump of black coal. There is only space to mention a few of them here.

The first is pitch, used for roofing purposes, then comes *benzol* and *toluol,* from which T. N. T. and other powerful explosives are made. The rest can hardly be mentioned in their order but among them are *carbolic acid, tannin* for tanning leathers, moth-balls, beautifully colored dyes, perfumes, photographic chemicals, waxes, phonograph records, medicines, and very nearly a little bit of everything.

Who would think that a barrel of sticky black tar, when heated and treated in various manners would change into beautiful dyestuffs, perfumes, medicines, etc., according to the will of the trained chemist?

Carbon's Friends and Associates

Carbon atoms not only like to associate with oxygen but have a very strong friendship also towards hydrogen and nitrogen and often join company in the most varied proportions with one, two, or all three of these friends. A great number of different compounds are thus formed, some of them being extremely complex. Most of these more complex compounds of carbon are found in animals and plants or are produced by the transformation of substances derived from those sources and so are usually studied under the head of *organic* chemistry.

You are now familiar with carbon dioxide, but this is only one of the gases formed by the union of carbon and oxygen. Carbon also forms gases when united with hydrogen or nitrogen. The combination of one atom of carbon with one atom of nitrogen results in a colorless, suffocating, intensely poisonous gas called

Cyanogen, which is useful in many ways to the chemist and in various industries but of no particular interest to us in our present study of chemistry.

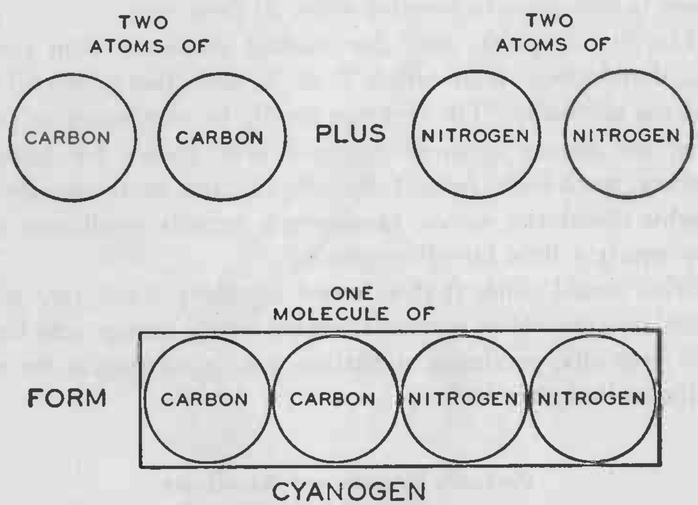


FIG. 26. — Carbon and nitrogen unite and form an extremely poisonous gas called cyanogen.

The gases which are formed by the union of carbon and hydrogen are, however, very interesting and very important because we come into continual contact with them.

One of the common *hydrocarbons* or substances composed of hydrogen and carbon is *acetylene*. Acetylene is a gas, formed when two atoms of carbon and two atoms of hydrogen combine into a molecule.

During hot summer weather, while walking along the edge of a swamp or a stagnant pool, you may have seen bubbles of gas rising to the surface of the water. Some of this gas may

be collected by holding an inverted bottle filled with water over the ascending bubbles. It will take fire readily when ignited with a lighted match and will burn with a bluish-yellow flame. The common name for this gas is

Marsh-gas, but the chemist calls it *methyl hydride*. That which is found in the swamps is the product of vegetable mat-

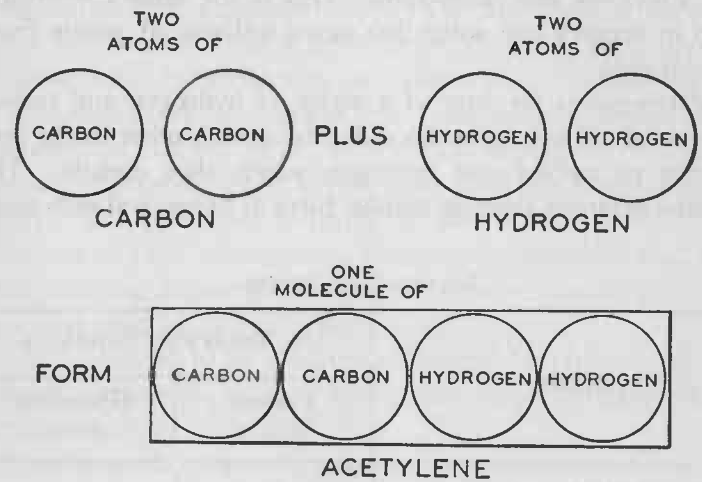


FIG. 27. — Acetylene is a gas formed when two atoms of carbon combine with two atoms of hydrogen.

ter decaying under water where the supply of oxygen is insufficient to oxidize the vegetable matter into carbon dioxide and water. A molecule of marsh-gas is composed of

1 atom of carbon, and
4 atoms of hydrogen.

Marsh-gas forms a very considerable portion of the illuminating gas made by distilling coal and also forms the explosive "fire-damp" found in coal mines.

When the gas chlorine is allowed to act slowly on marsh-gas there is formed a compound the molecules of which are made up of

1 atom of carbon,
1 atom of hydrogen, and
3 atoms of chlorine

and which we call *chloroform*. This is the same chloroform used in surgery and which has saved millions of people from terrible pain.

Marsh-gas is the first of a series of hydrogen and carbon compounds whose molecules differ from each other in the proportion of carbon and hydrogen which they contain. The chemist arranges these in tabular form as below and calls them the

MARSH-GAS SERIES

NAME	ITS MOLECULE CONTAINS	
	Carbon Atoms	*Hydrogen Atoms*
Methyl hydride, or marsh-gas	1	4
Ethyl "	2	6
Propyl "	3	8
Butyl "	4	10
Amyl "	5	12
Hexyl "	6	14
Heptyl "	7	16
Oxyl "	8	18
Nonyl "	9	20

You may perhaps be wondering why this list showing the marsh-gas series is of any interest to us. The fact of the matter is that a great many common substances are associated with this group of chemicals.

Petroleum (literally rock oil) is a thick, greenish, oily liquid which is mainly a mixture of hydrocarbons of the marsh-gas series. Advantage is taken of the fact that the different components boil at widely different temperatures.

If petroleum or "crude oil" is therefore distilled and the vapor condensed, the first substance which is obtained when the oil is heated to a temperature of 70 to 90 degrees is *gasoline*. Then follow *naphtha* at a temperature of 80 to 120 degrees, *kerosene* at 120 to 150 degrees and *benzine* at 150 to 300 degrees.

This petroleum or mineral oil, from which gasoline and kerosene are distilled, is to-day foremost among the irreplaceable commodities of which the world is gradually exhausting its supply. The petroleum industry in the United States dates back only to 1859 when oil was found near Titusville, Pa., and when pumping began the oil flowed in a tiny stream of 40 and then later only 15 barrels a day.

There are said to be over three hundred by-products of petroleum, each with its own use. They range from artificial vanilla extract to

Vaseline, which is a hydrocarbon whose molecule contains

22 carbon atoms and
46 hydrogen atoms.

Vaseline appears in the residue of the petroleum after the lubricating oils have boiled off.

By cooling the residue of the retorts with a freezing mixture some of the solid members of the marsh-gas series appear and we secure the white flaky substance, called

Paraffin, used in waterproofing paper, laundry work, and as an ingredient in candles. A molecule of paraffin contains

28 atoms of carbon, and
58 atoms of hydrogen.

There are many other interesting things which we could learn about the hydrocarbons, but space does not permit. The object of bringing this interesting group of chemicals to your attention has not been merely to acquaint you with something about their chemical properties but also to show you how closely related a great many different appearing substances really are and how they may be said to belong to one great family in many cases.

Two facts common to all the hydrocarbons are their apparent indifference and unfriendliness to most other chemicals and the formation of carbon dioxide and water when they are burned. No matter whether you burn marsh-gas or paraffin or kerosene the resulting compounds are the same, namely, *carbon dioxide* and *water vapor.*

Besides the hydrocarbons, there is a vast group of closely related brothers, sisters and cousins of a chemical family known by the name of *Carbohydrates,* which are *hydrogen, carbon* and *oxygen* compounds. We eat a great many of these at every meal.

Starch is perhaps the most familiar carbohydrate of the household and is a substance whose molecule is formed of

6 atoms of carbon,
10 atoms of hydrogen, and
5 atoms of oxygen.

It is found in wheat, corn, potatoes, and in the roots, stems, and fruits of many other plants. Flour, tapioca, and sago are varieties of starch. You can easily make starch from some potatoes by rasping them on a grater. Mix the pulp thus formed, with water and squeeze it in a linen cloth. The fibre of the potatoes will remain behind, but the juice, together with a large portion of the starch, will pass through. If you let the liquid thus obtained remain quiet for some time, it will become clear. The starch settles to the bottom so that the water may be poured off and the starch dried.

A singular property of starch is its power of forming a blue compound with *iodine*. If you make a paste by pouring boiling water on starch and then mix a few drops of the paste with some water in a test-tube, the solution will turn a deep blue if some iodine is introduced.

If you mix a small quantity of the ordinary corn starch or laundry starch to be found in the kitchen pantry, with cold water and then heat the mixture, stirring it until it boils, it will first become slimy and then turn into a thick jelly. The little grains of starch absorb water and swell up. The swelling of many of our most common articles of food, such as rice, barley, peas, etc., when boiled in water, is now readily explained when you are told that they contain a large amount of starch.

When linen and cotton fabrics are passed through a thin paste of starch, they acquire, after drying, a degree of stiffness and become glossy when pressed with a hot iron.

Another substance which has somewhat the same composition as starch is

Cellulose, which is the material that forms the framework of the cells of plants. It is the outer wall of every vegetable cell and is, therefore, found in every part of every plant. Cellulose, which has been abstracted from the plants and spread out in thin layers is familiar to us in the form of paper. Other forms of cellulose are cotton and linen cloth.

The tiny starch particles in vegetable matter are enclosed in little cells of cellulose. Cellulose is a fibrous, tough substance which our stomachs cannot digest. From this fact you can understand why we cannot digest a raw potato. When a potato is cooked, the cellulose walls surrounding the starch are burst, so that the liquids in the body can get at the starch and *turn it into sugar*.

There are several different kinds of

Sugars, but they are all simply different proportions of our old friends, carbon, hydrogen, and oxygen. The sugar found dissolved in the juices of sweet fruits, such as grapes, is called *grape-sugar* or *glucose* by the chemist. The most familiar form of sugar is the

Cane-sugar, which we use on the dining-table.

When a solution of sugar in water or the juices of plants or of fruits containing sugar such as the juice of grapes, apples, etc., is kept in a warm place for some time, a peculiar change takes place. The liquid begins to "work" or *ferment,* bubbles of carbon dioxide are given off and it will be found that the sweet taste of the sugar has disappeared. The solution has now a new smell and a new taste for by the process of fermentation, the sugar has been converted into carbon dioxide and *alcohol.*

This is somewhat the same process which takes place when yeast is put in bread dough and the dough left in a warm place to rise. The purpose of the yeast is to start fermentation quickly. When fermentation sets in, the sugar in the dough and part of the flour are gradually converted into carbon dioxide and alcohol, and the former being a gas, it causes the dough to swell up and become porous. The carbon dioxide is therefore what causes the bread to *rise.* When the bread is baked, the carbon dioxide is expanded still more, and, as it escapes from the bread together with the alcohol, which at the temperature of the oven is converted into vapor, it produces the desired *lightness* of the bread.

Alcohol is a very valuable carbohydrate which is much used in the arts. It forms the basis of all fermented and distilled

liquors; it is employed as a fuel and as a solvent. It dissolves many substances such as resin and oils, which are insoluble in water. The *tinctures* of the doctor are alcoholic solutions of various medicines.

Common alcohol, called grain alcohol, is produced by the fermentation and distillation of grain. Wood alcohol is manufactured by distilling wood.

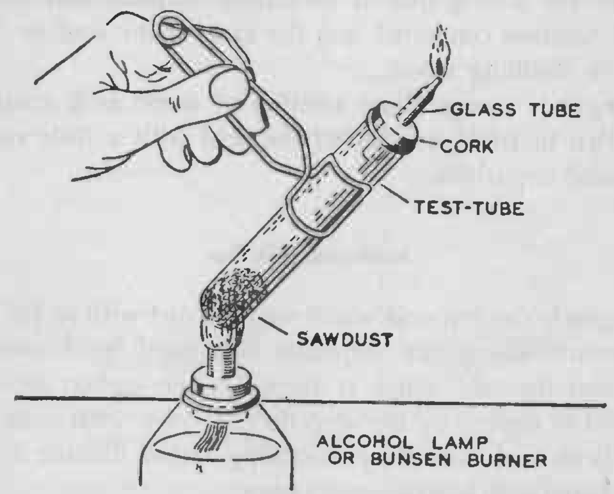


FIG. 28. — If you proceed as in the coal-gas experiment but use wood shavings or sawdust in the test-tube instead of soft coal, you can demonstrate the process of manufacturing wood alcohol.

If you proceed in the same manner as in the experiment for making coal-gas, but use wood-shavings or sawdust in the test-tube instead of soft coal, you can perform an experiment imitating the manufacture of wood alcohol.

When the wood becomes well heated, a gas will issue from the glass tube and this gas will burn when ignited. During the distillation of wood in this manner, the nature of the products varies somewhat according to the temperature employed. The gas issuing from the glass tube consists principally of carbon dioxide, marsh-gas, and hydrogen. The most important constituents of the liquid products which pass out in the form of vapor are *wood alcohol* and *acetic acid*.

Acetic acid. When the alcoholic liquid formed by the fermentation of apple-juice, grape-juice, or other fruits is allowed to stand for a long time it eventually becomes sour and the alcohol becomes converted into the same *acetic acid* as is produced by distilling wood.

Vinegar is a very dilute solution of acetic acid, containing about two to four per cent of the acid with a little coloring matter and impurities.

Acids and Alkalies

Vinegar is the first *acid* which we have met with so far in our experiments except the sulphuric acid used in decomposing water and the acid which is formed when carbon dioxide is dissolved in water. By the way, do you know what soda water is? It is an acid formed by dissolving carbon dioxide in water and flavored with a little sweet syrup.

It is somewhat difficult to explain the nature of an acid to the young experimenter whose knowledge of chemistry is practically limited to the information contained in this chapter but a very simple means whereby you can recognize an acid when you meet with one can be suggested.

Purchase a few strips of *red litmus* paper and some *blue litmus* paper at a drug-store. If you dip a piece of blue litmus paper into an acid, the color will change to *red*. The juices of a great many fruits contain acid, and if you experiment with the blue litmus paper, you will discover acids in many of the substances found in the kitchen. The juices of lemons, oranges,

grapefruit and rhubarb as well as vinegar and ginger ale are a few.

The strong acid nature of lemon-juice may be shown by an experiment in which you can make an *electric cell* out of a lemon.

Cut a lemon in half and stick a strip of sheet zinc and one of sheet copper into one of the pieces, about an inch apart, as shown in the illustration. If you connect a wire to each of the strips and from there to a telephone receiver, you will hear

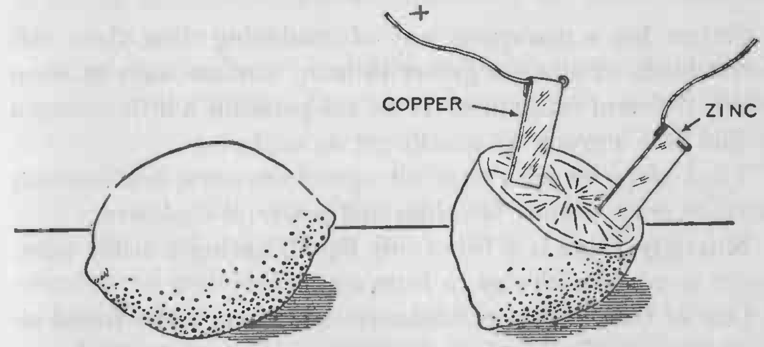


FIG. 29. — The strong acid nature of lemon juice can be shown by the experiment of making a voltaic cell out of a lemon.

a strong click in the receiver every time that the circuit is made or broken, showing that a current of electricity is produced by the action of the acid in the lemon on the metals.

Alkalies have the power of turning red litmus paper blue. Ammonia, caustic soda and lime are common *alkalies*. Acids and alkalies have the property of neutralizing each other.

It has already been explained that the manufacture of soap consists of adding caustic soda to hot fats or oils. This process results in a solid substance which is the soap and also in a liquid. The liquid is largely *glycerine*, that sticky sweet-tasting substance which we use to rub on chapped hands or a sore throat. Who could think that this apparently innocent substance would become a powerful explosive when it meets with the right partner?

Glycerine, when pure, is a colorless, sirupy liquid which is also a member of the carbohydrate family. Its molecules are composed of

3 atoms of carbon,
8 atoms of hydrogen, and
3 atoms of oxygen.

Nature has a marvelous way of combining these three different kinds of atoms together in many various ways to form widely different substances. If we can persuade a little nitrogen to join such a group we usually get an explosive.

Thus, glycerine with some nitrogen from *nitric acid* becomes *nitroglycerine,* a most ferocious and powerful explosive.

Nitroglycerine is a heavy oily liquid, having a sickly odor, which is mixed with clay to form *dynamite.*

One of those common substances which are to be found almost all over the earth and whose real nature is hidden to nearly every one except the chemist is *clay.* The peculiar action of clay on being mixed with water, forming with it a compact ductile mass, which may be kneaded into any shape, is well known.

Clay is, however, the name for a kind of earth composed of two silvery metals, *silicon* and *aluminum,* joined together in a molecule with some hydrogen and oxygen. It is very seldom found pure but is mixed with sand, fossils, limestone, iron, and vegetable matter. These foreign substances are what gives it the various colors of red, blue, yellow, and brown.

China clay, or *kaolin,* is the purest variety found in nature and has a number of practical uses, among which are the making of chinaware, its use as a filler for cotton goods and paper, in coating book and wall paper, and in paint manufacture.

Wet clay is soft and plastic, but when heated to a high temperature so as to drive out all water is one of the most indestructible of substances and capable of withstanding a very high heat. For that reason, furnaces are lined with "fire" brick made of baked clay and the crucibles or pots in which metals are melted at high temperatures and used in foundries are made of the same substance.

Brick-making and pottery-making are clay industries. The bricks in the chimney and the dishes on the dining-table are both made out of baked clay.

When clay is "fired" or baked at a high temperature, it becomes hard and brittle. But it is still porous. In order to avoid this porosity, the variously shaped pieces of baked clay composing the dishes are *glazed.* The glaze is a coating of a sort of glass with which the dishes are covered and then rebaked. After the final baking they come out of the oven or "kiln" smooth and polished.

The manufacture of brick, pottery, china, and porcelain for dishes and electrical purposes is a huge industry in most countries.

You yourself can easily mold various shapes out of clay by hand and make different kinds of pottery. The shaping of the clay is accomplished in factories by means of metal molds into which the clay is pressed or by means of a "potter's wheel."

How to Make a Small Potter's Wheel

The molding of clay on the potter's wheel, technically known as "throwing," is an art which dates back many hundreds of years, the wheel having been used in the very early Egyptian ages.

Wherever pottery is made there are still potter's wheels in use, and there is no difference between the principle of the wheel used to-day and that of ages ago. The primitive form consisted of a small round table, set on a pivot, and free to revolve, so that it might be turned by hand. The improved

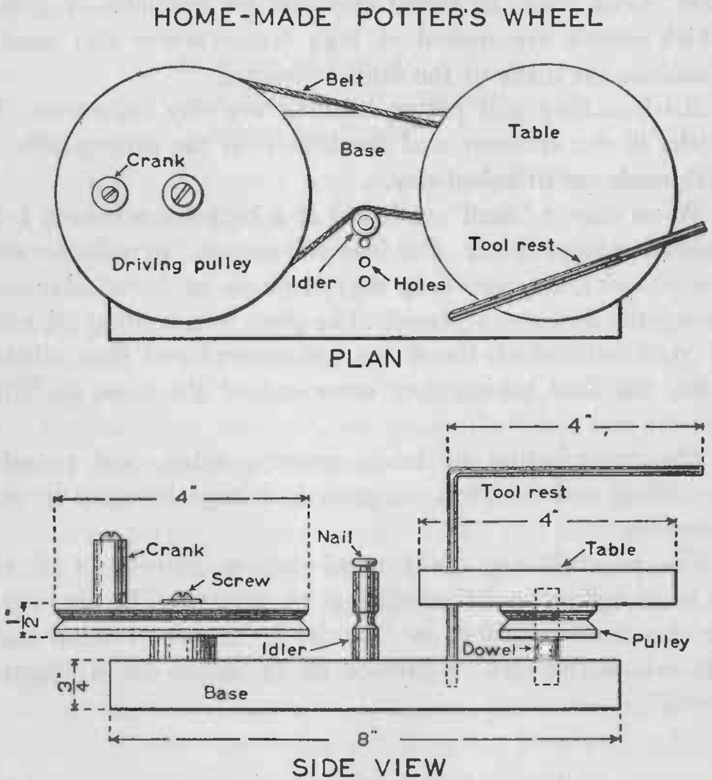


FIG. 30. — Plans for a small potter's wheel which can be used for shaping clay.

forms have a treadle connected with the table, so that the potter can give it a continuous motion by the action of his feet.

The model wheel described below will do real work and it is possible with its aid to "throw" or mold a large variety

of hollow and flat clay pieces. The only modification is that on account of the small size of many of the pieces, a tool will be found better than the fingers or hands for shaping the clay.

It consists of a wooden base, eight inches long, three and one-half inches wide and about three-quarters of an inch thick. The driving-wheel or pulley is four inches in diameter and one-half an inch thick. It has a groove turned in the edge to accommodate the driving-belt. The wheel is fitted with a handle so that it may be easily turned. A large round-headed wooden screw, passing through the centre of the wheel forms the pivot.

The table is a circular piece of wood of the same diameter as the wheel and carries a wooden pulley about one and one-quarter inches in diameter on its under side.

The driving-belt may be made from a leather shoe-lace. In order that it may drive the table without slipping, when pressure is put on the clay, the machine is provided with an "idler," which may be moved back and forth and brought to bear tightly against the belt.

The idler is simply a piece of dowel with a groove turned in it near the bottom. It has a hole bored through its axis so that it will slip over a nail easily. A number of small holes into which the nail will fit tightly are made in the base.

The table is mounted by boring a hole from the underside. The hole should not, however, pass all the way through. It is then placed over a wooden dowel projecting up from the base. The dotted lines show the arrangement. The diameter of the dowel should be about five-sixteenths of an inch and the hole in the pulley should only be just large enough to allow the latter to revolve freely. It must not be large enough to allow the wheel to wobble.

The tool-rest is a piece of one-eighth inch brass rod, bent at right angles. The lower end is inserted in a hole in the base. The tool itself is a piece of hard wood about three-eighths of an inch in diameter and five inches long. One end is brought to a round point and the other slightly flattened.

The completed potter's wheel should be securely fastened to a table by means of a clamp. Practice turning the wheel for a few minutes in the direction shown by the arrow in the illustrations. Form a piece of clay roughly into a ball, place it on the wheel as near the centre as possible and press it down lightly so that it will stick in place.

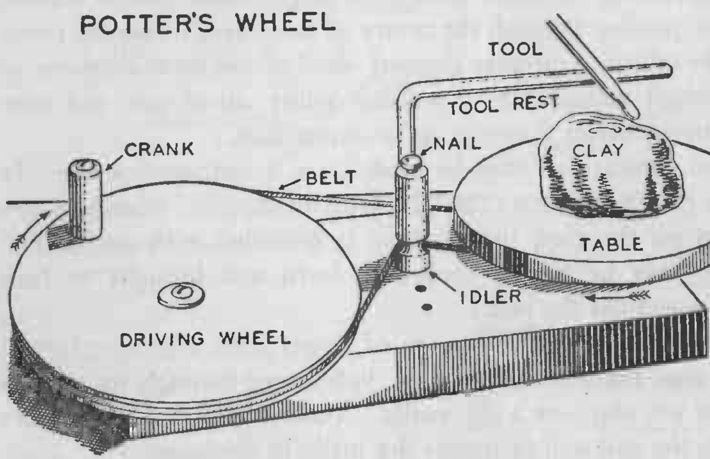


FIG. 31. — The completed potter's wheel ready for operation.

Hold the tool against the rest as shown and while the wheel is revolving at good speed, press the tool lightly against the ball of clay and work it until it is true and smooth.

When making small articles such as cups, vases, etc., it is better to use the tool rather than the fingers to spin the clay with. Do not try to cut the clay, but by a slight pressure and by moving the tool slowly and keeping the tool clean, the clay will be spun into whatever shape is required.

One of the prettiest pieces to make is a cup and saucer in one

piece, and it is well worth a little patience to learn to do this sort of work quickly and nicely.

First spin a round ball of clay and then make the inside of the cup with the tool, smoothing it up with the finger. The sides of the cup should be left quite thick. The tool is then held firmly and pushed down just outside the edge of the cup, forming the saucer.

Carefully smooth up the saucer and outside of the cup and edge and undercut it from the whirling table with the flat

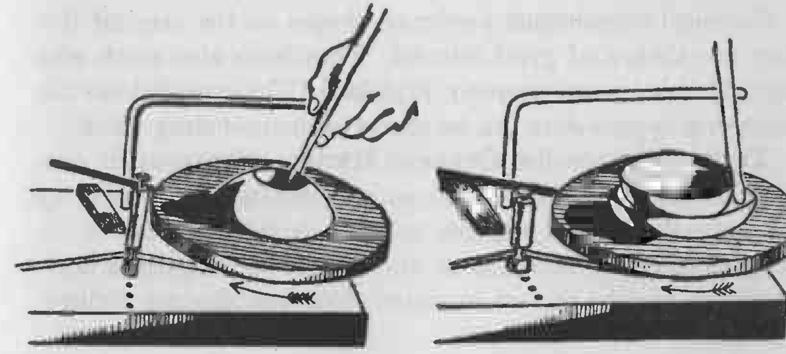


FIG. 32. — At left, starting to spin or "throw" a cup. At right, forming a saucer on the cup.

end of the tool or with a penknife, thus removing it from the table. A handle is easily molded from a little clay with the fingers and pressed onto the cup.

After a little practice, the whole process from the forming of a ball to a finished vase need not take more than a few minutes.

Any molding clay can be used on the wheel, but if a little fire-clay can be obtained, articles made with it can be dried hard in the sun and afterwards baked in a clear fire so that they become real pottery.

The number and variety of articles that can be made in this manner are practically unlimited.

After a bowl has been made, give it a touch at the top and it becomes a large bowl. A touch at the outside edge and the top moves in and it will become a straight vase. Or again, it is a bowl until the pressure of the fingers as it spins around on the table presses it back again into a ball.

Miscellaneous Chemical Experiments

Chemical experiments border so closely on the magical that they are always of great interest. They have also much educational value when properly explained. The material for the following experiments can be procured at most drug stores.

Testing Water for Organic Matter. Water often contains invisible vegetable and animal substances known by the general name of organic matter. A microscope will reveal the presence of much of the animal and vegetable matter which may be present in water. You can also use a chemical test.

Fill three clean mayonnaise jars with equal quantities of water as follows: Fill the first with water from a well, the second with distilled water, and the third with water from a small pond or ditch. With a medicine dropper add to the water in each a few drops of a solution of permanganate of potash. Add the same number of drops to each jar, making each as nearly as possible the same color—a bright, clear purple.

Allow the jars to stand for an hour undisturbed. At the end of that time the distilled water will be unchanged; the well water will also not have changed, or perhaps will have lost only a small amount of color. But the ditch water will have lost color, possibly changing from purple to brown. Ditch water and pond water usually contain organic matter. Well water

seldom does, and pure distilled water never. Here is the explanation of the change in color of the water containing organic matter.

Potassium permanganate is a chemical composed of potassium, manganese and oxygen. It is a powerful oxidizing agent. It will burn or oxidize organic matter very quickly, and in doing so loses some of its own color. The chemical action produces manganese dioxide, a chemical which is brown. The fingers are stained brown by a solution of potassium permanganate in water. The organic substances in the skin are oxidized by the solution and the fingers become coated with a layer of brown manganese dioxide.

Curious Chemical Growth. Aluminum has a very strong attraction, or affinity as the chemist calls it, for oxygen. This means that aluminum and oxygen combine whenever they have an opportunity. When exposed to the air aluminum becomes coated with a thin layer of aluminum oxide (the combination of aluminum and oxygen). You can see the formation of aluminum oxide take place by means of a simple experiment. Scrape a piece of aluminum clean and bright. Upon this spot drop some mercuric nitrate solution and allow it to dry. The surface of the aluminum will be immediately oxidized, and the action will take place so rapidly that white tufts of aluminum oxide will appear and grow to a height of nearly a quarter of an inch in five minutes. The oxide is a fine white powder. If brushed off it will be almost immediately replaced.

Chemical Plants. The strange growths produced in this experiment are not actually plants, but their appearance has earned them the name of "chemical plants."

They are formed by throwing small pieces of any of the following chemicals, manganese sulphate, iron nitrate, nickel sulphate, cobalt nitrate and copper chloride, into a glass tumbler containing a dilute solution of sodium silicate. Sodium silicate is the chemical sometimes called *water glass* and often used for preserving eggs, fireproofing, etc.

The chemicals thrown into the sodium silicate solution dissolve and form new chemical compounds which sprout into various fantastic plant-like shapes and grow several inches in the course of a few minutes.

A Chemical Trick. A knowledge of chemistry will enable an amateur magician to perform many startling tricks. Here

FIG. 33. — A chemical trick by means of which water, milk, wine and ginger ale appear to be poured from the same bottle. See text for instructions.

are directions for a simple trick in which water, milk, wine and ginger ale appear to be poured from the same bottle.

First dissolve two teaspoonfuls of iron sulphate in a quart of warm water contained in a milk bottle. Add about ten or twelve drops of sulphuric acid. The liquid in the bottle will be colorless and will resemble plain water.

Next, you will need four clean glass tumblers. One tumbler which is to appear to contain water when the trick is performed, requires no preparation. However, in the second, which is to appear to contain wine, place a few crystals of permanganate of potash which have been crushed to a fine powder. In the third, place a small amount of calcium chloride solution. And in the fourth, place some sodium bicarbonate moistened with a few drops of water.

When the liquid in the milk bottle is poured into the first glass, it will remain colorless and appear to be plain water. In the second glass it will become a red liquid, while in the third it will have the appearance of milk. The liquid poured in the last glass will bubble and fizz when it strikes the last glass and give a good imitation of ginger ale or champagne. It should hardly be necessary to say that none of the liquids are good to drink.

Plastics Are One of the Chemist's Great Achievements

There are a great many substances in the world which did not exist 50 years ago. They are the creation of chemists. Some of the most useful of these man-made materials are the "plastics." The name "plastic" is applied to a wide range of substances which may be heated and pressed into various forms and shapes and which remain rigid after cooling, or which, when made up with water, are soft and may be molded and retain their shape permanently after drying.

One of the great benefits which plastics brought to the modern world is "safety" glass. Before safety glass was universally used in the windshields and windows of automobiles, two out of every three persons injured in an automobile accident were cut by flying glass. Safety glass consists of a sheet of transparent plastic sandwiched between two sheets of glass by heat and pressure so that the glass adheres firmly to the plastic. When safety glass is shattered, the razor-edged fragments remain attached to the plastic instead of flying about.

Probably the first plastic man learned to use was potter's clay. When mixed with water to form a dough, pressed into shape and baked in a fire it became rigid and permanent in shape. The first cooking utensils were made of clay. We still use dishes made of this material.

The first man-made plastic was glass. When heated, glass softens and can be pressed and blown into a wide variety of forms. When cold it is rigid. Rubber and Portland cement are also plastics, broadly speaking.

Ordinarily, when we speak of plastics, we do not have in mind glass, clay, rubber or Portland cement. We are thinking of more recently invented material such as Celluloid, Bakelite, Beetleware, Plaskon, Tenite, Lucite, etc.

There are more than a thousand trade names for plastic materials. We are surrounded by plastics. They have thousands of uses, many of them unknown to you, unless you are a chemist.

You can not get far away from plastics while you remain in a civilized community. When you awake in the morning and put on your shoes, the shoes may have plastic soles. The varnish on your bed and on the floor probably contains a plastic. Your hair comb, the handle and bristles of your tooth brush are plastics in nine cases out of ten. The switch buttons you press are plastics, so is the major portion of your telephone. The crystal which protects the face of your watch is a transparent plastic. These few examples of the wide use of plastics indicate what an important role these materials play in our daily routine.

Celluloid was the first "modern" plastic. It was invented by John Wesley Hyatt, a printer who was trying to make a substitute for ivory. Celluloid is made from gun cotton. It is highly inflammable and dangerous when stored in quantities.

Bakelite

The invention of Bakelite by Leo Hendrick Baekeland was the most important event in the history of plastics.

Baekeland was born in Ghent, Belgium. For a time he was an assistant professor of chemistry at the University in that city. He came to the United States while still a young man and immediately found employment in a small chemical plant which manufactured photographic supplies. Two years later he opened his own office as a consulting chemist.

The young consultant was not swamped with clients and consequently had time to putter with his own ideas. At that time there were no photographic papers which could be printed by artificial light. Sunlight was necessary. Amateur and professional photographers both needed a paper which was not dependent upon sunshine. Baekeland's experiments resulted in a photographic paper with which prints could be made at any time by gaslight or electric light. He called the new paper Velox and formed the Nepera Chemical Company to manufacture and sell his invention. Velox soon became a very popular photographic paper. George Eastman, the founder of the Eastman Kodak Company, envied his ingenious competitor and it is reliably reported that he paid Baekeland one million dollars for the Velox patents and the Nepera Chemical Company.

Baekeland was still a young man when he disposed of his Velox business to Eastman. The deal gave him a great deal of money to assist his ability and energy. He decided to undertake a chemical problem which had long baffled all other chemists who had tackled it. He planned to make, if possible, a synthetic resin which would take the place of shellac.

Minute insects are the source of shellac. The insects suck the sap of certain types of fig-trees in India. Twigs and insects become coated with the resinous substance which is shellac.

Multiply 10,000,000 by 1,000,000 and the answer will be the enormous number of tiny insects required to produce the 65,000,000 pounds of shellac which the world consumes annually. Shellac, dissolved in alcohol, was once in universal use as a varnish. Cast into sticks, it is sealing wax. Mixed with wood flour and lamp black, it is molded into phonograph records, buttons and typewriter and electrical parts under such names as Electrose, Electrite and Buttonite.

A chemist-made shellac could be cleaner, cheaper, more uniform and perhaps much superior to insect-made shellac. So Baekeland went to work at the problem. For nearly 100 years it had been known by chemists that artificial resins somewhat similar to the resin of pine trees could be made experimentally in the chemical laboratory. So far, it had not been possible to produce a satisfactory chemist-made resin on a commercial scale. To begin his experiments Baekeland repeated the work of other experimenters. Then he carried out some of his own ideas. Experiments went on night and day. Carefully observed facts were jotted down in notebooks. Four years passed, years filled with toil and disappointment. Then in 1907 came the answer to the problem so that two years later, Baekeland was able to announce a new man-made resin which he called Bakelite. Its chemical name, descriptive of its molecule, is oxybensylmethylenglycolanhydride. It was produced largely by the reaction between a smelly, white, crystalline solid called phenol and the equally smelly formaldehyde. The new resin looked like amber. It could be molded under heat and pressure and moreover it hardened under the influence of heat to a point where it possessed much more strength than the best amber or the hardest natural resins. When made into varnish, Bakelite provided a protective coating far more durable than shellac or any of the best natural resins such as copal which were used in varnish making.

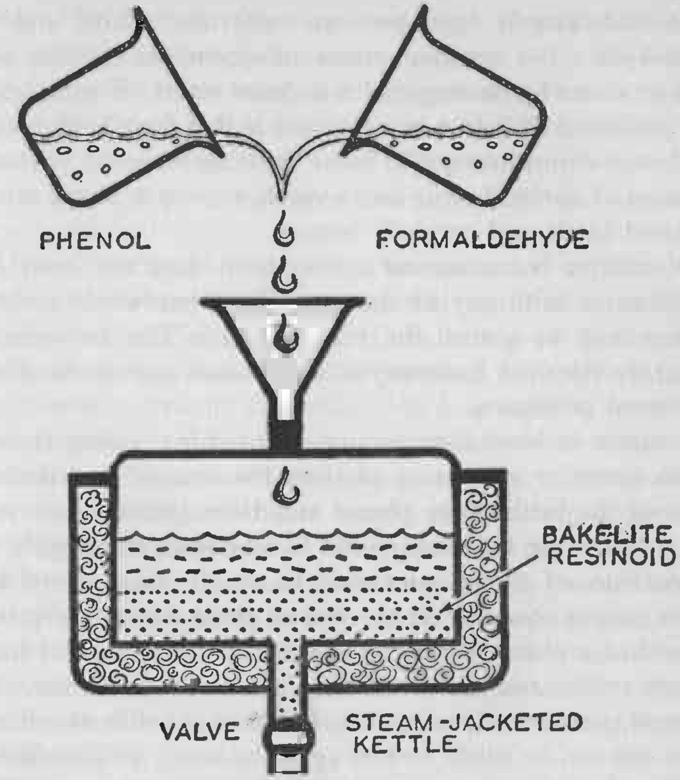


FIG. 33A. — The Bakelite Resinoid Process.

Bakelite was the first of several plastic materials called phenol "resinoids." A resinoid is the chemist's term for a synthetic or man-made resin, so called to distinguish it from natural resins. A resinoid is not anything nature put on earth. Nature supplies the raw materials but chemists do the manufacturing.

There are other phenol resinoids and also resinoids made from other materials besides phenol and formaldehyde.

The principle of manufacturing Bakelite resinoid is simple.

It is made largely from two raw materials: phenol and formaldehyde. The common name of phenol is carbolic acid. It is produced by heating coal in a closed retort. Formaldehyde is a gas which dissolves in water and in that form is frequently used as a disinfectant. To make Bakelite resinoid, phenol, a solution of formaldehyde and a catalyst are put into a steam-jacketed kettle and carefully heated.

A catalyst is a chemical agent which does not enter into combination with any of the ingredients but whose presence is necessary to control the reaction. It is like an orchestra leader, he does not make any of the musical sounds; he directs the sound producers.

A steam-jacketed kettle is one enclosed in a casing through which steam or water may be passed to heat or cool the contents of the kettle. The phenol and formaldehyde soon react and in order for the reaction not to take place too rapidly, the temperature of the mixture must be closely watched and kept under proper control. At the end of three hours, the process is finished and at the bottom of the kettle is a layer of heavy molten golden resinoid covered by a layer of hot water. The resinoid is drawn off and cooled. It is then as brittle as ordinary rosin but can be easily melted again by heat. It will dissolve in a number of solvents, notably alcohol and acetone.

Natural resins may be melted by heat and solidified by cooling innumerable times but not Bakelite resinoid. When it is heated, Bakelite resinoid melts but continued heating for a short time at the proper temperature causes it to harden and after hardening it cannot be softened again at any temperature. Furthermore it is no longer brittle and will not dissolve in ordinary solvents.

All of the phenol resinoids have these same properties and have many uses. They are used in varnishes, lacquers, paints, cements and as waterproof glue. The modern waterproof

plywood is bonded with this wonderful material. Sheets of paper, cloth, or fibre glass can be impregnated with the resinoid and compressed into sheets of very strong, durable lumber. Finely powdered phenol resinoid mixed with wood flour and with dye to give it suitable color is a molding powder which can be pressed into an almost endless number and variety of useful articles.

Urea Plastics. Through the chemical union of mixed ammonia and carbon dioxide gases a white crystalline substance known as "Urea" is produced. Urea is a good fertilizer but it also has other uses. When it is mixed with formaldehyde and heated a resinoid is formed which in its final state is as clear, transparent and colorless as glass. It is almost unbreakable. When urea-formaldehyde resinoid is mixed with a filler and coloring matter it can be molded into almost any form by heat and pressure. The pastel colored "unbreakable" tumblers, spoons, cups and saucers are usually molded of this material. The gleaming, white one-piece housing of many of the scales seen in delicatessen stores, groceries, and butcher shops are usually molded of urea-formaldehyde plastic. Plaskon and Beetleware are well known brands of urea-formaldehyde plastic molding powder.

Thermosetting Plastics and Thermoplastics. Phenol-formaldehyde and urea-formaldehyde are both *thermosetting* plastics. When put under pressure and heated sufficiently they "set" and harden permanently. There are also *thermoplastic* plastics. These can be softened by heat, hardened by cooling and then softened again by heat any number of times. Thermoplastics never "set" permanently. Phonograph records are made from thermoplastics. The two most useful thermoplastics are cellulose acetate and polystyrene.

Cellulose acetate is made by the reaction between acetic acid and cellulose. Cellulose is obtained from cotton. Cellulose acetate plastic can be given more brilliant color and higher lustre than phenol-formaldehyde or urea plastics. Such articles as costume jewelry, steering wheels, toys, combs, brush handles and eyeglass frames are commonly made of this beautiful material.

Polystyrene has a number of trade names among which are Lustron, Amphenol and Lucite. It is produced by a series of reactions between benzene and the natural gas called ethylene. Pure polystyrene is clear and transparent. In sheet form it is used as cowling, windows, windshields and a substitute for glass on airplanes. A polystyrene rod will carry light like a pipe carries water. The bent rod on the up-to-date flashlight which a doctor uses to examine your nose, throat and ears is made of polystyrene. Polystyrene can also be colored and molded by heat and pressure into almost any desired shape.

The Vinyl Plastics are another group of thermoplastics which have wide use in varnishes, safety glass, molding compounds, etc. Butacite and Vinylite X are Vinyl plastics. They are made from ethylene.

How Thermosetting Plastics Are Molded

Hardened steel molds, heat and heavy pressure are used to form steering wheels, eyeglass frames, knob or other finished articles from powdered plastic. The molds are jacketed so that they can be alternately heated by steam and cooled by cold water. They are pressed together in a hydraulic press. The molds are exact counterparts of the pieces to be made. They are divided into two parts, one called the stationary platen and the other the movable platen.

A carefully weighed amount of molding powder is put into the cavities in the movable platen and the press is closed. The powder is compressed by a pressure of 2000 pounds or more per square inch. It melts in the hot mold (heated by

steam in the jackets). A moment after melting, it hardens and cannot be softened again. The press operator then shuts off the steam and cools the mold by sending cold water through the jackets. The press is opened, the mold comes apart and the finished piece is removed. Unless the piece is a very large one, the mold is built so that several pieces can be produced at one operation of the press.

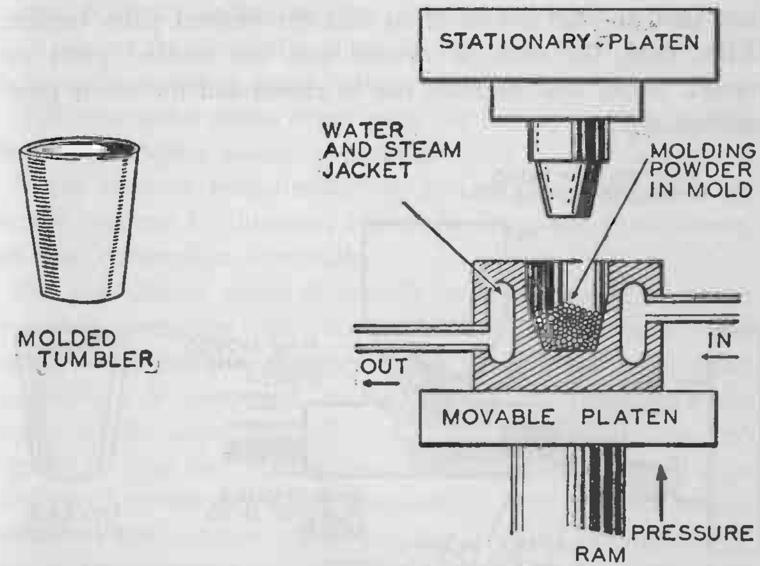


Fig. 33B. — Molding a Thermosetting Plastic. Heat and heavy pressure, the latter supplied by a hydraulic press, are required. The mold is for making the molded tumbler shown at the left. The portion of the mold called the cavity is shown in section.

Thermoplastic Molding

Thermoplastics are usually molded into the infinite number of articles in which these materials find their way to the consumer by an "extrusion" process. The molding powder is placed in a hopper connected to a cylinder called the heating chamber.

A small opening in one end of the heating chamber leads into the mold. There is a ram or plunger in the heating chamber which can be moved back and forth by water pressure. When the ram is moved away from the mold some of the molding material drops into the heating chamber and melts. Then when the ram is moved forward toward the mold it forces the molten thermoplastic into the mold. Water is then used to chill the mold so that the molded parts harden. When cold, the mold is opened and the molded parts removed. After this the mold can be closed and the whole process repeated.

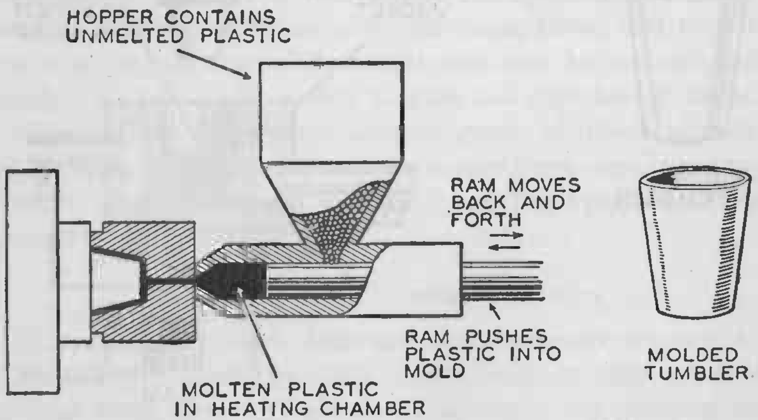


FIG. 33C. — Molding a Thermoplastic Plastic. This is a more rapid process than molding a thermosetting plastic. The mold shown is also for making a molded tumbler. The portion of the mold called the cavity is shown in section.

A Plastic Made from Cow's Milk

You are well aware that butter and cheese are made from milk but do you also know that many buttons and umbrella handles have come from this same source. Not all the milk produced by dairy farms is for food. Milk is also a raw material

for certain chemical industries. One of the common plastics, of which Galalith is an example, is made from milk. In addition to water, butter fat, mineral salts and milk-sugar, there are about three pounds of a substance called casein in 100 pounds of skimmed cow's milk. A very useful plastic can be made from casein. The white curds which are formed when an acid or the substance known as rennet are added to skim-milk are casein. Rennet is obtained from the stomach lining of calves. It is one of the chemicals called an enzyme and is often used to make the pudding called junket.

You can make casein from milk. It is easy for the young chemist to prepare casein from milk.

When milk is undisturbed for a time the cream rises to the top and can be skimmed off. Milk from which the cream has been removed is skim-milk.

Put one pint of sweet skim-milk in an agateware saucepan or a glass ovenware dish (do not use an aluminum pan) and heat it very gently to a temperature of 90 degrees F. The temperature is important in the process and to insure the success of the experiment do not let the milk rise above 100 degrees F. Use an ordinary thermometer, the kind that hangs on the wall to measure room temperature. Stir the milk before taking its temperature. When it has reached 90 degrees F remove the saucepan from the fire and pour a half cupful of vinegar into the milk at the same time stirring the mixture well. Thick, white curds will form. These are casein. Left behind in the liquid are albumin and milk sugar. You can separate the casein from the liquid by straining it through a fine sieve or a piece of cheesecloth. After straining wash the casein in fresh water, strain it again, press the water out and spread it around in a clean dish to dry. The hard dry granules which form are the casein of commerce. An amazing number of things can be made from it, among them glue, paint, coatings for paper, bristles for brushes, buttons, insulators, felt hats and fabrics.

In order to form the casein plastic used for making buttons, knobs, insulators, umbrella handles, etc., dry casein granules are powdered, mixed with a filler or coloring matter and moistened with enough hot water to form a dough. The dough is then formed into sheets, rods, tubes or other shapes and placed in a solution of formaldehyde which "sets" them and makes them as hard as stone.

Thousands of people, though probably unaware of the fact, wear fine clothing and felt hats made at least partly of fibres which came from cow's milk. The fibres are made from casein. After being extracted from milk, the casein is dried and ground and treated with chemicals so that it becomes a thick, sticky, honey-like liquid. This liquid is squirted under heavy pressure through tiny holes called spinnerets and forms soft luxurious fibres called Aralac. Aralac fibre is blended with wool, mohair, cotton, rayon or fur and produces fabrics and felts of unusual beauty.

The foregoing pages should now have brought the young reader to at least a small realization of the tremendous importance of chemistry and its applications in actual life. If he has not been interested, the book is to blame, for the subject is one full of interest and delight. Of course this tremendous field cannot be more than lightly touched upon in a single chapter of a book, and the main purpose has been simply to try to hold your interest until you have read it through, in hopes that you will then have a better understanding of how closely some of the things in this world are linked together, and possess a desire to know more about them.

CHAPTER III

MECHANICS

Some More About Energy

THE young man who is experimenting with physics and chemistry is exploring where all may yet be strange and new to him, but, others, older and more experienced, have gone before and left behind them guideposts to mark the way and prevent him from becoming lost in a seeming wilderness. These guideposts are the definite, *underlying principles of science* which have been discovered, and special emphasis has been here and there employed to bring them strongly to your attention. In the last part of the Introduction to this book, some of the principles which we know about energy were explained, and although these were guideposts of great importance they are of little consequence when compared to one weighty fact which you must always bear in mind if you really wish to understand your adventures in science. Whenever you are performing an experiment, or constructing apparatus of any sort, *you are invariably dealing with ENERGY* in one form or another. Energy came into play in every experiment in the last chapter, because all chemical action involves *chemical* energy and sometimes heat, light, and electrical energy as well.

When experimenting with any of the apparatus described in learning about Heat, Light, Electricity, Magnetism, Radio Telegraphy, etc., you will not only be dealing with these particular forms of energy, but often concerned with the subject of Mechanics. You may understand that heat will boil water and may be caused to drive a steam engine, but some knowledge of *mechanics* is required as well, in order fully to appreciate just how a steam engine moves. That is why this subject is brought to your attention before you are told how to do some of those things. It is probably safe to assume that the reader of this book considers himself to be interested in mechanics, and if he were asked "Why?" would answer, "Because it has to do with machinery and such things." But, in spite of the fact that nowadays there is an almost endless variety of different kinds of machines, they are all really only instruments by which *energy* may be applied or regulated.

Everything which is in motion, whether it is the huge flywheel of a powerful engine or a spinning-top, possesses *kinetic* energy. The pendulum swinging on a clock and the water rushing through an intake to drive a turbine possess *kinetic* energy and also the energy of gravitation.

When you wind your watch, you store up energy in a spring and *the energy of elasticity* keeps the little wheels moving until "run down."

If you try to break a stick of wood or tear a piece of cloth apart, it is the *energy of cohesion* which resists, and tries to hold the little particles of cloth or wood together. So you see you have often been dealing with energy when perhaps you did not know it.

A *machine* may be as simple as a pin for fastening clothes together or as complicated as a huge loom for spinning patterned fabrics, but in every case, kinetic energy, elasticity, gravitation, or cohesion must be depended upon for its successful operation.

Cohesion. The energy which holds things together is called *cohesion*—a word which simply means *sticking together*. Just why cohesion takes place we do not know, but it is one of the commonest things in the world. When you pull on one end

of a rope, what makes the other end of the rope move? It is because of cohesion between all the particles of which the rope fibre is made.

You can't make a rope out of sand because the sand has no cohesion, except just the least bit when it is wet. Cohesion is one of the most important things in the world. The world itself could not exist as it is without the energy of cohesion. Everything which we call solid is solid because the tiny particles of which it is made stick or hold together. All solid things possess the energy of cohesion just as if the tiny parts of which they are made had little hands and were holding on to each other. That is why things can be solid, and why they can have a shape and hold it.

The earth possesses an enormous energy of the sort we call gravity and if there were nothing else to act against this power of the earth's gravitation, everything would crumble down flat so that all the matter particles might be pulled down as near as possible to the centre of the earth.

You could not build a bar out of water, because water possesses very little cohesion to overcome gravitation and it is easily pulled down flat. Some substances possess cohesion of great strength as for instance iron or steel. You can make a bar of almost any shape out of steel and the earth cannot pull it down.

Substances may have cohesion at one time, like ice; may have less at another time, like water, and may yet at another time have absolutely no cohesion at all, like water-vapor.

It is the energy of cohesion, therefore, which holds the particles composing the rods, gears, belts, pulleys, springs, etc., of a machine together. There is of course a limit to the power of cohesion and the engineer who designs and builds machinery must be familiar with the cohesion or *strength* of the various materials which he uses in order for his device to be successful.

Terrible accidents have happened because the tubes in a boiler, the tracks on a railroad, or the flywheel of an engine did not have enough cohesion or *strength.* A huge flywheel has often flown to pieces because it did not possess enough cohesion energy to make the parts stick together.

If you twirl an umbrella which has been out in the rain and wet, very slowly, the drops of water will hold on to the umbrella tightly enough to whirl around with it. But if you spin it faster and faster, the drops of rain will fly off from the umbrella. The *cohesion* of the drops to the umbrella was sufficient to make them stick at first but as they went around faster and faster, it was not sufficient to keep them sticking in place, and so off they flew.

In the same manner, sometimes when the wheel on an engine has been running around too rapidly it has flown to pieces because the cohesion of the particles was not great enough.

The Energy in a Rubber Band

Elasticity. Whenever objects are stretched, compressed, bent, or twisted, they tend as a rule to spring back to their original normal size and shape. Some materials such as tempered steel, rubber, etc., possess this property to a greater extent than others.

If you stretch a steel spring or a rubber band, the particles of steel or rubber, when pulled from their original positions, show a tendency to return and you can feel a distinct pull. Whenever you wind a watch or a phonograph motor, you stretch a steel spring out of its normal position, and it is the energy which the spring exerts in trying to assume its original shape that turns the train of gears. This force is the *energy of elasticity.*

Elasticity is an extremely common property of a great many substances and of great importance. If it were not for this sort of energy, almost every object which we touch or come into contact with would soon become badly distorted and out

of shape. The very pencil which you write with bends a little when you bear down on the point to mark on a piece of paper, only an imperceptible bit, it is true, but if it were not for elasticity causing it to spring back into shape, it would soon become badly bent from continued usage.

Think out for yourself how the table is compressed when an object is laid upon it; how the floor bends when you walk over it; how a bridge yields when a heavy load crosses it, and any other cases of stretching, compression, bending, etc., and you will realize what an extremely important energy is the energy of elasticity.

The Energy of a Moving Object

Kinetic energy. Anything which is in motion possesses energy of the sort we call *kinetic* which simply means "moving." The heavier the object is, and the faster it moves, the more energy it possesses. If a small rowboat bumps against a wharf, it does no damage to the pier but if a huge steamship misses her berth, the tremendous kinetic energy stored in the ship on account of its enormous weight may cause serious damage. Surely you would rather be struck by a small hailstone than a baseball. The baseball is heavier than the hailstone and possesses more kinetic energy.

FIG. 34. — If you first get up speed you can stop pedaling and coast a short distance on a level road. The kinetic energy stored in your body and in the bicycle because of their weight and motion carries you forward.

But a small object can sometimes travel at such a high speed that it possesses more energy than a heavier, more slowly moving body. You can catch a heavy ball with your hands but if you were to attempt to stop a much lighter though rapidly moving bullet it would seriously injure you.

When you are riding a bicycle along a level road you can coast a short way if you stop pedaling. The kinetic energy stored in your body and the bicycle because you are moving, will continue to carry you forward.

Remember therefore that all the moving parts of any apparatus or machines which you may build possess *kinetic* energy when they are in motion.

Fig. 35.—It is the energy of *gravitation* which enables you to coast downhill on a bicycle.

The Energy Which Makes the Raindrops Fall

Gravitation. We often speak of an object as weighing a certain number of pounds or ounces, but do we stop to think what we really mean?

One of the laws of nature is that all objects attract each other and if they could, they would all bunch up together in one big mass. This attraction between objects is so extremely small, that while it can be measured with very delicate instruments, it is not great enough actually to cause them to move, and so we do not usually have any evidence of it before our eyes. Large objects exert a much greater attraction for each other than smaller ones. This earth upon which we live is so huge that it exerts a very noticeable effect upon all other bodies. Everything on this earth is being pulled down by the energy of gravitation so as to get us as close as possbile to the centre

of the earth. That is why a stone which we hold in our hands falls when we let go of it. It is pulled down by the energy of gravitation and tries to get as close as possible to the centre of the earth. That is also why water flows down mountains, down brooks, down rivers, always downward and into the sea. The

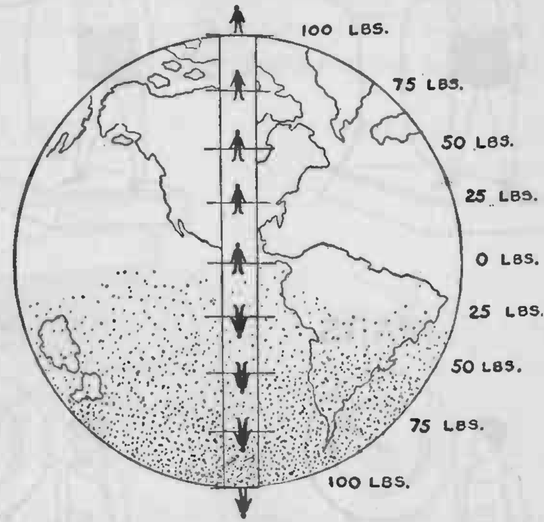


Fig. 36.—If you could descend a shaft which passed through the center of the earth your weight would grow less as you moved down from the surface. At the center of the earth you would have no weight.

bottom of a hill is nearer the centre of the earth than the top, and the energy of gravitation is the force which makes the brook run and enables you to coast downhill on a bicycle or a sled.

A *pound,* an *ounce,* or a *gram is only a measure* of the force with which the energy of gravitation pulls an object towards the centre of the earth. If gravitation ceased, there would be no more weight.

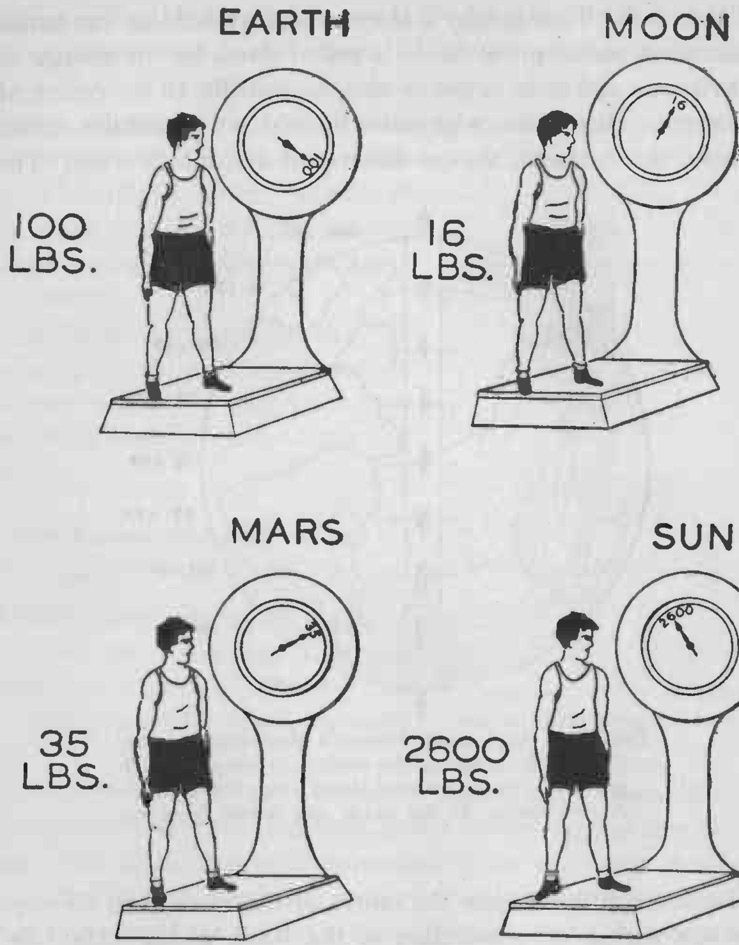


FIG. 37. — For each 100 lbs. that you weigh on earth your weight would be 16 lbs. on the moon, 35 lbs. on Mars and 2600 lbs. on the Sun.

Gravitation does cease at the *centre* of the earth. If a hole could be drilled right through the earth from the north pole to the south pole and you could descend into the shaft thus formed *you would weigh nothing* when you reached the centre.

As you started to leave the centre and pass out toward the other side you would gain in weight until you reached your normal weight on the surface at the south pole.

Since the earth's force of gravity is due to its enormous size, the gravity on the other heavenly bodies, such as the moon, Mars, and the sun will vary according to their size.

If you weigh one hundred pounds here on earth and could go up to the moon and be weighed in the same pair of scales

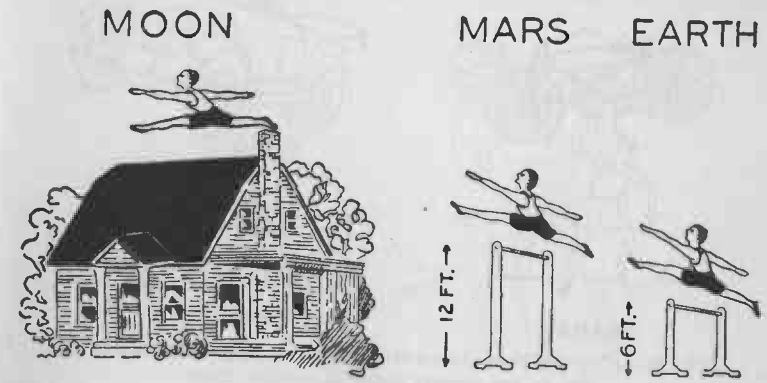


FIG. 38. — The force of gravity is much less on the moon and on Mars than it is on earth. If you can jump a hurdle 6 ft. high on earth, you could jump 12 ft. on Mars and over a house on the moon.

you would only weigh about sixteen pounds. On Mars you would weigh about thirty-five pounds while on the sun, its enormous mass would tend to draw you down to its centre so strongly that you would weigh 2600 lbs., or over one ton. You would be so heavy on the sun that you would not be able to raise your own weight but on Mars you would be so light that you could easily jump over a hurdle ten or twelve feet high, while on the moon you would have no difficulty in jumping over a house.

Other objects would be proportionately lighter, and on Mars you could lift your motorcycle with one hand while on the moon you could make reputation as a strong man by picking up an automobile and putting it over your head.

The energy of gravitation is always at work. No matter where you go, except to the centre of the earth, you cannot avoid it. It is the force which brings the raindrops down out of the sky and then sends them trickling into brooks and rivers

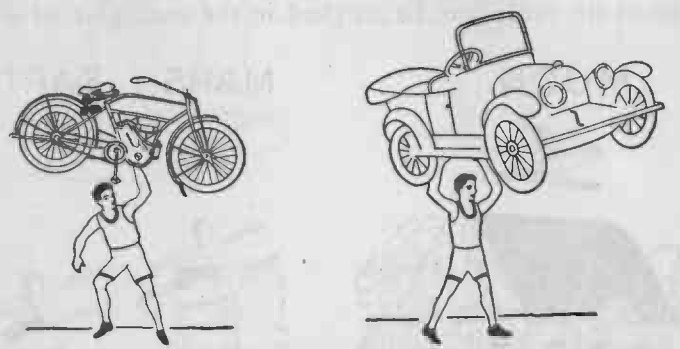


FIG. 39. — You could pose as a strong man on Mars or on the moon due to the weaker force of gravity there.

to rush down to the ocean. This energy of gravitation, combined with the kinetic energy of the water because it is moving, is the force that drives water-wheels and turbines. Here in the United States, we have machinery doing work which would require nearly three billion men. The energy which drives this enormous amount of machinery is principally produced by burning coal or oil but some of it is furnished by the kinetic energy of waterfalls.

Something About the Principles of Mechanics

Machinery utilizes energy to accomplish some useful purpose. A loom may use the kinetic and gravitation energy of

a stream of water running through a turbine to weave rugs and fabrics. An automobile changes the heat and chemical energy of burning gasoline into motion for carrying us from place to place. Machines apply and control energy by means of various levers, pulleys, gears, springs, etc.

The gyroscope, telautograph, harmonograph, pantograph, hydraulic ram, water wheel, etc., described farther on in this chapter are all machines for utilizing energy for some particular purpose by means of various levers, pulleys, and other

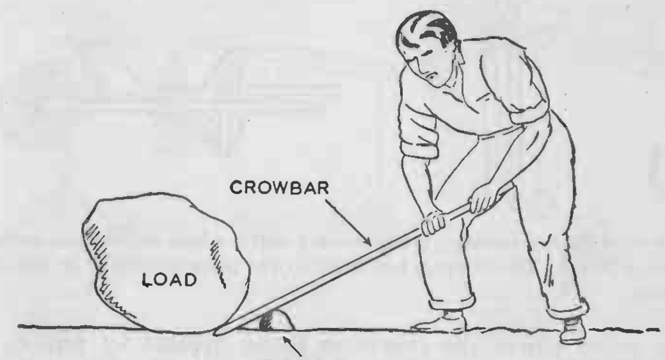


FIG. 40. — The crowbar is one of the most common forms of lever and is used for moving large stones and other heavy objects.

mechanical movements. You can derive a great deal of pleasure in building and using any of these devices and incidentally learn a great deal about various forms of mechanical motion.

There are certain fundamental principles or laws governing levers, pulleys, and gears which it is well to know.

The Lever. Any rod or bar, straight or curved, which is used to raise a weight or produce motion and which rests on a fixed point or *fulcrum* is called a *lever*. One of the most common forms of lever is the *crowbar,* used for raising large stones and other heavy bodies. A pair of scissors or pliers or nutcrackers is a double lever. The fulcrum is the pivot or screw. A wheelbarrow is a form of lever in which the fulcrum is set on a wheel.

The force obtained by a lever depends upon the length, the power applied, and the distance of the weight and power from the fulcrum.

The illustration shows two levers. A bar of wood is resting on a fulcrum and arranged so that the distance from the fulcrum

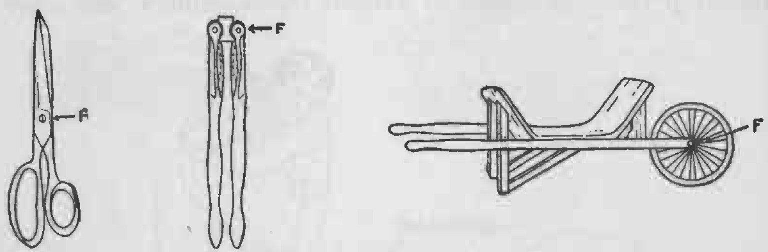


FIG. 41. — A pair of scissors, a nut-cracker and a wheel-barrow are common forms of levers. The fulcrum is located at the point marked F in the illustration.

to the point where the power is to be applied by pulling on a rope is twice as great as that between the fulcrum and the weight. The force with which you must pull on the rope is only one-half the weight of the object to be lifted, but the end of the lever to which the rope is attached will move twice as far as that from which the weight is suspended.

If the position of the fulcrum on either lever is shifted so that the distance between the point where the power is applied by pulling on the rope is four times as great as that between the fulcrum and the weight, the force with which you must pull is only one-fourth the weight of the object to be lifted, but the end of the lever to which the rope is attached will move four times as far as the weight.

You can see, therefore, how by making the distance between

the weight and the fulcrum very small and the other part of the lever quite long in proportion, it is possible to move a very heavy weight with little effort. From this you must not think that a lever makes power out of nothing. The secret lies in the special way in which the power is applied to the weight it has to move. If we use a crowbar to move a heavy stone, we shall

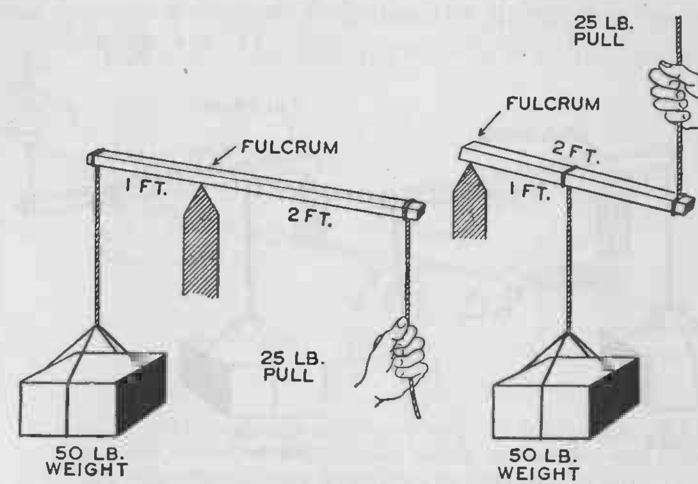


FIG. 42. — If a lever is arranged so that the distance from the fulcrum to the point where the power is applied is twice that between the fulcrum and the weight, the pull on the rope necessary to lift the object must be only slightly more than one-half the weight of the object to be lifted. A 25 lb. pull will lift a 50 lb. weight.

see that the two ends of the lever move through very unequal distances in the same time. The end which is under the stone moves a very short distance. The other end moves a much greater distance. We have not enough strength to move the lower end of the lever which is under the stone by pressing there, but we can get the stone to move by using our strength at the top end of the lever over a greater distance. Less power is required there, but it is required to act through a greater distance.

The seesaw is a form of lever which may enable you better to understand how a small weight can move or balance a much greater weight. It is possible for a small boy sitting at one end of a seesaw to balance a much heavier boy, sitting *half-way* along towards the other end. The light weight at one end balances the heavy weight on the other end because the power

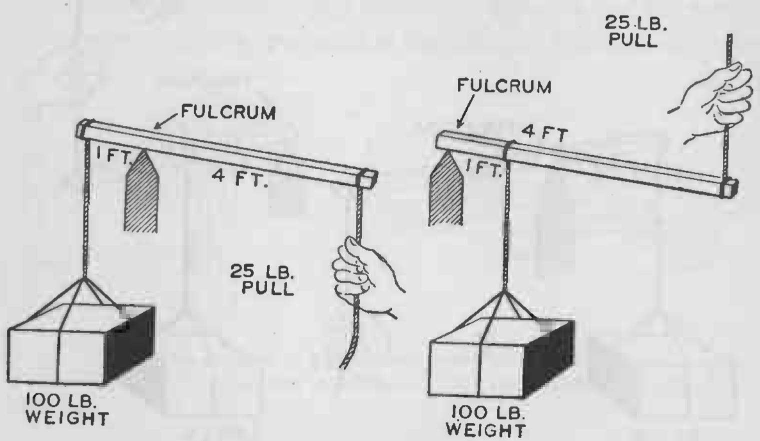


Fig. 43. — If a lever is arranged so that the distance from the fulcrum to the point where the power is applied is 4 times as great as that between the fulcrum and the weight, the pull required to lift the object must be only slightly more than one-quarter the weight of the object to be lifted. A 25 lb. pull will lift a 100 lb. weight.

of the two forces depends upon their distance from the *fulcrum* or point where the seesaw is supported. If we weigh the two boys and measure their distances from the centre of the seesaw, we shall have some figures which show plainly the condition on which a seesaw can be balanced. When the weight of one boy, multiplied by his distance from the centre of the seesaw, is exactly equal to the weight of the other boy, multiplied by his distance from the centre of the seesaw, the two boys will balance.

Pulleys are really a kind of circular lever and by their means it is possible to make a small amount of energy acting over a considerable distance raise a heavy weight a shorter distance.

There are two kinds of pulleys, *fixed* and *movable*.

A fixed pulley affords no mechanical advantage in making it possible to lift a heavy weight with a small amount of power, but is simply convenient in changing the direction of the application of the force. If a fifty-pound weight is hung on one end

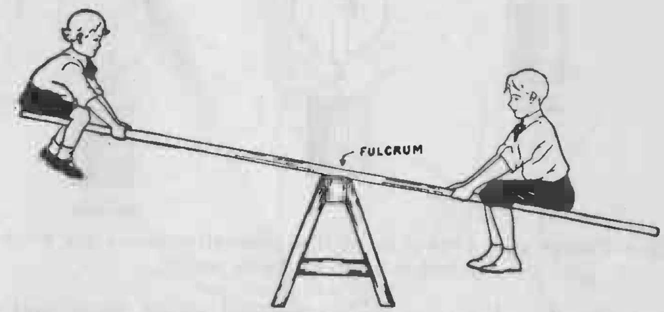


Fig. 44. — The seesaw is a form of lever. A light weight at one side will balance a much heavier weight on the other side if the lighter weight is farther away from the fulcrum.

of a rope passing over a fixed pulley, it will require a fifty-pound pull on the other end of the rope to balance the weight. The rope will have to be pulled down a distance equal to that which the weight is raised.

But in the case of a movable pulley, where one end of the rope is suspended from a beam and the weight is attached to the pulley, a fifty-pound weight may be balanced by a pull of only twenty-five pounds. An upward pull on the rope which is slightly in excess of twenty-five pounds will raise the weight, but the rope will move twice the distance which the weight rises.

If several pulleys are joined together on a common axis

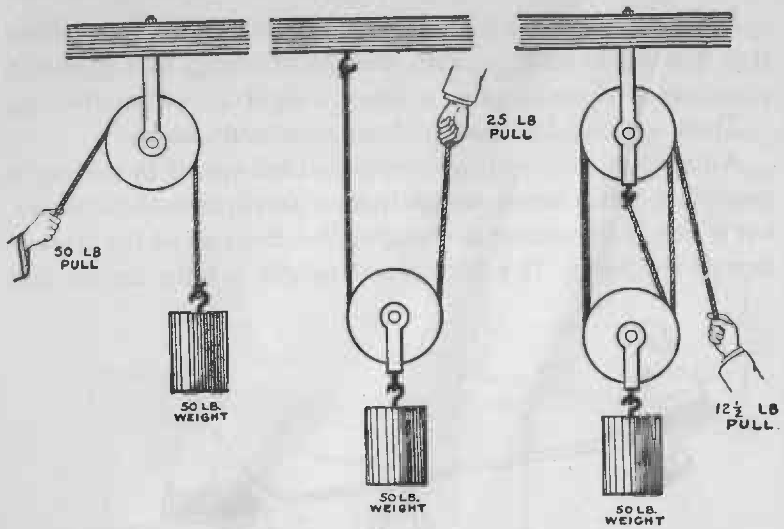


FIG. 45. — Pulleys are a form of lever. The illustration shows how much pull is required to balance a 50 lb. weight.

which is fixed and a rope passes around all of them and also around a similar but movable combination of pulleys, the arrangement is called a *block and tackle.* A proper block and tackle enables one man to lift a very heavy weight such as a piano or a safe. The rope upon which the man pulls must, however, move several times the distance which the weight rises.

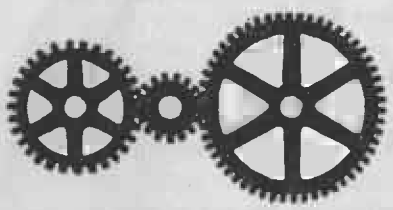


FIG. 46. — Gears are wheels whose motion is transmitted from one to another by means of teeth around their circumference.

Gears are wheels, the motion of which is transmitted from one to another by means of teeth fitting in each other on the circumference of the wheels.

If a small gear is meshed with another gear of four times its size, the small gear will revolve four times to one revolution

of the large one. If the shafts or axles of the two gears are the same size and a cable or rope supporting a weight which would tend to turn the pulleys is wrapped around each, a weight of ten pounds on the shaft of the small gear will balance a weight of forty pounds on the shaft of the larger gear.

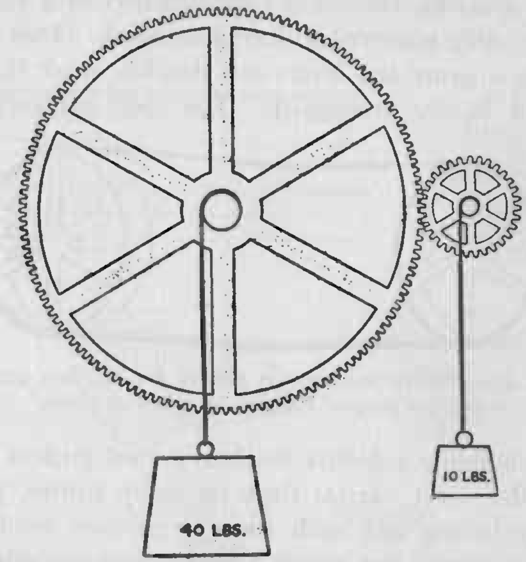


FIG. 47. — Gears are a form of lever. If a small gear is meshed with another gear four times its diameter, the small gear will revolve four times to each revolution of the large one.

Motion can be transmitted from one wheel to another by means of a flexible belt or chain passing around the circumference of each. Such wheels are really gears, coupled together by the belt or chain instead of their toothed edges.

If you have paid close attention to what has been said in the preceding pages about the lever and the various forms which it takes in the shape of pulleys, gears, etc., you will be prepared to understand that no machine, however simple or complex, can *create* energy. Machines use and apply energy but they do not create it. While it is true that by means of a system of levers or a machine, one man may lift a weight, which would require a hundred men without a machine, it would take him *one hundred* times as long.

Anyone who has watched the construction of a large building has probably observed a derrick at work. This is an example of how gears and levers can simplify work that muscle alone could hardly accomplish. The steel erector's derrick

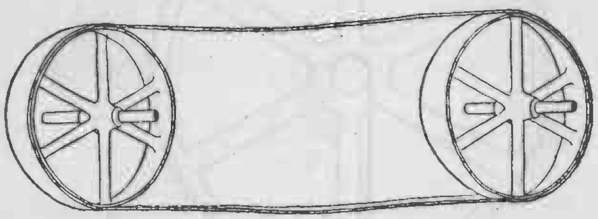


FIG. 48. — Power transmission pulleys are in effect gears which are coupled together by a belt or chain.

used on a building job lifts the heavy steel girders from the trucks in the street, carries them up many stories, puts them where they belong and holds them in position until they are fastened. A derrick can handle a heavy beam weighing several tons as easily as a carpenter can carry an ordinary plank.

Now you are ready to pursue your adventures by putting levers and pulleys to work.

How to Build a Pantograph

The pantograph is a practical and helpful instrument often used by architects and designers in copying plans or designs. It will produce an enlarged or reduced copy of the original, or one which is the same size.

It is a simple arrangement depending upon a system of levers for its operation. Elaborate pantographs, made in a very

accurate manner are often an important part of some types of engraving-machines, embroidery looms, etc.

To make one, take four sticks of wood, five-eighths of an inch wide and one-quarter of an inch thick. Two of the sticks should be eighteen inches long, and two of them nineteen inches long. Small holes, half an inch apart, should be drilled along the entire length of each stick. The holes should be about one-

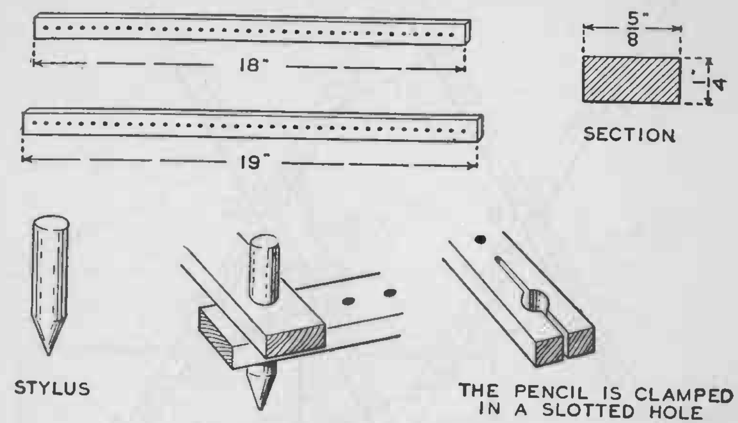


FIG. 49. — Parts of the pantograph.

sixteenth of an inch in diameter. One of the long sticks should have a large hole, into which a pencil will fit tightly, bored an inch from one end.

Make a stylus like that shown in the illustration. Join the two shorter sticks by inserting the stylus through the end holes as at *S* in the illustration. Join the two longer sticks together with a screw eye as at *E*. Screw eyes also join the short and long sticks together where they cross.

The free end of the long stick *A*, is pivoted to a small wooden block one-half an inch thick and two inches square by means of a screw eye. The block must be fastened to the table when the pantograph is used.

The joints must all be firm, so that there will not be any lost motion in the apparatus.

The drawing or design to be copied is placed under the stylus and fastened to the table so that it will not move. A sheet of blank paper is placed under the pencil. If the outlines of the

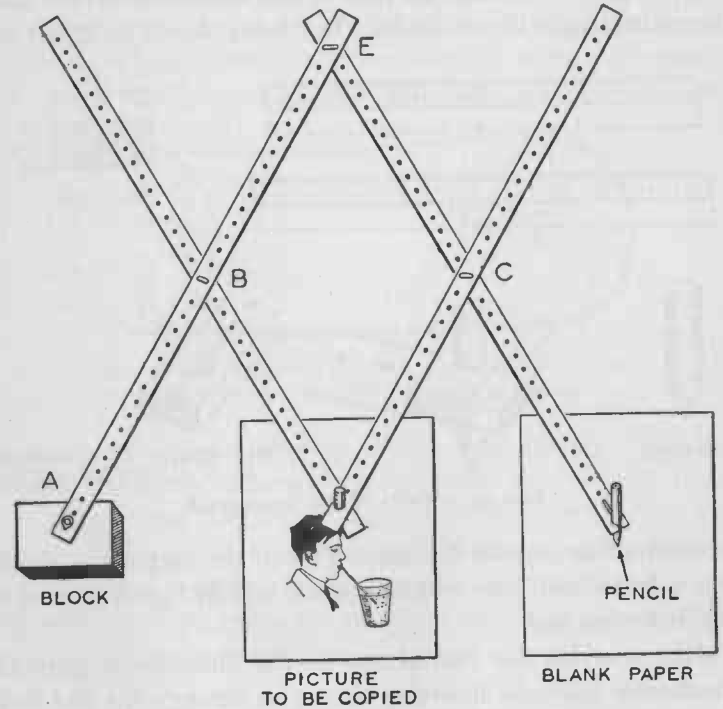


FIG. 50. — The completed pantograph.

drawing to be copied are traced with the stylus, the pencil will move and reproduce it on the paper. By varying the position of the screw eyes so that the sticks cross each other at different points and the relation of the levers is changed, the size of the drawing produced is also changed. If the points *B* and *C*

are in the middle of the sticks, the pencil will trace the picture in its original size. The distance from *S* to *B* and from *S* to *C* should always be kept equal or the drawing will be distorted.

A Mechanical Telautograph

The term "telautograph" is the name given to an electrical instrument invented by Elisha Gray which will reproduce at

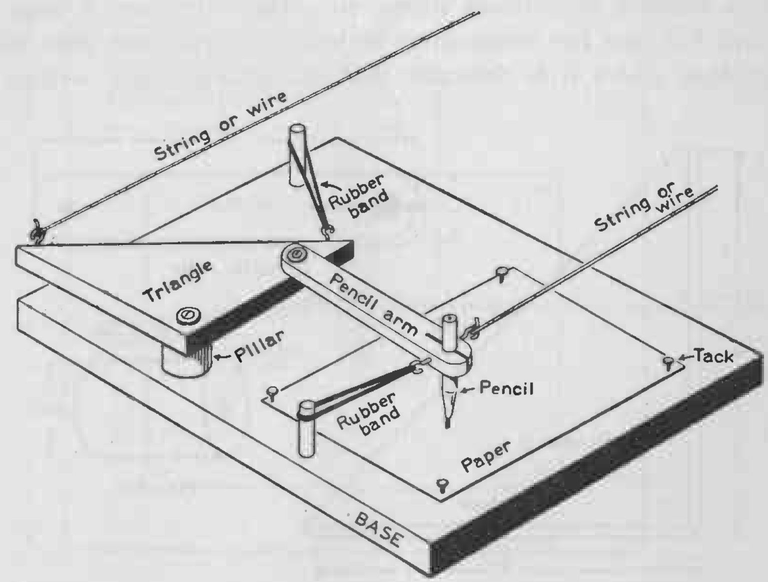


FIG. 51. — A mechanical telautograph like that above will transmit writing and drawing from one room to another.

a distance the writing or pictures made with a pen. The name is compounded from the Greek words meaning "afar," "self," and "write."

At the transmitting station, a pen is connected by cords to a mechanism by means of which the motions of the pen cause a pulsatory current to pass into two telegraph line wires. The pulsatory currents produce a motion in the armatures of a system of electromagnets. The movement of the armatures is such as to move a receiving pen so that it follows the motion of the transmitting pen. Another electromagnetic arrangement lifts the receiving pen off the paper at the end of each word or line, and still another serves to move the paper forward at the end of each line.

These devices can now be seen in a great many hotels, railway stations, department stores, etc., where they are in practical daily use for transmitting orders, etc., from one place to another where it is desirable that the message be a written

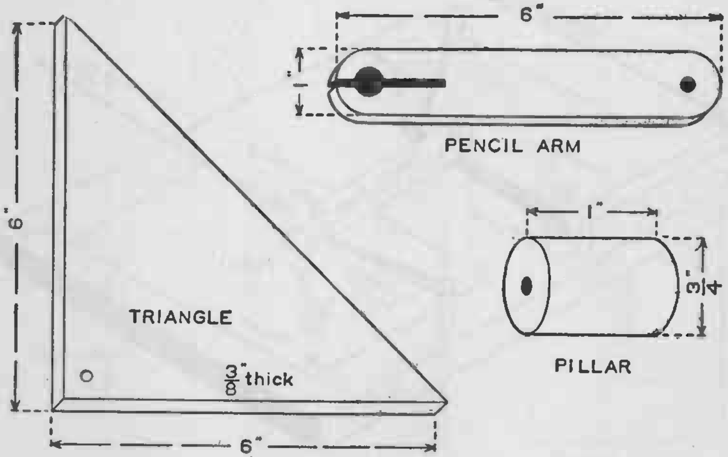


FIG. 52. — Parts of the mechanical telautograph.

record. The telautograph is used in a great many of the United States coastal fortifications to transmit the range and firing orders. The use of a telephone is limited in such a place on account of the noise. The mechanical telautograph illustrated is a simple arrangement, depending, like the pantograph, upon a system of levers for its operation. It is capable of reproduc-

ing, with considerable accuracy, writing and sketches made with a pencil. Two of these machines set up at the opposite

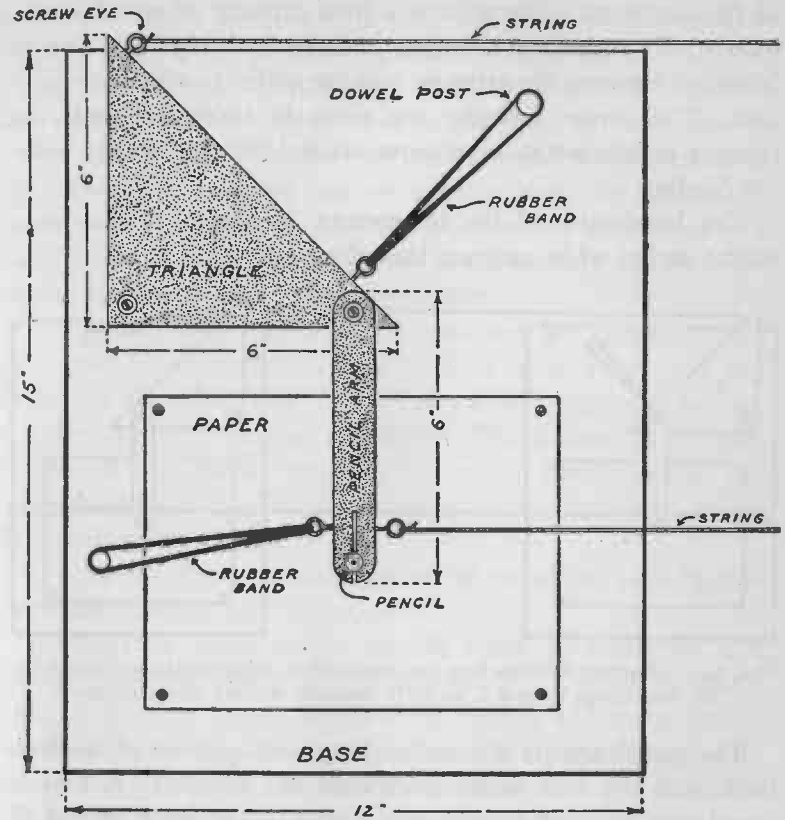


FIG. 53. — Plan of the complete mechanical telautograph.

ends of a long hall or room will transmit writing and pictures back and forth.

A right-angled triangle is cut out of wood three-eighths of an inch thick. Each of the two sides joining the right angle is six inches long. A one-quarter inch hole is bored through the right-angled corner of the triangle to receive a round-headed wood screw and a washer as a pivot. The triangle is mounted on a pillar fastened near the upper left-hand corner of the baseboard. The pillar is a little cylinder of wood, three-quarters of an inch in diameter and one inch high. A washer is placed between the triangle and the pillar to eliminate friction. The screw forming the pivot is tightened until the triangle is firm but still can move around the pivot easily without binding.

The baseboard of the instrument is fifteen inches long, twelve inches wide, and one inch thick.

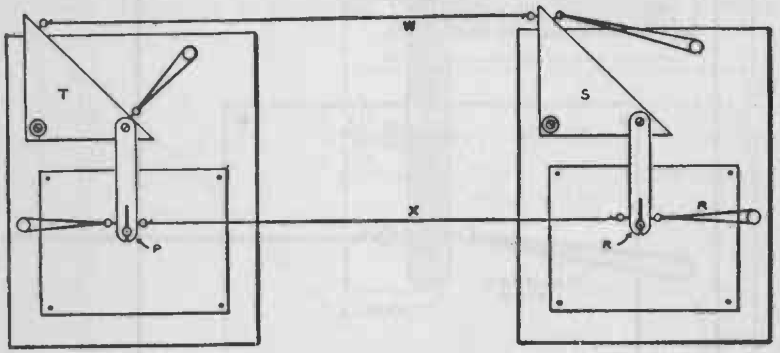


Fig. 54. — Diagram showing how two mechanical telautographs are connected by the strings W and X so as to transmit writing and sketches.

The pencil arm is six inches long, one-quarter of an inch thick, and one inch wide. Both ends are rounded. A hole is bored near one end to receive a pencil. The pencil should fit in tightly, and so a saw-slot is cut the same distance up into the end to prevent the wood from splitting and to hold the pencil tightly. The other end is bored to receive a wood screw so that it may be pivoted to one corner of the triangle as in the illustration. A washer placed between the arm and the triangle will permit the parts to move without friction.

Two screw eyes are fastened to the end of the pencil arm

near the pencil. A rubber band runs from one of these to a dowel post set in the left-hand side of the base. A piece of steel wire or, in the case of a very short line, a stout string is fastened to the other screw eye and runs to the corresponding eye on the other instrument. A third screw eye is placed at the corner of the triangle where the pencil arm is pivoted.

A rubber band is fastened to this eye and stretched across to a dowel post near the rear or upper edge of the baseboard. A screw eye is placed at the other free corner of the triangle and a line connected to it which runs to the corresponding corner of the triangle on the other instrument.

The rubber bands on both the machines are adjusted until they exactly counterbalance the pull of each other and the weight of the connecting lines. The rubber bands pull against the line, that is, in reverse directions. This makes it necessary to connect one rubber band on the second instrument to the free corner of the triangle instead of to the corner at which the pencil arm is pivoted.

A piece of paper is placed under the pencil of each instrument and fastened with tacks.

Writings or drawings are usually made on a surface and are therefore confined to two dimensions. If a pencil is drawn across a sheet of paper from left to right it will leave behind it a horizontal line. If it is then moved at right angles to this line, it will produce a vertical line. A line at an angle of forty-five degrees may then be formed by moving the pencil horizontally and vertically at the same time and at the same rate of speed. It is thus possible to analyze any line, straight or curved, into two component motions and reproduce them on our little machine.

Two complete "telautographs" may be set up and arranged so that the lines turn a corner as may often be necessary when running from one room to another. The triangles are the same size as those used on the instruments themselves and are pivoted in the same manner.

If the pencil, *P*, is moved from left to right in order to make

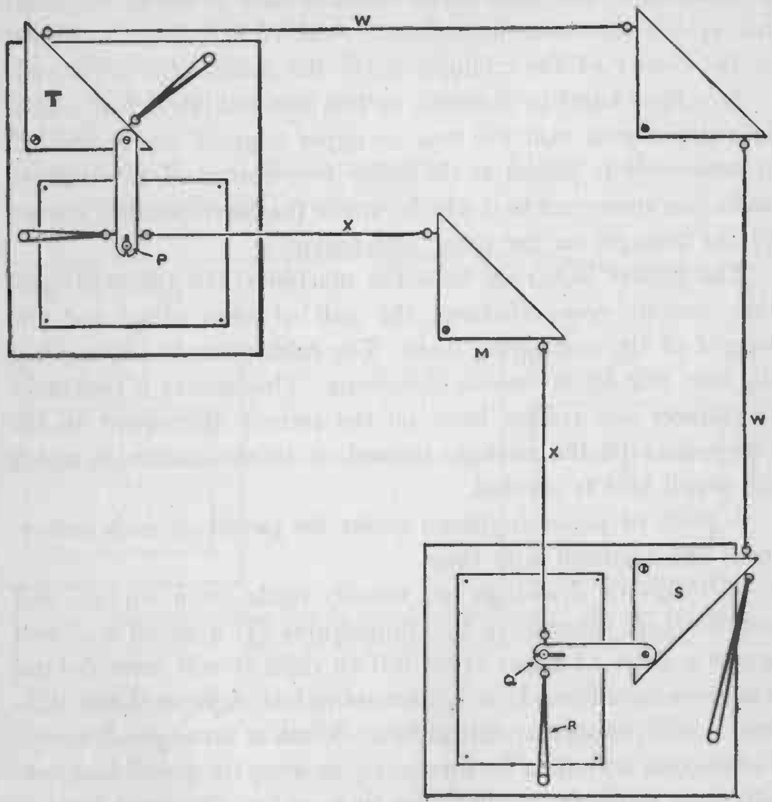


FIG. 55. — The wires or strings, W and X, connecting the telautographs can be made to turn a corner by utilizing two "bell cranks" as shown above.

a horizontal line, the wire, *X*, will slacken and the triangle, *M*, will transmit its motion so that the rubber band, *R*, may pull the pencil, *Q*, across the paper, the same distance that *P* moved. If *P* is then moved up, the wire, *X*, will remain station-

ary as regards its tension, but the triangle *T* will move around its pivot and pull *Q* in a straight line at right angles to the first. A slanting line made by *P* will result in a movement of both wires and will be properly reproduced by *Q*.

The only difference that the machine makes in the facsimile is that the lines are sometimes slightly irregular, due to a sticking tendency of the pencil, if an attempt is made to reproduce fine writing. The writing is always connected, since no provision is made for raising the pencil at the receiving end.

The writing should always be large and clear. The size of the "telautograph" may vary from that described to one in which the various parts are made four or five times as large. The larger the machine the farther it will operate. For a line of any appreciable length, a steel wire should be used to connect the instruments and very stout rubber bands to keep the wires taut.

Simple Experiments with Pendulums

Tie a stone on the end of a piece of string and fasten the other end of the string to a firm support. Pull the stone to one side a short distance and then let it go. It will swing to and fro for a long time. This is a *pendulum*. Once you have started it, it swings back and forth by gravity until it stops. Why won't it swing forever? What stops it? The principal thing which stops it is the resistance of the air. While your pendulum is swinging back and forth, count the number of swings, until you reach one hundred. Commence to count at the beginning of a minute as shown by the second hand on your watch and note how many seconds have elapsed during one hundred swings of the pendulum. This time, divided by one hundred will give the time of a single swing.

Shorten the string so that it is only one-half as long as before and count the number of seconds which elapse during one hundred swings. You will find that the pendulum now swings considerably faster. A short pendulum always swings faster than a long pendulum.

You may wonder if a heavy pendulum will swing faster than a light one. Try it and find out for yourself. Make two pendu-

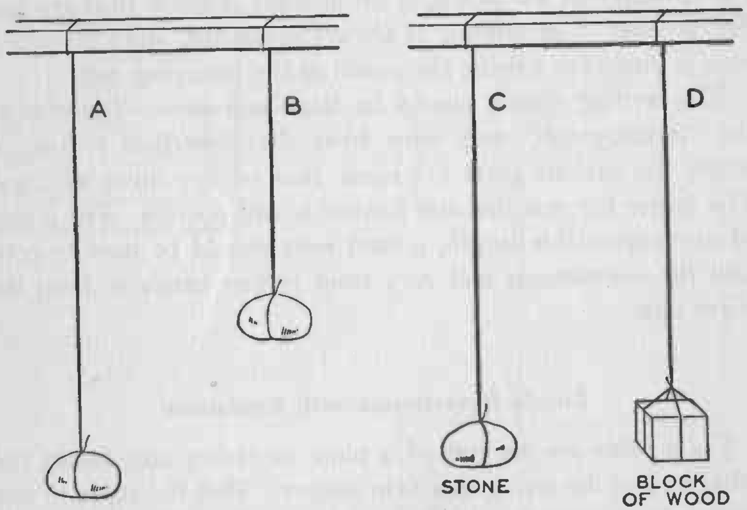


FIG. 56. — A is a simple pendulum consisting of a stone tied to a string. B is a pendulum of the same kind as A but has a shorter string. C and D are pendulums of exactly the same length. The weight used on C is a stone. The weight used on D is a block of light wood weighing less than the stone.

lums of exactly the same length, using a wooden block as the weight on one and a heavy stone on the other. Start the pendulums swinging at the same instant. They will keep pace very closely and any slight difference which you may notice will be due to the fact that their lengths are not exactly equal.

The weight of a pendulum does not affect its time of swing. The time depends upon the length, and two pendulums of the

same length will swing back and forth at the same rate of speed.

This fact is utilized in the measurement of time by employing the pendulum to regulate clocks. As the pendulum swings back and forth, it allows the ratchet wheel to move one tooth for each swing of the pendulum.

The height of a pendulum above sea level and its distance between the earth's poles and the equator affect the time of its swing slightly. A pendulum 39.11 inches long will swing across and back to the point it started from in just one second at sea level.

You can utilize the principle of the pendulum to build an interesting device called a "harmonograph."

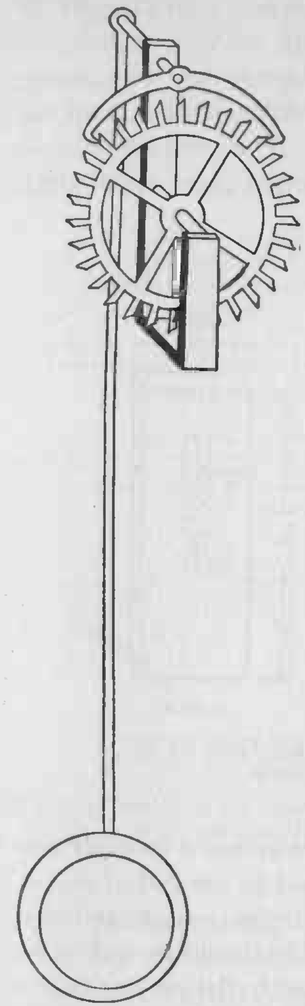


FIG. 57. — A practical use for the pendulum is to regulate clocks. The illustration shows the pendulum and escapement of a clock.

How to Build a Harmonograph

Probably few boys have heard of a harmonograph and fewer still have ever built one. It is really a very interesting piece of apparatus, and nothing else so easily constructed will afford such endless amusement.

When the harmonograph is set up and in motion it will draw countless beautiful and intricate designs which it would be practically impossible to draw free-hand. The harmonograms, as they are called, are symmetrical in detail and no two will ever be exactly alike. You may try to make a duplicate innumerable times, but without success.

The apparatus is not complicated, and consists of two pendulums swinging from a board. One pendulum swings with the board and the other at right angles to it. The latter has a small table attached to it which carries the sheet of paper upon which

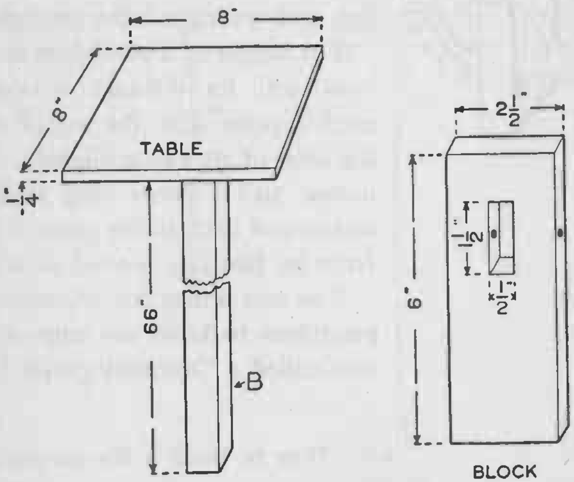


FIG. 58. — Details of the table, stick and block for the harmonograph are shown above.

the design is to be traced while the former has a movable arm with a pencil or stylographic pen attached to one end of it.

The table is a piece of wood, eight inches square, and one-quarter of an inch thick. The upper side should be well sand-papered so that the paper will lie perfectly flat on it. Bore a small hole through the centre of this piece and screw it on the end of a stick, *B*, sixty-six inches long and one inch square. It is well to help the screw with a little glue so that the table cannot twist.

The pendulum carrying the pencil is not quite so simple. Make a block of wood, *C*, six inches long, two and one-half inches wide and one-half an inch thick. Cut a hole one and one-half inches long and one-half an inch wide in this block, one inch from the top as shown. A small hole, one-eighth of an inch in diameter, must be bored across the width of the block,

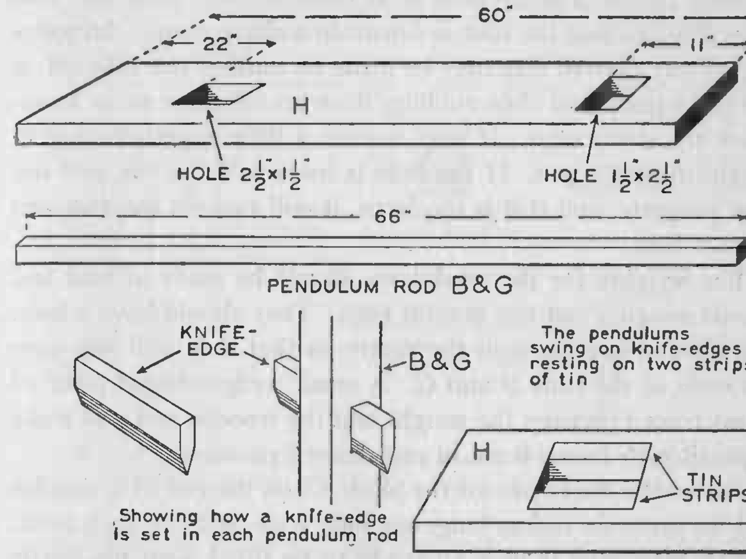


FIG. 59. — Details of the table, pendulum rod for the pen arm and the knife edges used on the harmonograph are shown above.

through the centre of the square hole and out the other side as shown in the drawing.

The pen arm is a stick of wood, thirty inches long, and one-half an inch wide by one-half an inch thick. Nine inches from one end, bore through the arm a small hole into which a piece of one-eighth-inch brass or iron rod will fit tightly. The rod is used as a spindle and should be two and one-half inches long. Slip the arm through the slot in *C* and put the spindle in place so that when the arm and the block are assembled they will appear as in the sketch.

On the long end of the arm, fit a tin clamp or clip into which the pen will fit.

The pen is easily made from a piece of one-quarter-inch glass tubing. Heat the tube in the flame of an alcohol lamp or a Bunsen burner and as soon as it becomes soft draw the two ends apart so that the tube is drawn to a sharp point. An opening of any desired size may be made by cutting the tube off at the right point and then rubbing it on an oil-stone so as to remove the sharp edge. It may require a little experimenting to obtain the right pen. If the hole is too small, the ink will not flow properly, and if it is too large, it will run out too fast and form a blot.

The weights for the pendulums should be made of lead and should weigh about five pounds each. They should have a hole, one inch square through the centre so that they will slip over the ends of the rods *B* and *G*. A small wedge-shaped piece of wood forced between the weight and the wooden rod will make it possible to fasten them in any desired position.

Fasten the lower part of the block, *C*, on the end of a wooden rod, *G*, sixty-six inches long, one inch wide, and one inch thick.

The apparatus is now all ready to be fitted with the knife-edges or blades upon which the pendulums swing. Measure from the lower ends of the two pendulum rods, *B* and *G*, a distance of five feet and make a pencil mark.

Make two strips of brass or steel, two inches long, one-sixteenth of an inch thick, and three-eighths of an inch wide. File one of the long sides to a sharp edge. These are the pivots upon which the pendulums swing. Force one through each of the sticks, *B* and *G*, at the point marked by the pencil line with the sharp edge downwards. In the case of the pendulum, *B*, carrying the little table, it will not matter which side the knife-

edge passes through, but care should be taken to see that the blade is at right angles to the pencil arm.

The apparatus is mounted on a board, sixty inches long, four inches wide, and about three-quarters of an inch thick. Twenty-two inches from one end, cut out a rectangular hole, two and one-half inches long, and one and one-half inches wide. Eleven

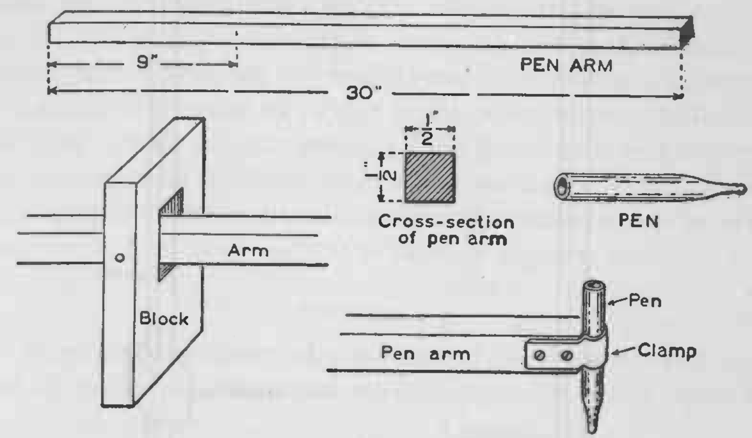


FIG. 60. — The pen is made from a piece of glass tubing. It is clamped on the end of the arm and the arm is supported in the block.

inches from the other end, cut a second hole of the same size. In the case of the first hole, its length must lie with the length of the board and in the case of the second, it should be across the board. Fasten a piece of tin or sheet iron, two and one-half inches long by one and one-half inches wide at the side of each hole as shown in the illustration.

The harmonograph is now ready to set up and operate. Place the long board between two step-ladders or some high objects at least five and one-half feet from the floor. Set the shaft with the pen upon it in the hole which runs with the length of the board, and the other pendulum carrying the table

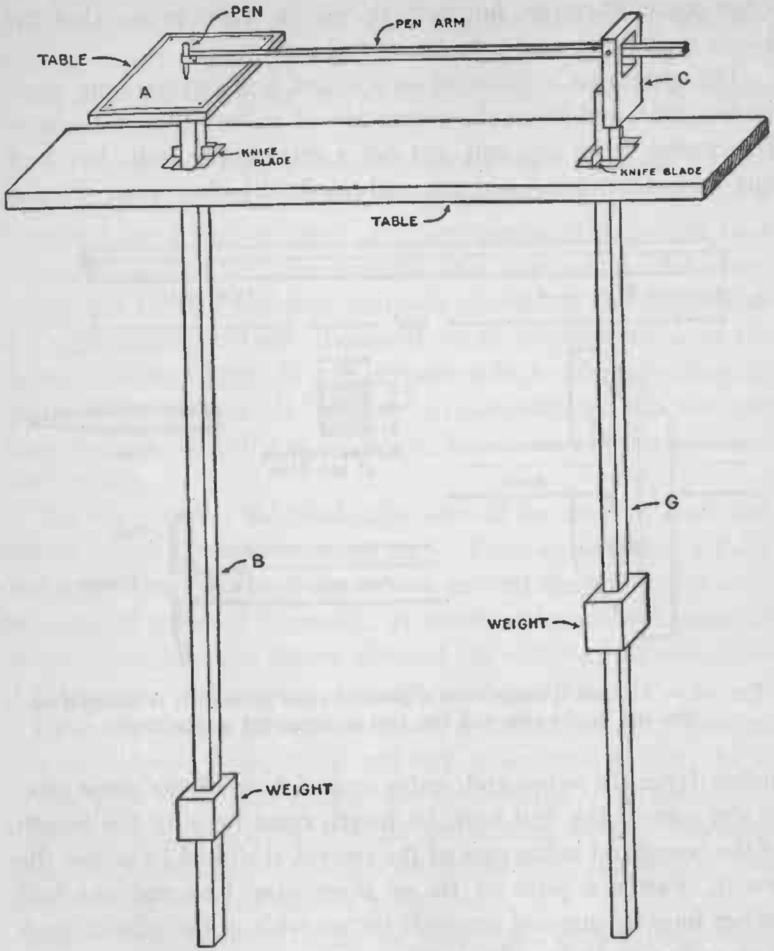


Fig. 61. — The completed harmonograph.

in the other hole. Set the weights on the rods and a piece of smooth paper on the table. Fasten the paper in place with thumb-tacks at the corners. Put the pen in the clip at the end of the arm and fill it with ink.

Hold the pen up off the paper with one hand and set the pendulums swinging on their knife-edges, one, one way and the other, the opposite way. Let the pen down gently on the paper and watch the result. It will surprise and interest you.

You can vary the designs greatly by altering the length of the pendulums, that is, raising or lowering the lead weight. You will find by experiment that you can secure the best results when the pendulums swing in ratios of one to two, two to three, one to three, etc. By ratio is meant the number of swings of one to the number of swings of the other in the same length of time. With any one setting of the pendulums, you can get any number of different designs by starting the pendulums swinging at different times in relation to each other, or by giving one a hard push and the other only a gentle start.

The Gyroscope

Have you ever heard of a *gyroscope?* A gyroscope is a sort of top which is a wonderful scientific toy. Every top, when it

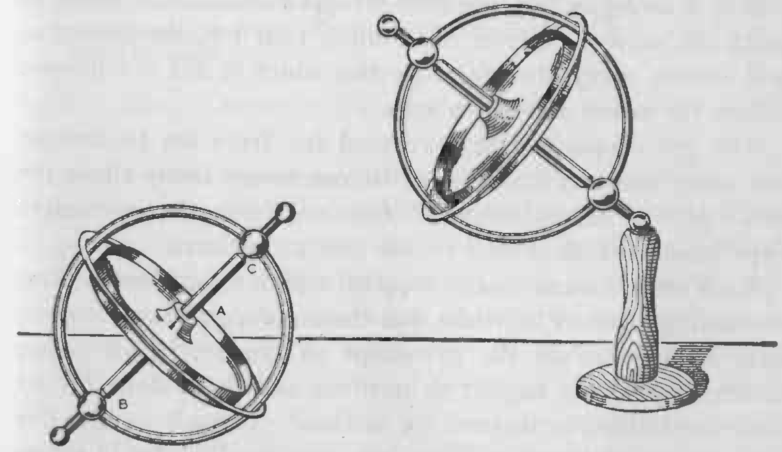


Fig. 62. — At the left is a toy gyroscope at rest. At the right, the same gyroscope is shown spinning on its stand.

spins, exhibits gyroscopic action. That is why it stands up and balances itself on its point when spinning and falls down as it stops.

A heavy wheel, capable of rotating about its axis with considerable speed is called a *gyrostat*. The *gyrostat*, together with the arrangement by which it is supported, is called a gyroscope. Sometimes the word gyroscope is wrongly applied to the simple rotating wheel.

The most common form of gyroscope is a sort of top which is supported at both ends. You will perhaps understand better by referring to the illustration which shows one lying at rest. This toy may perhaps be familiar to many boys, who have seen it sold on the streets of the larger cities by peddlers. Some of you may have had the opportunity of making it perform the curious tricks of which it is capable.

The wheel, *A*, can rotate about the axis, *B C*, with very little friction at *B* and *C* and when set in motion will continue to spin for a long time. If the wheel is set to spinning by pulling a string, which has been wrapped around the shaft, in much the same manner as in spinning your top, the apparatus will exhibit many strange properties which it did not possess before the wheel started to spin.

Toy gyroscopes can be purchased for from ten to twenty-five cents, and any young scientist can secure many times the value of the money expended for one, from the instructive experiments which it will enable him to perform.

Each one of these tops is supplied with a set of instructions explaining some of its tricks, but there are a great many practical applications of the gyroscope of much scientific value which they wholly neglect to mention and these alone are of sufficient interest to warrant its purchase. Those boys who live in a city or large town will probably have no difficulty in securing one from almost any toy-store but those who live in the

country will probably have to send away to a mail-order house.

Just why a rotating wheel or gyrostat should possess the properties which give the gyroscope its peculiar characteristics cannot be explained by even a learned scientist. A great many theories and explanations have been made, but they are not perfectly satisfactory in all respects and are so complicated, on account of involving intricate mathematics that the young experimenter will this time have to forego his desire fully to comprehend the *causes* at work in producing its actions, and

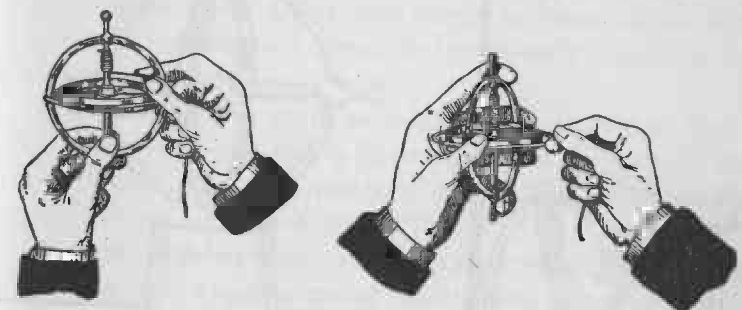


FIG. 64.—The left-hand sketch shows how to hold the gyroscope while winding on the string. The right-hand sketch shows how to start the wheel spinning.

content himself merely with a knowledge of the *effects* which take place.

As a scientific instrument, it is used to demonstrate the principle of rotation, equilibrium of bodies when in motion, effects of gravity, centrifugal force, etc. When mounted on a pedestal, it illustrates the rotation of the earth, the inner wheel supposedly revolving three hundred and sixty-five times to one revolution of the outside frame, thereby showing the rotation of the earth about its axis every twenty-four hours and about the sun once a year. The thin circle of the frame corresponds to the Equator, the thick one to the Meridian and the two pivots to the North and South Poles.

More lately, it serves also to illustrate the principle of the gyroscopic devices used in the Navy to steer ships and torpedoes and on the monorail cars to preserve their equilibrium.

In order successfully to perform experiments with the gyroscope it is necessary that the wheel should revolve at high speed. Great care should be taken in winding. Slip the end of the

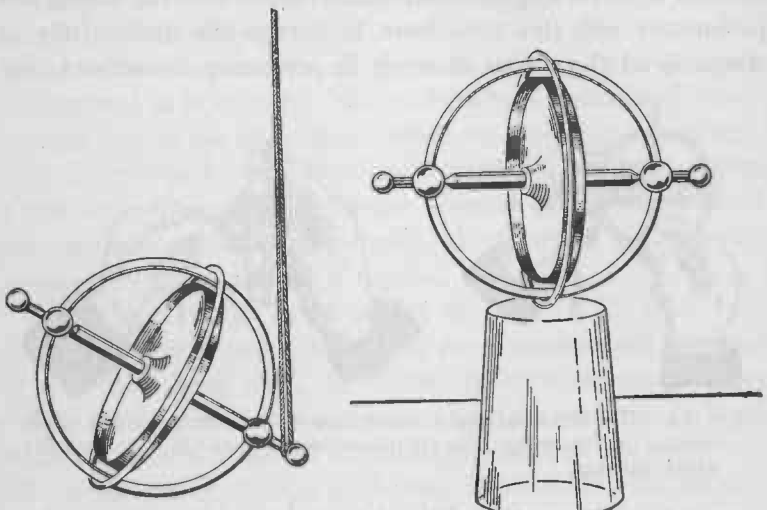


FIG. 65. — At the left a gyroscope is spinning in a loop of string. At the right a gyroscope is shown spinning on its circle on the bottom of a glass tumbler.

string through the hole in the spindle, holding the gyroscope firmly between the thumb and forefinger of the right hand. Turn the spindle between the thumb and forefinger of the left hand, guiding the string with the right. Wind the string around the spindle from the hole to the wheel and back again, as tightly and as smoothly as possible, so that it will not slip when you draw it off. Do not wind the string past the hole towards the end of the spindle.

When starting the wheel, hold the gyroscope firmly in the

left hand and draw off the string with a steady pull, increasing the speed of the pull as rapidly as possible but without a jerk.

The accompanying illustrations show some of the balancing feats which a spinning gyroscope will perform.

In placing the gyroscope in any particular position do not try to hold it there but let go of it quickly so that it can take care of itself as soon as you get it in the desired position. Remember also that the wheel is very carefully balanced and like every other nicely adjusted mechanism, should be carefully used if it is to act as intended. Great care should be taken not to drop it or bend it. A little oil should be occasionally placed on the points of the spindles.

The gyroscope will stand vertically on its pivot just like a spinning top or if one end is placed upon the pedestal, it will slowly revolve around its centre of support and illustrate the rotation of the earth as explained above.

The same experiment may be varied somewhat by suspending the gyroscope in a loop of string. It will then spin at any angle you place it, either above or below the horizontal.

If the gyroscope is supported on a wire or string passing through the groove under the pivot, it will balance itself and slide back and forth the entire length of a room if the string is given the proper grade.

Fasten the lower end of a string firmly to some object and pass a loop around the gyroscope pivot. Hold the string vertically so that if you give it the proper amount of tension, the gyroscope will slip slowly down the string, the whole frame revolving and the gyroscope remaining in the same angle you placed it. It may be stopped at any point by tightening the string.

Wind the gyroscope up so that it revolves at high speed and place it in its box. You now have a magic box which will stand on its corner and spin if you set it with the pivot down.

Figure 66 shows the gyroscope spinning in its box with the cover removed, the point resting on the pedestal.

The whole gyroscope will slowly revolve around on the bottom of a glass tumbler in a direction which will be determined by the end of the spindle which is uppermost. Tipping it over at the opposite angle or placing a slight weight on the high side will cause it to reverse its motion.

If you pick a spinning gyroscope up in your hands by means

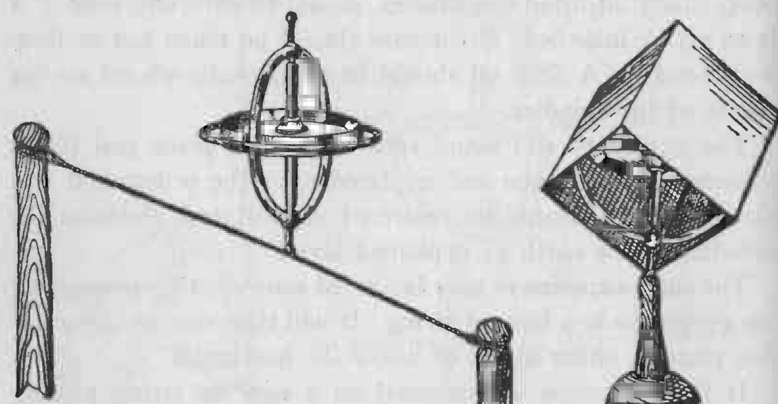


FIG. 66. — The gyroscope walking tight-rope. At the right, the gyroscope is spinning in its box and the box is balanced on one corner.

of the framework and try to give it a sudden twist you will find that it will resist in certain directions and push back just as if it were alive. The gyroscope tends to keep its axis of rotation fixed in space and it is this tendency which is the cause of the resistance felt when it is suddenly twisted or turned. This is the peculiarity of the gyroscope which is made practical use of in a number of ways, chief among which are the steering of torpedoes, stabilizing of ships and aeroplanes, balancing of monorail cars, and the gyroscopic compass.

Torpedoes would not be very effective missiles if some means

of causing them to keep to their intended course were not provided. This is accomplished by the gyroscope.

The same principle at work in keeping your top from tumbling over while spinning on the sidewalk or your sister's hoop rolling along without falling, holds the torpedo true to its path of destruction. Modern warfare makes full use of the skill and knowledge of trained mechanics and scientific minds in building weapons.

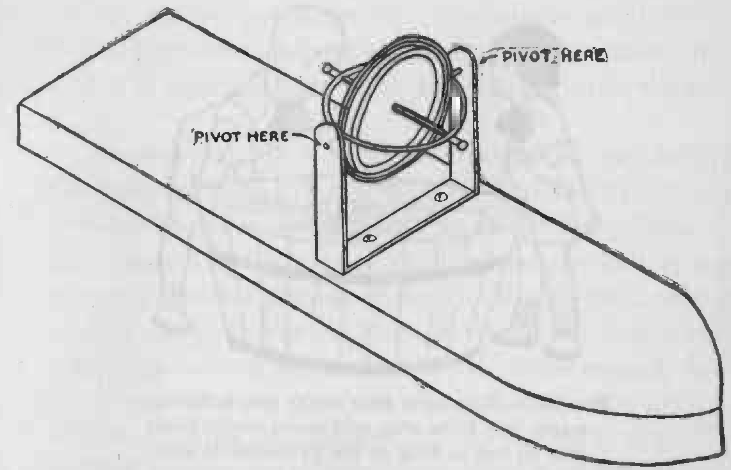


FIG. 67. — A model boat fitted with a toy gyroscope to show the stabilizing effect of its spinning wheel.

The tendency of the gyroscope to resist any changes in the position of its axis has also been utilized to good advantage in eliminating the rolling of steamships. Those who have ever taken a sea voyage know that a ship rolls very violently from side to side during rough weather. This is especially true of boats which have a narrow beam, that is, are not very wide in proportion to their length, such as destroyers, etc.

Gyro-Stabilizers

Large gyroscopes installed on ships to reduce the rolling and pitching of the vessels in a seaway are called *gyro-stabilizers.*

This scheme was first perfected by an inventor named Dr. Schlick. It consists of a heavy flywheel with a vertical axis which can rotate about a port and starboard horizontal axis, located in the central part of the vessel. The flywheel is usually about four or five feet in diameter and is driven by an electric

FIG. 68. — No matter how rough you make the water, the little ship will resist every tendency to roll as long as the gyroscope is spinning.

motor. The rolling force of the sea is counteracted to a large extent by the gyroscopic action of the flywheel and the device is so efficacious that the side to side rolling of torpedo boats has been reduced from 30 degrees when the gyroscope was not running to one or two degrees when it was running.

You can easily carry out some very interesting experiments along these lines by fitting a toy gyroscope to a model boat.

A piece of pine or other light wood about three and one-half inches wide, sixteen inches long and one inch thick, pointed

at one end so as to form a bow, will serve for a boat and together with an ordinary gyroscope top is practically all that is required.

You will have to mount the gyroscope in a frame so that it is only free to swing in certain directions. The frame is made out of a piece of strip metal of almost any sort. Stiff sheet brass, tin, or galvanized iron will all serve equally well.

It is bent in the form of a "U" and has a small hole near the upper end of the vertical portion of each upright, into which the pivots on the gyroscope fit. The pivots consist of two pieces of one-sixteenth inch round brass rod soldered to the small ring at opposite points and at right angles to the axis of the wheel.

Before the gyroscope is mounted on the hull, find the proper position, by moving it together with its frame to various points until one is found where the boat floats perfectly level.

Then fasten the frame in position across the hull by means of two small screws passing through holes in the lower part. Then snap the gyroscope in place and bend the frame so that the gyroscope cannot slip out but yet is loose enough to turn freely. Place the boat in a tub of water and rock the tub or disturb the water so that the boat rolls from side to side. Notice this rolling motion very closely and then wind the gyroscope and start it spinning. Now rock the boat so that there is a tendency to roll and you will find that all the side motion of the boat has disappeared.

The reason that the gyroscope is pivoted instead of being mounted rigidly is so that it will not resist the forward up-and-down motion of the boat. If it were mounted in that manner the hull would be stiffened so that the bow could not rise with the waves and they would break over it instead of passing under and to the sides. It would make the ship decidedly unseaworthy.

Gyro-Stabilizers, built by the Sperry Gyroscope Co., have been installed on many transoceanic liners, sea-going yachts, airplane carriers, destroyers and submarines. The *Conte de Savoia* of the Italian Line, is the largest ship so far equipped. This ship has a length of 811 feet and a beam of 96 feet. The horse-power of the main engines is 120,000 and the cruising speed of the ship is 27 knots.

The *Conte di Savoia* Stabilizer Plant comprises three separate gyroscopes. Each rotor has a diameter of thirteen feet and weighs 110 tons. The normal speed of the rotors is 800 revolutions per minute. The normal horsepower of each of the three electric motors which spin the rotors is 390.

The Gyro-compass Steers Ships

By far the most interesting development of the amazing machine which was once only a toy top is its application in steering ships. Mariners have long known that the magnetic compass is subject to several sources of errors which greatly limit its usefulness. The gyro-compass has none of the faults of the magnetic compass, and in addition to indicating the way *will steer a ship.*

Even since the world was created it has been whirling around on its axis every twenty-four hours. The gyro-compass is the only man-made device which uses the earth's rotation. It is the earth's rotational motion which causes the axle of a properly mounted gyro-wheel to take up a position in line with the earth's poles. Thus the gyro-compass indicates the True North. Since it does not make use of magnets or needles like a magnetic compass, it is not affected by the material of which the ship is built, the character of the ship's cargo or the motion of the boat upon which it is used.

By connecting a gyro-compass to suitable electrical mechanism for controlling electric motors, it becomes a machine for automatically moving the rudders so as to hold the ship to a certain course. Such a machine is called a gyro-pilot. Sailors sometimes speak of it as an "Iron Quartermaster" or "Metal Mike." A gyro-pilot will steer a vessel far more accurately than the best quartermaster.

What Makes an Airplane Fly

Not many years ago airplanes weighed only a few hundred pounds and could carry only one or two passengers besides the pilot. The famous machine with which Glenn Curtiss won the world's speed record at Rheims, France in August, 1909 weighed less than 500 lbs. Nowadays large transport and bombing planes weigh a great many tons and carry an extremely heavy load. How can such an immense weight be lifted off the ground and carried through the air at high speeds?

Men were long in discovering the mechanical principles which enable an airplane to fly. But now engineers can make plans for a new airplane and predict how well it will behave in the air before it is built.

In order to understand how an airplane flies you must perhaps change some of your ideas about air. Since air cannot be seen we do not always appreciate the fact that it has body or substance. Even though it is very thin it nevertheless does have substance or body. It has weight—probably more weight than we ordinarily realize. A barrel of air weighs about half a pound. The air in a room fifteen feet square and with ceiling of average height weighs about 150 pounds.

It is the substance or body of air which makes it possible for an airplane to fly. The propeller of an airplane is the means of driving a plane through the air. The wings lift and support it. The controls guide and balance it.

An airplane propeller is really a section of a screw—a screw made especially for screwing into air. Air has sufficient body so that an airplane propeller can screw its way into air in much the same manner as a metal screw bores its way into a block of wood. But the propeller alone is unable to make an airplane fly. As already stated, a plane must have wings—wings to lift it off the ground and support it in the air. If you examine the wings of an airplane, you will be able to see how they are shaped—thick and rounded in front and tapered to a thin edge

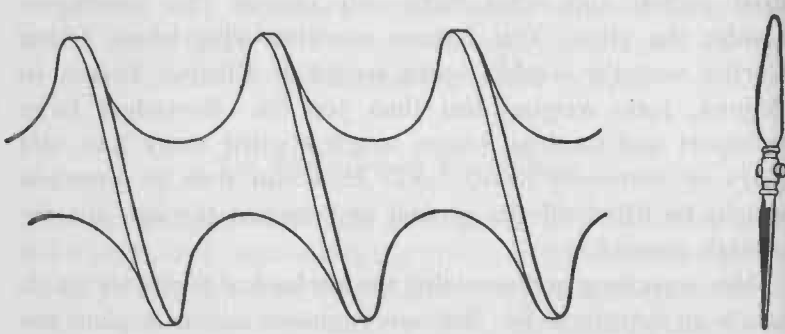


FIG. 69.—The airplane propeller shown at the right is in effect a huge screw such as that shown at the left. It "bores" its way into the air.

at the rear. They are practically flat underneath but are markedly convex on top. The thick front edge, the thin rear edge—the shape of the wing—are important. When a properly shaped airplane wing is inclined so that the front edge is raised slightly higher than the rear, it will lift as it is moved forward through the air. It lifts because as it moves forward, air rushes over and under the upper and under surfaces. The air which passes under the wings exerts a pressure against the under surface and produces a lift. Because of the shape of the wing and the angle at which it moves forward, the air rushing over the top surface does not follow the curve but produces a sort of pocket

above the wing in which there is a partial vacuum. This partial vacuum is a suction which exerts a tremendous lifting force on the wing and does most of the work of supporting the plane and its load. The partial vacuum or suction on the top of the wings produces about two-thirds of the total lift. The pressure upon the under surface furnishes the other one-third.

When the propeller screws its way into the air and pulls the plane forward, the ship lifts off the ground as soon as the lifting power of the air rushing above and below the wing surfaces becomes greater than the weight of the ship and its cargo.

While the propeller and wings do the actual work of lifting the plane and moving it through the air, they alone are not sufficient to make a practical airplane. Feathers are attached to an arrow to stabilize or balance the arrow in its flight. An airplane is provided with a tail having surfaces which serve the same purpose as the feathers. One of these surfaces is really a small wing or supporting surface at the tail of the fuselage. It is called the *horizontal stabilizer* and it maintains the "fore and aft" balance of the ship. Hinged to the rear edge of the stabilizer is a movable surface called the elevator. The *elevator* may be moved up or down by means of the control stick in the cockpit. The movements of the elevator control the ascent and descent of the plane. Pulling on the control stick moves the rear edge of the elevator up and points the nose of the ship up. Pushing on the control stick points the nose down. Birds use their tails in much the same manner as an elevator and stabilizer to balance and control their flight.

The stabilizer is not the only surface on the tail of an airplane. There is also a vertical surface or fin to help keep the ship on a straight course. The rudder is hinged to the rear edge of this vertical fin and acts exactly like the rudder on a boat. It steers the airplane. It may be moved to the right or left by two pedals in the cockpit. The rudder alone is not used to turn the ship however. It is operated in conjunction with the ailerons. The ailerons are movable surfaces hinged to the rear edge of each wing. They keep the ship on an even keel when it is going straight ahead and bank it when making a turn. When you ride around a corner on a bicycle you have to lean

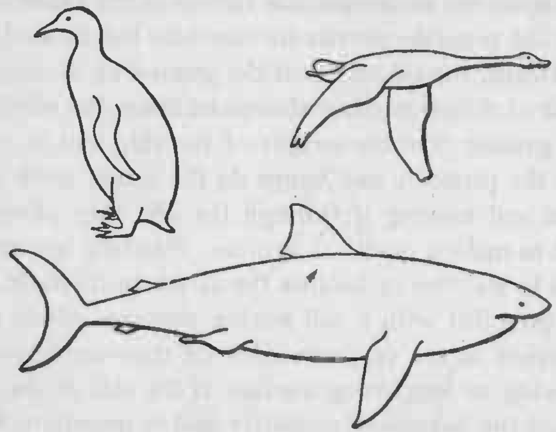


FIG. 70. — Nature has streamlined birds and fishes to enable them to slip through air and water with the least resistance.

or bank. So does an airplane when it turns. The ailerons are connected to the control stick so that swinging the stick to the left or right will move them and bank the plane to the left or right. They work in opposite directions so that an aileron on the left side moves up when the aileron on the right moves down and vice versa.

Streamlining
Something Men Have Learned from Birds and Fishes

If you examine a bird or a fish carefully, giving particular thought to its shape, you cannot fail to be impressed that the form of both of these creatures indicates that they were in-

tended to move rapidly. They are wedge-shaped at both ends. Any object intended to move rapidly through a medium which presses around it from all sides as air and water do around a bird and a fish, can attain better speed with such a tapered form than if flat either in front or behind. Nature knew how to streamline or shape a body so that it would offer a minimum

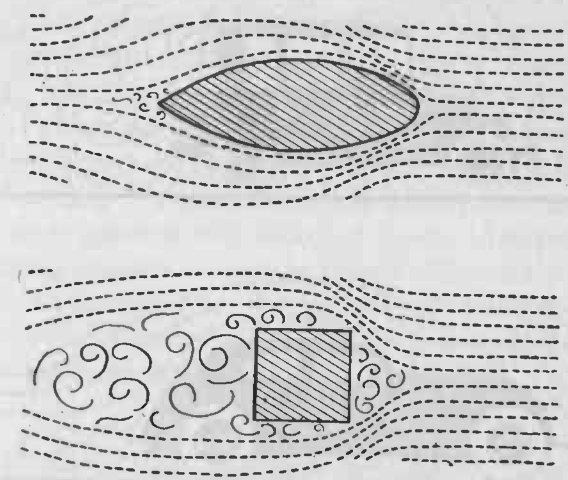


FIG. 71. — The dotted lines represent streams of air slipping past a square object and a streamlined form. Notice the turbulence or "air-hole" stirred up in the wake of the square object. The streamlined object is more easily pushed through the air because it creates less disturbance in its passage.

resistance to motion, long before men learned the secret. The first airplanes did not include much streamlining in their design.

But now all airplanes are streamlined. Every part of an airplane which does not perform any of the actual work of lifting the machine is shaped so that it will slip through the air with the least resistance. The wheels, struts, wires and the fuselage of a fast airplane are all streamlined.

When any object which is not streamlined is moved through the air it pushes some air ahead of it. The air at the sides is slightly compressed and does not have time to expand and close up the space behind the moving object. This "air hole"

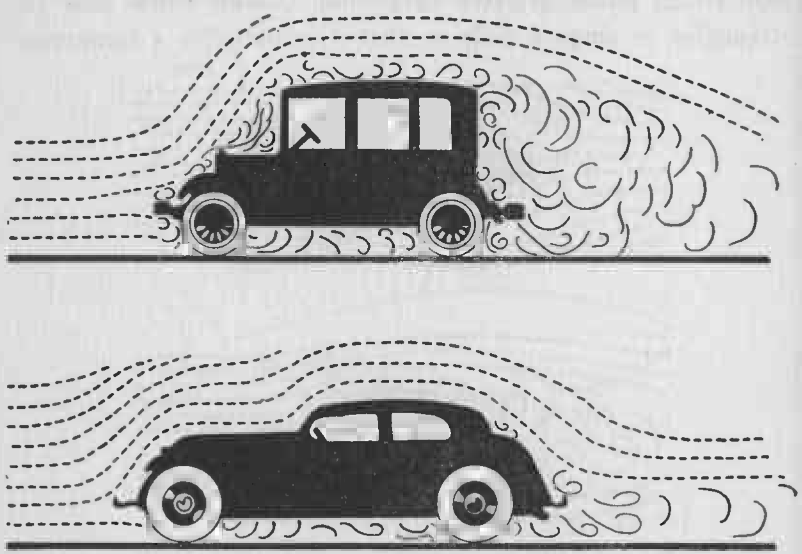


FIG. 72.—The disturbance created in the air by an old-fashioned automobile body is illustrated at the top. At the bottom is shown a modern streamlined automobile body and its effect in moving through the atmosphere.

or suction causes a drag which tries to keep the object from moving forward.

A streamlined form does not allow an "air hole" to form. It is the shape of least resistance. It requires the least power to move it through the air. It is a long fish-shaped form with the blunt end as the front.

The air pressure against a flat surface one foot square is about one and one-quarter pounds at a speed of twenty miles an hour. At forty miles an hour, although the speed has only

been doubled, the pressure against the same square foot of surface is nearly five pounds or *four times as great.* At sixty miles an hour, the pressure is nearly eleven pounds. Air resistance increases very rapidly at high speeds—much faster than the speed.

The lessons learned from airplane building and by experimenting with various objects in wind tunnels are now being used in designing automobiles and locomotives. A wind tunnel is a large tube through which air is moved at high speeds by means of fans. An ordinary automobile with a square front and rear will run backwards with less air resistance than when it runs forward. To streamline a car saves power, and saving power saves gasoline and increases speed. Automobiles are now tending towards streamline shapes. They are rounded in front with a tapering rear. Projections such as lamps and mud guards are also rounded and tapered so that they do not offer as much resistance in pushing the air aside.

Rockets and Jet Motors

The fastest airplanes are those propelled by jet propulsion motors and rockets. Rockets and jet propulsion motors are entirely different in construction but are similar in principle in that they both obtain their power from a jet of hot gases.

Power from a jet is an ancient idea. The Greek Eolipile (illustrated in Fig. 3 in the first chapter) which Hero of Alexandria invented about 100 A. D. was the first engine to convert the energy of heat into the energy of motion and it used jets to accomplish this. In this case the jets were of the hot vapor called steam. Hero used jets in his engine because they were simple. Jets still provide the simplest form of motor.

The principle involved in securing power from a jet is Newton's third law of motion which states that every action is opposed by an equal and opposite reaction. Another way of stating this law is to say that to every action there is opposed a reaction which is equal in force and opposite in direction. The recoil of a rifle that kicks or propels the butt back against the shoulder is the reaction of the force that drives the bullet forward and is a good illustration of the law. A rocket motor and a jet motor are like a rifle. But the bullets they fire are not lead. They fire molecules of hot gases which pour out the nozzles at high velocity. The recoil of these molecular guns, the reaction, is what propels them. They recoil or kick, that is, move back in the opposite direction from the bullets they fire.

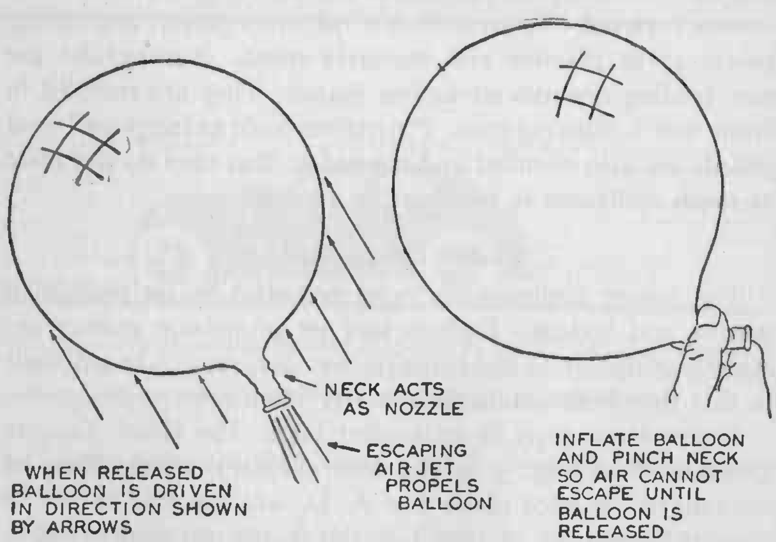


FIG. 72A. — A Toy Balloon Demonstrates the Reaction of a Jet and the Force that Drives a Rocket.

You can demonstrate the reaction from a jet in many ways. One of the simplest is to inflate an ordinary rubber toy balloon by blowing in it. Pinch the neck with the thumb and forefinger so that the air cannot escape. A sausage shaped balloon will

give a better demonstration than a round one. Hold the balloon above your head. The neck should be underneath. Release it and the air pressure inside the balloon will cause air molecules to rush out through the neck in the form of a jet. The reaction from the action of the air molecules will drive the balloon 10 or 15 feet away from your hand.

This simple balloon experiment is a good illustration of the action and reaction in a rocket or rocket motor. The neck of the balloon corresponds to the rocket nozzle, the air rushing out through the nozzle is just as truly a jet as the hot gases roaring out of a rocket.

The Skyrocket. A few decades ago, the evening sky in the United States on July 4th was enlivened by hundreds of thousands of "skyrockets." In many communities this form

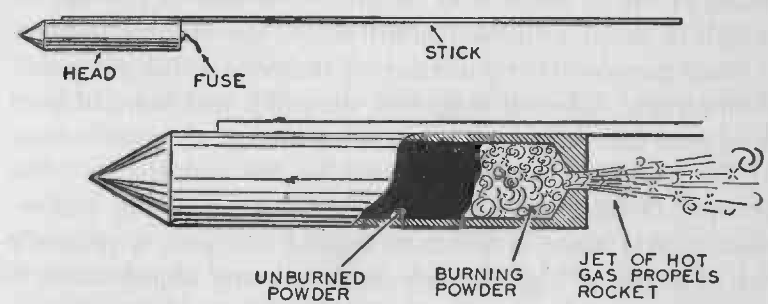


FIG. 72B. — The Skyrocket. In the enlarged view of the head the case is shown cut away to reveal the burning powder and the hot gases which form the jet.

of fireworks celebration is now prohibited by law. When a skyrocket has spent its energy there still remains a stick and smoldering case which falls to earth. Spent rockets are likely to start fires and it would not be at all beneficial to be hit on the head by one of these man-made meteorites. Today star shells have largely replaced rockets for pyrotechnic displays.

When a shell explodes and scatters its brilliant colored "stars" or golden "rain" there is nothing left of it but a few shreds of paper.

Examination of a skyrocket makes it easier to understand the rockets used as weapons in warfare and to propel airplanes.

A skyrocket consists of a cylinder of cardboard attached to one end of a long slender stick. It is like an arrow. The pointed cylinder is the arrowhead and the stick is the shaft of the arrow. It guides the rocket in its flight. The cylinder is strong and light, usually made of several layers of cardboard cemented together. The cylinder is filled with gunpowder, packed tightly and treated so that it will burn slowly for several seconds and not explode in a flash. The powder charge is ignited by a fuse projecting from the back end of the cylinder. When a rocket is set in position to be fired, it is laid in an inclined trough or stood with the pointed end of the cylinder upward.

Black gunpowder is a mixture of charcoal, sulfur and potassium nitrate. When it is ignited, the sulfur and charcoal burn in oxygen furnished by the potassium nitrate. A great volume of hot gases is suddenly created by the combustion. The pressure of these gases in their effort to escape from confinement to find space in which to expand will push a projectile out of a gun at high velocity or shatter any object which is not strong enough to resist the pressure.

In a skyrocket the hot gases can escape through a hole in the back of the cylinder. This hole corresponds to the nozzle in a rocket motor or jet motor. Since the powder in the rocket burns more slowly than the explosive charge in a gun, there is time for the hot gases to push out through the hole and not burst the cylinder. The jet of hot gas rushing out of the cylinder pushes back against the inside of the cylinder. If the rocket is pointed upward, it is pushed up into the sky.

The important thing to remember about the action of a

skyrocket is that its forward motion is obtained from the push *back* of the jetted gases against the rocket itself. It is not due to the push of the jet against the air behind the rocket. A skyrocket would operate equally well in a vacuum where there is no air.

Bazookas. The bazooka rockets used as weapons are not much different from the old fashioned skyrockets. They consist of a tube loaded with a special propellant powder. The rear end of the tube is fitted with stabilizing fins which keep the nose of the rocket pointed forward in the same way that the feathers on an arrow guard it in its flight. When the rocket is fired the jet of burning gas roars out of a nozzle located between the stabilizing fins. The front end carries a warhead loaded with high explosive and a detonator which sets off the charge when the rocket strikes its target. The terrific striking power of the bazooka comes from the explosion of its warhead. It literally melts a hole in thick steel armor plate. The rocket is launched from a tube called the launcher. A 4.5-inch rocket, equivalent in fire power to a 105-mm shell together with launcher weigh about 50 pounds. There is no recoil of the launcher when a rocket is fired from it. A soldier can hold the launcher on his shoulder when a rocket is fired from it. The rocket emerges from the front of the launcher. The hot jet of flaming gas blows out the rear.

Rockets Speed Take-off of Airplanes. When assisted by rocket propulsion, the take-off run of the conventional engine- and propeller-driven airplane can be reduced as much as 60 per cent. Transports and bombers can get off the ground with heavier loads than normally; airplanes are enabled to use small or damaged airstrips. Flying boats can get off the water like ducks. The rockets used for this purpose are mounted in pairs, either two or four, on each side of the plane's fuselage. The rocket tubes are charged with a solid fuel which incorporates

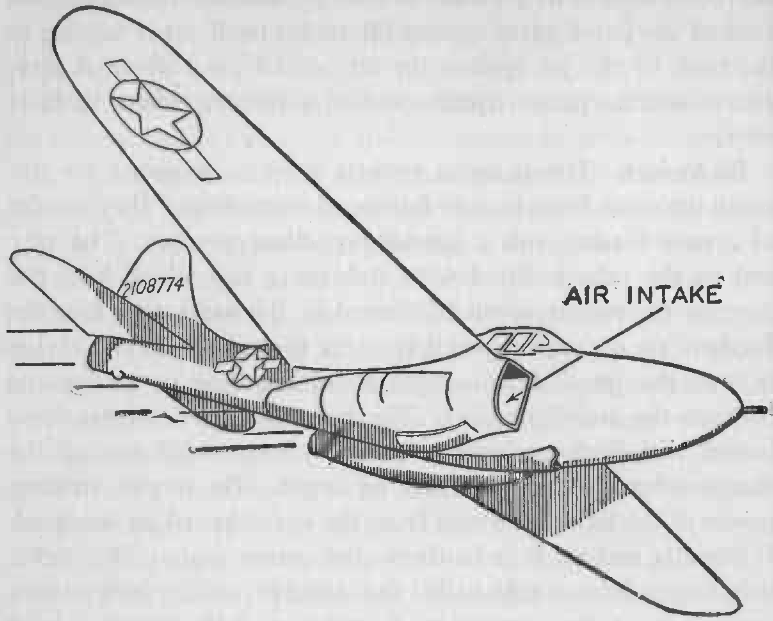


FIG. 72C.—A Propellerless Airplane. The jet-propelled P-59 is driven by gas turbines which suck in air through intakes on each side of the fuselage. The hot gases are jetted through two nozzles astern.

oxygen in its mixture. The charge is ignited by an electric spark under control of the pilot. The burning fuel creates a flaming jet which produces a propelling force of about 300 H.P. in each rocket. There is only enough fuel in each rocket to supply motive power during the take-off. When the plane is in the air burned out rockets are detached and dropped.

The Difference Between Rocket Motors and Jet Propulsion Motors. The speed limit of airplanes equipped with propeller-driven, internal combustion engines has apparently been nearly reached. Efforts to secure speeds above 450 miles per hour from gasoline engine driven planes produce negligible

results. Higher speeds must apparently be secured by applying jet propulsion. Propellerless airplanes whose motive power is the reaction of two invisible streams of hot combustion gases have already reached high speeds and altitudes which launch a new era in man's locomotion.

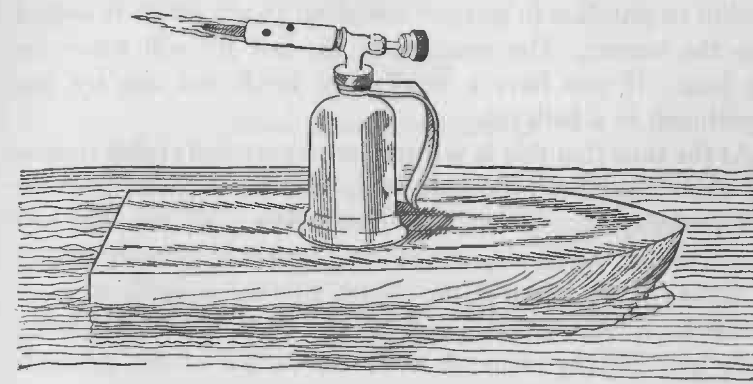


FIG. 72D.—An Experimental Jet Propulsion Motor.
See text for explanation.

One of the illustrations shows a jet propelled P-59 which has set new speed records in air travel. Jet propulsion is the same force that propels a rocket. The basic difference between a rocket motor and a jet propulsion motor is in the fuel supply. A rocket motor carries its own supply of oxygen for burning its fuel. Jet propulsion motors "breathe," that is, take in air. Their fuel burns in oxygen contained in the air which they suck in.

It has already been explained that the oxygen for burning the skyrocket's fuel is furnished by the potassium or sodium nitrate in the powder and that the oxygen in the bazooka's fuel is also incorporated in its powder charge. The fuel for the rocket motors in the large "stratosphere" rockets is usually alcohol which burns at a furious rate in oxygen carried in the rocket. The oxygen supply of a rocket motor is soon exhausted, but the oxygen supply of a jet propulsion motor is unlimited. It outlasts the fuel supply.

A very simple form of jet propulsion motor is represented by a blow torch on the deck of a toy boat. The torch burns alcohol or gasoline in oxygen contained in air which is sucked into the burner. The reaction of the hot jet will move the toy boat. If you have a small blow torch you can try this experiment in a bath tub.

At the time that this is written jet motors and rocket motors are experimental. A diagram of today's jet propulsion motor will probably be obsolete in a short time. So far, the best results in driving an airplane at super speeds have been secured by utilizing the gas turbine. Much of this work is a secret of the U. S. Army and Navy. Rapid developments are being made and nothing more than a bare outline of the principle can be given now.

The gas turbine consists of a rotary compressor and a turbine wheel on the same shaft. The compressor sucks in enormous quantities of air, compresses it and forces it into a combustion chamber where it is mixed with fuel (alcohol, gasoline, etc.) and ignited by an electric spark. The resulting hot gases and expanding air rush through the turbine nozzles and push against the buckets on the turbine wheel which spins the compressor. Still flaming hot and under pressure the gases pour in a continuous blast through an exhaust pipe or nozzle out into the atmosphere. This jet, like the jet of the rocket, by its reaction produces the forward push that propels the plane at high speed.

CHAPTER IV

LIQUIDS

Some More About Matter

I AM trying to make this book as interesting as possible, and while I realize full well that you would probably much rather perform some experiment than to read "dry facts," I am certain that you will enjoy your adventures to a far greater extent if you will occasionally bear with me long enough to take the necessary time and trouble while we understand a few things. You would hardly think of starting out on a long journey without making sure of taking proper baggage along with you and likewise you should not expect to make a trip in science without being properly prepared with that *knowledge* which is to be your scientific baggage.

We must, in order to be well equipped for our further explorations in the Land of Science, once again return to a subject partly dealt with in the Introduction to this book and go over a few points in regard to *Matter*.

We have also learned that in spite of the great many different forms of matter, it exists in three states: solid, liquid, or gaseous. Water, for instance, is liquid at what we call ordinary temperature, solid ice in the cold, and steam vapor when very hot. Most forms of matter are subject to these three phases at different temperatures and different pressures, although some change from the solid state to the gaseous without first becoming a liquid.

If we imagine the molecules of any substance as each one an individual toy balloon, all bobbing and blowing around loose with nothing to hold them together and acting as though they were all trying to keep as far as possible from one another, they are like a *gas*.

If then, we imagine them as bounding around "every which way," sideways, forward, backwards, and over and under one

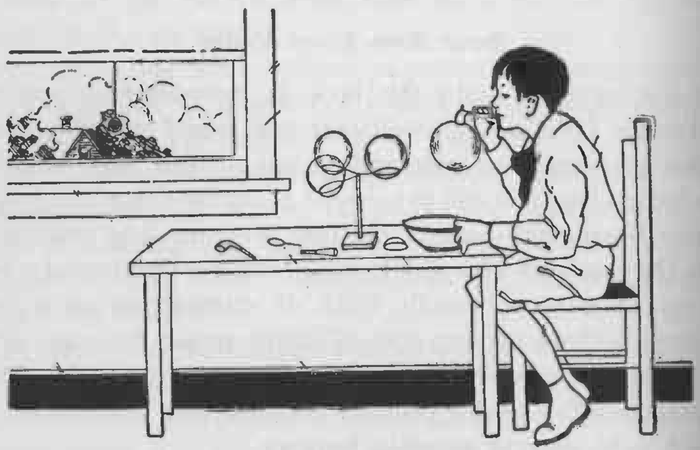


FIG. 73.—You can learn a great deal about science from a soap-bubble

another, but always held somewhat together, we may liken the mass which they constitute to a *liquid*.

When they clinch together we have a *solid*.

If you put the molecules of a gas under a pressure and cool them they become a liquid. Cooling slows down the motion of the molecules; heating increases it.

If you cool a liquid still more, the molecules will freeze or turn to a solid. Some of their freedom of movement which they had when a liquid is lost, and they seem to cling together.

Liquids and gases are far more like each other than either one of them is like a solid, and that is because they will both

run or flow. The shape of a gas or a liquid changes from moment to moment if it is allowed to, because both gases and liquids flow. So both liquids and gases are known in the language of science as *fluids* which simply means "things that flow."

Gases do not readily lend themselves to experiments with apparatus which we can easily perform in a kitchen laboratory. Air and water vapor are the most common gases with which we deal in everyday life and since we shall learn more about them in the chapters dealing with Sound, Heart, and Meteorology, we will pass them by now.

Liquids, however, offer a fine field for adventure, and since water is the most common liquid, we will try to learn something about this particular state of matter by trying some experiments with water. You may remember that I have already told you that the entrance to a great land of Scientific Adventure lies wherever your toys or those things which you use for amusement may happen to be. I am going to prove it by showing what you may learn from a mere soap-bubble.

I do not suppose there are many boys who have not blown soap-bubbles and, while admiring the wonderful brilliancy of one of these fairy spheres floating away in the air, marvelled just how it is that such a really wonderful thing is so easily produced. I hope that none of you think you are too old to play with bubbles or have grown tired of it, because there is more in a common bubble than those who have only played with them generally imagine. Sir Isaac Newton, the famous English philosopher and scientist, spent a great deal of time studying bubbles and films, and many useful scientific facts were learned from his experiments. You cannot pour water from a pitcher, or tea into a cup, in fact you cannot do anything with a liquid of any kind, without setting into action the forces which control the creation of a soap-bubble and about which I am going to tell you more.

An Interesting Experiment. The first experiment for you to try is one which you have probably performed many times without knowing that it was an experiment at all.

Take a common camel's hair paintbrush, such as artists use, and dip it in a tumbler full of clear water. When you lift it out, the hairs will cling together and come to a point, in fact, you may have often wet a brush for just that purpose. If

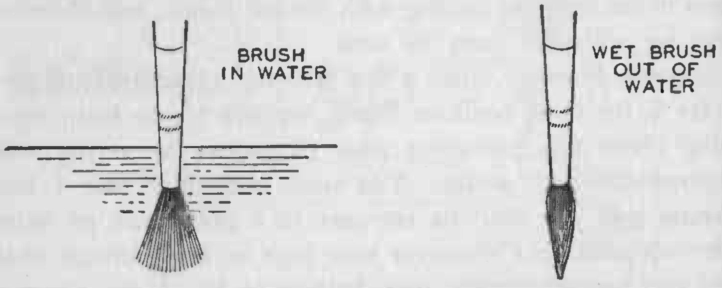


FIG. 74. — If you dip a camel's hair paint brush into water the hairs will spread out while the brush is immersed but cling together as soon as lifted out. Capillary attraction draws the hairs of a wet brush together while it is out of water.

you were asked why the hairs cling together, you would probably reply that it is because they are wet. If you think so, dip the brush in the water again and hold it there. Look at it through the sides of the tumbler while it is still immersed in the water and it will be evident that the hairs do not cling together at all and yet they surely are wet now also because they are actually in the water. The reason you would give at first for the hairs clinging together is therefore not exactly the right one, although it is partly so. The hairs cling together, not only because they are wet, but for some other reason as well, which you probably do not yet know. Before I tell you this other reason, I am going to suggest another experiment.

The "Skin" on a Water Drop

Dip an ordinary medicine-dropper or pen-filler in water and draw it full. Then lift it out and slowly squeeze the bulb so that a drop gradually forms at the lower end. Watch the drop very closely as it slowly grows until it has attained a certain definite size and then suddenly falls away. Squeeze out a few more drops, slowly and carefully, and notice that every drop, when it falls away, is exactly the *same size* and *shape*. This fact cannot be due to mere chance; there must be some reason for it. Do you not wonder why the water remains until it forms a large drop? It is heavy and ready to fall at all times but does not do so until it is a *certain size*. Then it suddenly breaks away just as if whatever was holding it was not strong enough to carry a greater weight. It acts as if the water was hanging in a little elastic bag and as though the bag breaks each time when there is too great a weight for it to carry.

There is of course really no bag there, but the *surface* of the water *is* like an *elastic skin*. That is why the hairs on the brush do not cling together, simply because they are wet. It is necessary that the brush be taken out of the water so that the surface or skin of the water is present to bind the hairs together.

The Elastic Skin on the Surface of Water

Now that your experiments have given you good evidence that there is a sort of an elastic skin on the surface of water, and, by the way, it exists on the *free surface* of all liquids. (By *free surface* is meant that which is bounded by a gas or vapor, as, for instance, air. For example, in the case of a pail of water, the free surface is the top surface exposed to the air.) You can also easily discover that this skin is always under a tension and can exert quite an appreciable force.

This Surface Tension, as it is called, and "tension" simply means *stretching,* is always squeezing the water together and trying to reduce the area of the liquid surface to the least possible size. That is why the hairs in the brush are drawn together when the brush is wet and exposed to the air.

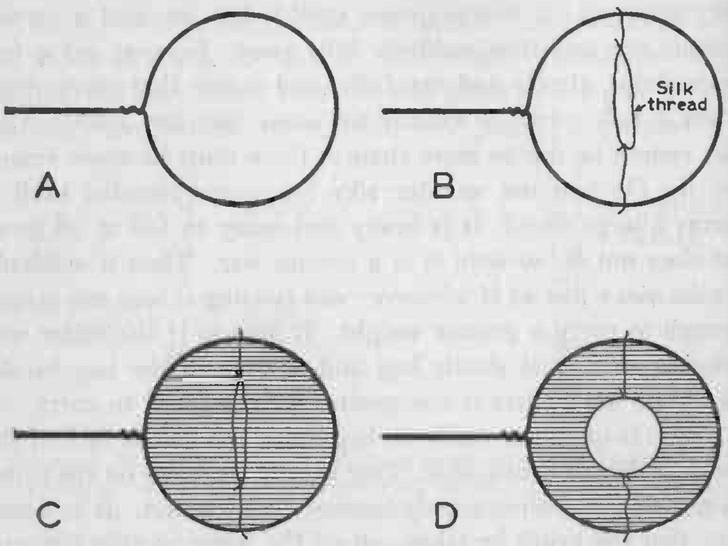


FIG. 75.—The tension of a water film can be shown by a small wire frame (A) with a loop of thread tied across it as at B. Dip the frame in a soap solution so as to form a soap film on the frame as at C. If the film is broken inside the loop by means of a hot wire, the tension of the film will pull the thread into a circle.

The Tension of the Water Surface, which is just like a piece of stretched india rubber, can be made very plain by dipping a little wire frame in a solution of soap and water, such as is used for blowing soap-bubbles. The wire frame is easily made out of some thin, stiff wire bent so as to form a circle at one end about two inches in diameter. Tie a fine silk thread across the ring rather loosely, making the thread double for a short distance in the middle. After dipping the frame in the

soap solution, it will on removal carry a thin film of soapy water stretched across it. The silk thread will lie in the film and assume almost any random shape. But if you take a small hot wire which has been heated in the flame of a match or a candle, and use it to break the film inside of the silk loop, the thread will be stretched out and assume a circular form, because that is the form which makes the space within as great as possible and therefore leaves the *space outside as small as possible.* You will notice, that, although the circle will not allow itself to be pulled out of shape, it can move about in the ring quite freely, because such movement does not make any difference in the space outside of it.

The fact that the tension of the soap film is strong enough to stretch the silk thread out into a circle gives some idea of the considerable force exerted by the surface of a water film in the effort for it to make itself as small as possible.

Why "Skating Bugs" can walk on the Water. Although the strength of the water skin is very small where big things are concerned, it is very strong when very small things are acted upon. Most of you, especially those who have lived in the country and have gone down to play by the side of a brook or pond, must have often seen water-spiders and "skating bugs" running around over the surface of the water without sinking in.

For some reason their feet are not wetted by the water and do not break through the surface skin. Where they rest on the water with each foot, there is a small depression formed. The surface tension at each little depression just supports the weight of the tiny creatures and they are enabled to run about over the top of the water as well as if on the ground.

The Shape of a Drop of Water. There is still another way of easily showing how strong this elastic skin of water is and how great a force it exerts.

Suppose that you take about a half-teaspoonful of water and suddenly pour it out, what will happen? It will, of course, fall down and be dashed against the floor or whatever is underneath and be broken up into innumerable little drops.

If, however, you take the same quantity of water and lay it carefully upon a piece of waxed paper which has been dusted over with lycopodium (Lycopodium is an extremely fine powder which you can obtain at a drug store and is the spore of a fern), the lycopodium will prevent the water from wetting the paper. The weight of the water—that which made the other water fall—will squeeze it out into a large flat cake. The *surface tension* is holding the water together just as if it were held by the sides of a little shallow dish.

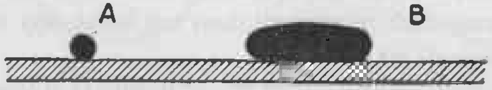


FIG. 76. — The natural shape of a drop of water is round as shown at A but if the drop is large it flattens out as shown at B. The surface tension of a large drop is not as strong as that of a small drop and not able to counteract the energy of gravitation to the same extent. Gravity partially overcomes the surface tension of a large drop and pulls the drop down into a flat cake as shown at B.

What do you suppose would happen if the weight of the water or the force which is pulling it downwards and causing it to spread out flat could be prevented from acting? In such a case, the drop would then only feel the squeezing of the elastic skin which would try to pull it up into such a form as to make the surface as small as possible. It would immediately change into a perfectly round ball, because no other shape has such a small surface in comparison to its volume.

You will be able to see this with your own eyes, if instead

of taking so much water, you take only a drop about as big as a pinhead. Then the weight which tends to squeeze it out will be far less, while the skin will be just as strong and the small drop will appear like a perfect ball.

The smaller the drop, the more will the molding power be able almost entirely to counteract the weight of the drop. A very minute drop will mold so perfectly into a ball that you cannot tell by looking at it that it is not perfectly round. This is most easily seen with quicksilver. A large quantity rolls about like a flat cake, but the very small drops appear quite round.

This property of a liquid to mold itself into little balls, on account of its surface tension is taken advantage of in

Making Lead Shot. Shot is manufactured by pouring molten lead through a sieve in the top of a high tower. The lead is divided up into small drops by the sieve, and as they fall from the top of the tower towards the earth, the surface tension of the molten lead molds each drop into a perfect sphere. The lead cools and hardens before it reaches the ground. The balls are then sorted according to their sizes.

How the Surface Tension makes Water Climb Uphill

The surface skin on water and other liquids explains several other interesting experiments and these experiments in turn explain some of the practical uses to which we put these phenomena in everyday life.

When a solid body is dipped in a liquid which wets it, for example, a glass rod in water, the liquid, as if in opposition to gravity is raised upwards against the sides of the rod, and the surface of the water, instead of being flat, becomes slightly concave.

If, on the contrary, a glass rod is dipped into a liquid which does not wet it, as for example, mercury, the liquid will be depressed by the sides of the rod and assume a convex shape.

Capillary Tubes. These phenomena are much more marked and best seen in tubes of extremely small diameter, called capillary tubes from the Latin word *capillus,* meaning a hair.

Making Capillary Tubes is easy and is accomplished by heating an ordinary glass tube in the flame of a Bunsen burner. When the tube has become soft, suddenly stretch it out until it is not much larger in diameter than a coarse thread or a

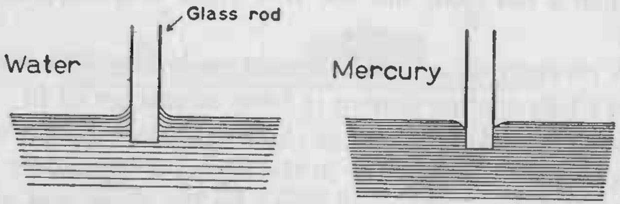


FIG. 77. — Water wets glass. The surface of water rises to meet a glass rod dipped into it. Mercury does not wet glass. A glass rod dipped into mercury depresses the surface.

piece of string. Cut it up into pieces about three inches long by scratching with a file at the desired point and then breaking it.

If you dip these fine tubes into some ink or into water containing some coloring matter so that you can see it more easily, the water will rush up into the tube and remain at a much higher level than that on the outside. The water has actually raised itself against the force of gravity. This requires an explanation. It is this. The inside of the tube is *wet* by the water and the elastic skin on the water is therefore attached to the tube. The surface tension of the elastic skin pulls up the water in the tube until the weight of the water in the tube, above the general level, is equal to the force exerted by the skin.

If you take a tube about twice as large, then this pulling action which is going on all around the inside wall of the tube at the surface of the water will lift twice the weight of water. The water will not, however, rise twice as high because the larger tube holds twice as much water for a given length as the smaller tube. It will not even rise as high as it did in the case of the smaller tube, because if it did, the weight of the water raised in that case would be *four* times as great. This will explain why the water rises so much higher in a smaller tube.

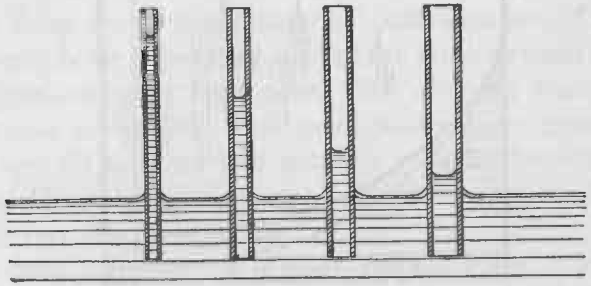


FIG. 78. — Capillary attraction raises water in a tube of small diameter. The water rises to the greatest height in the tube which has the smallest bore.

If you make a number of tubes of different sizes and place them in a row with the smallest one on one side and all the others in the order of their sizes, the water will rise highest in the smallest tube, lowest in the largest.

The Action of Capillary Tubes in raising Water Gives an Explanation why porous materials soak up a liquid. Capillary action makes it possible to soak up an ink drop with blotting paper. The pores of the blotting paper act like innumerable little capillary tubes and draw the liquid up inside. Capillary action causes oil to ascend in the wicks of lamps, sap in trees, and water to be absorbed by a sponge.

You can easily obtain the same sort of an effect as that given by the tubes with two pieces of window glass. Two panes of glass of the same size and measuring about four by five inches will serve nicely. Place them face to face with a common match-stick at one edge to keep them a small distance apart at that one edge while they meet together along the opposite edge. A rubber band stretched around the top and one around the bottom will hold them in position. Dip the pair of plates in

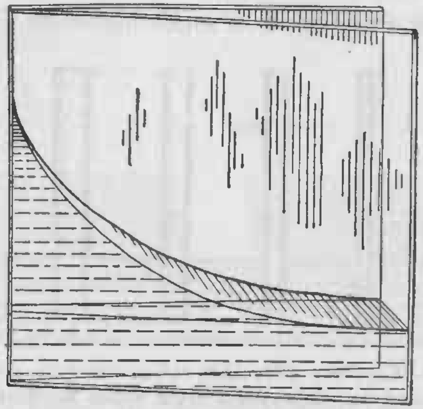


FIG. 79. — You can see the effect of capillary attraction with two panes of glass and some colored water.

some colored water and the water will creep up close to the top of the plates along the edge where they meet and as the distance between the plates gradually increases, so the height to which the water rises gradually gets less, and the result is that the surface of the liquid forms a beautiful, regular curve.

These experiments showing the existence and some of the properties of the "surface skin" on water will enable you better to understand just why and how it is possible to blow soap-bubbles.

Before trying any of the soap-bubble experiments, it is well

to learn some of the "kinks" in making bubbles, described below.

Hints for Blowing Bubbles

Soap-bubbles are at the best fragile, short-lived things, and in order thoroughly to enjoy them, they must be properly made so as to last as long as possible. Merely dipping a pipe into soap-suds and blowing is not the best way to make bubbles. There are many little tricks and precautions which will produce sturdy bubbles capable of lasting several minutes before they break.

The Soap is the most important consideration. Common yellow soap is far better than most of the fancy or toilet variety. Pure Castile soap is very good. The olive oil from which Castile soap is supposed to be made is sometimes mixed with cotton seed oil and then it is not very good for blowing soap-bubbles. If you buy Castile soap for this purpose, be sure that it is the very best.

The best water to use is pure distilled water. Clean rain water is also good. Do not use the first that runs off the roof, but wait until it has rained for some time before collecting it. If fresh rain water cannot be obtained, use water which has been boiled and allowed to cool. Water which is *hard,* that is, contains *lime* or *calcium,* does not make good bubbles. Rain water and distilled water are *soft,* that is, do not contain *lime.* Boiling water and allowing it to cool helps to *soften* it by eliminating the lime.

The Soap Mixture should be made by shaving the soap with the edge of a knife and dissolving in *cold* water. Stir thoroughly with a clean spoon until the soap dissolves and a thick suds stands on the top. After the solution has stood for a few minutes, remove the suds with a spoon.

Bubbles blown with soap and water alone do not last long enough for some experiments and their lasting quality may be greatly improved by adding a little pure glycerine to the soap solution.

The necessary amount of glycerine to add will depend upon the soap which is used and you can easily determine the right amount by a little experimenting.

Part of the soap solution should be placed in a saucer or shallow dish. This is a much better way than using a tumbler

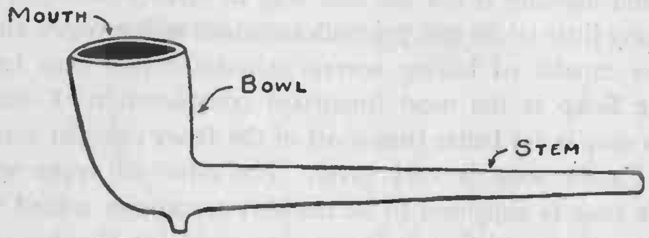


FIG. 80.—Use a clay pipe for blowing bubbles.

or a bowl because if the solution is deep the pipe will become too wet.

A Clay Pipe is usually employed for blowing bubbles and can be purchased at almost any tobacco store for five cents or less. The sort of pipe having a clay bowl and a bamboo stem is very good because it will not break so easily as those with clay stems.

A Cigarette Horn or holder like that shown in Figure 81 can be used to good advantage in blowing certain kinds of bubbles.

Cigarette-holders of this sort are usually sold at cigar counters at a low enough price and will be found useful when it is desirable to blow a very large bubble or to blow one rapidly. The stem of the cigarette-holder is not as restricted as that of the pipe and the air can be forced through it more quickly.

The ordinary paper straw used at soda fountains is especially useful for making very small bubbles as they are more

easily set free from the straw than from the cigarette-holders or pipe.

Before using the straw, split one end into quarters with a penknife for about one-half of an inch and then bend them back as shown in the illustration.

Blowing Bubbles requires care if you wish your experiments to succeed. Wet the mouth of the pipe or horn thor-

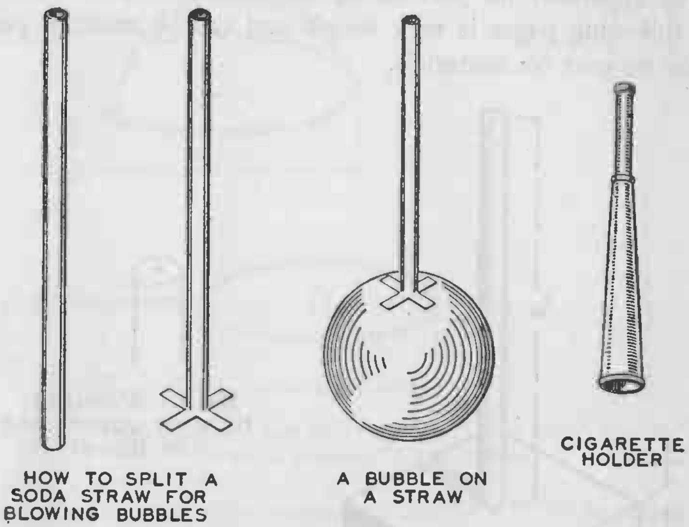


FIG. 81.—An ordinary paper straw can be used for blowing small soap-bubbles if the end is split as shown in the sketch. A cigarette holder like that shown to the right also is useful for blowing bubbles.

oughly to begin with, but do not stir the solution so as to make suds.

Dip the mouth of the pipe into the soap solution gently and do not immerse it too far, the purpose being to form a soap film across the opening which can later be stretched out into a round bubble by the pressure of the breath. When starting a bubble, blow gently at first, just breathe into the stem. Hold the tip of your tongue over the end of the stem while taking a breath, so that the air does not escape from the bubble.

When using the straw, blow very gently. Blowing too hard will either break the bubble or free it from the straw before it is finished.

Apparatus for Bubble Experiments

The apparatus for performing the experiments described in the following pages is very simple and can be made at practically no cost for materials.

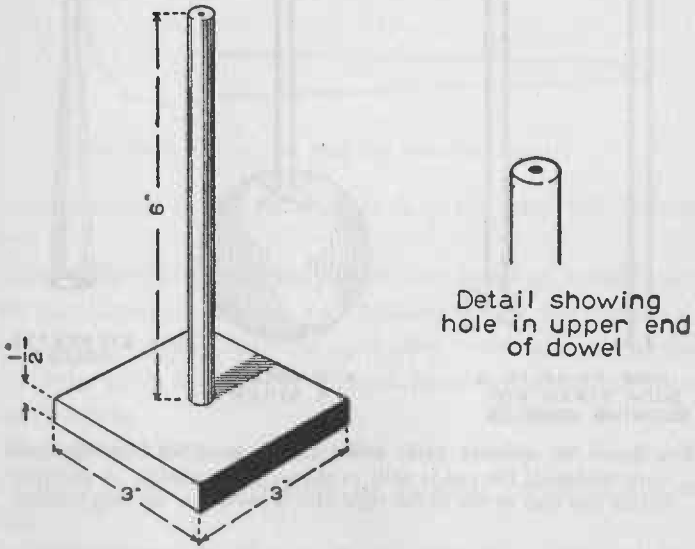


Fig. 82. — A stand made out of a square piece of wood and a dowel stick as shown in the illustration above is an important part of the apparatus needed for performing experiments described in this chapter.

The Stand consists of a square block of wood, four by four inches by one-half an inch, having a five-sixteenths hole through the centre to receive the lower end of a piece of five-

sixteenths-inch dowel, eight inches long. The dowel should force into the hole tightly.

The Rings should be made of brass wire. No. 20 or No. 22 B. & S. gauge is the right size. Make three or four rings, two inches in diameter like *A* in Figure 110 and two small ones an inch and one-half in diameter like *B*. Notice that the end of *A*

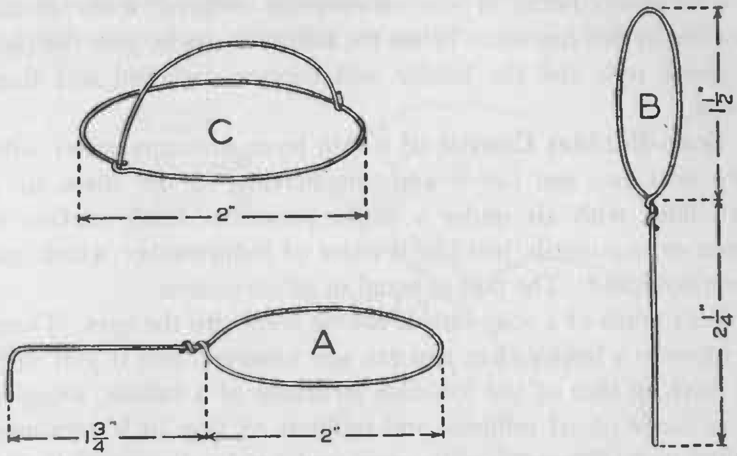


Fig. 83. — Make three or four wire rings like A, two like B and one like C to use in blowing "fancy" bubbles.

is bent down at right angles so that it will fit in the hole in the top of the dowel stick. One two-inch ring like *C* will be enough.

When using the wire rings for any experiments, remember that the ring must first be thoroughly wet with the soap solution or the bubbles will break when they touch it.

Experiments with Soap-Bubbles

What is a Soap-Bubble? If you dip your pipe into the soap-suds and lift it out, a thin film of soapy water will be formed across the mouth of the bowl. Blowing gently into the pipe will increase the pressure against the inside of the film and cause it to stretch out into a ball. Some of the water will run down to the bottom and form a drop. You can easily remove this by touching it gently with a wet finger which has been dipped in the soap solution. Your bubbles will be lighter and float in the air much better if you remove the drop of water at the bottom in this manner. When the bubble is made, give the pipe a quick jerk and the bubble will become detached and float away.

Soap-Bubbles Consist of a thin layer of soapy water with two surfaces, one inside and one outside, in the shape of a ball filled with air under a slight pressure. Each surface is tense or contractile just like a sheet of india rubber which has been stretched. The pull is equal in all directions.

This much of a soap-bubble can be seen with the eyes. There is more to a bubble than you can see, however, and if you wish to have an idea of the invisible structure of a bubble, imagine it as made up of millions and millions of tiny little creatures called molecules, each with arms and hands all around it and all these hands holding onto the hands all about them and pulling. Each little molecule has the same number of hands, so to speak, and pulls with the same force.

Why a Soap-Bubble is Round. This pulling causes the soap film to try to assume such a form as will make the surface as small as possible, just like the surface tension on a drop of water, and it assumes the shape of a sphere or ball because no other form has such a small surface in comparison to its volume.

The Colors of Soap-Bubbles. The colors of soap-bubbles change constantly because the thickness of the film continually varies. At first, a soap-bubble is almost colorless but in a short

time, if left to itself, gradually becomes thinner at the top due to the tendency of some of the water to run down towards the bottom by force of the earth's attraction.

The Thickness of the Soap Film. When the thickness of the film becomes less than about 0.000078 of an inch, the film begins to show color, first a faint red, then green above the red. Then reds and greens flash back and forth as the film grows thinner, the colors becoming more vivid until black spots ap-

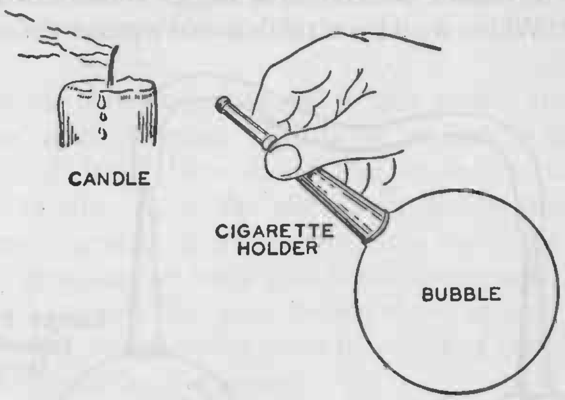


FIG. 84. — The elastic nature of a soap-bubble slightly compresses the air within the bubble. The pressure of the air will cause it to rush out through the cigarette holder with enough force to blow out a candle flame.

pear and the bubble bursts. The black spots are extremely thin, probably about *five-millionths of an inch,* the colored portions probably being at least ten times thicker.

The Pressure of the Air in a Bubble. A soap-bubble always exerts a constant effort to grow smaller but is prevented because the tension of the soap film is not great enough to compress the air in the bubble to any great extent. That it does compress the air and will grow smaller if the air pressure is relieved, is very easily shown by blowing a bubble with a cigarette-holder and holding the stem near a candle flame. The outrushing air will blow the candle flame and possibly extinguish it and the bubble will gradually grow smaller, showing that the soap film is just like an elastic bag. This experiment shows very plainly that, owing to the elastic skin which is always trying to reduce the area of its surface as much as possible, the air inside is under pressure and will get out if it can.

Is the Pressure Greater in a Large Bubble or a Small Bubble? Which would you think would squeeze the air inside

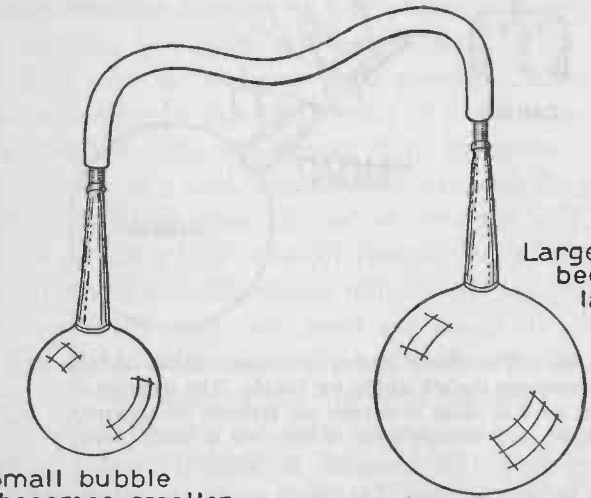


FIG. 85. — Two cigarette-holders and a piece of rubber tubing will enable you to perform an experiment which shows that the air pressure is greater in a small bubble than in a large one.

of it the more, a large or a small bubble? It is very easy to find out, so try the experiment. You will need two cigarette-holders and a short piece of rubber tubing which will slip easily but snugly over the small ends.

Slip one end of the tubing over the stem of one of the cigarette-holders, making certain that it is a tight fit and does not leak. Dip the mouth into the soap-suds and blow a small bubble about three inches in diameter. Do not shake the bubble loose but pinch the rubber tubing tightly so that no air can escape and quickly blow a large bubble about six inches in diameter on the other cigarette-holder. Slip the other end of the rubber tube over the stem and you now have a small bubble on one holder and a larger bubble on the other so connected that the air can pass from one to the other through the rubber tube.

Release the pressure on the rubber tube so that the air can pass from one to the other. Now if the pressure in the larger one is greater, it will blow air into the smaller one until they are equal in size. If, on the other hand, the pressure in the smaller one is greater, it will blow air into the larger one and gradually grow smaller itself until it has disappeared. That is just what happens. The small bubble closes up and expands the large one, showing that there is a greater pressure in a small bubble than in a large one.

When you blow a bubble, the *pressure decreases* as the bubble grows larger. The pressure in a bubble six inches in diameter is only one-half that in a three-inch bubble. The film is always stretched with the same force, no matter what size the bubble is. The pressure depends upon the curvature of the bubble. The larger a circle is, the less is its curvature. With a part of the surface of a ball, it is just the same, the larger the ball the less it is curved. In large bubbles where the curvature is small, the pressure is low while in small bubbles the curvature is great and so is the pressure. The pressure and the curvature rise and fall together.

Bouncing Bubbles. After a bubble has been shaken loose from the pipe, it will usually float away in the air if there is a slight draught or breeze blowing, but otherwise will fall toward the floor. If the floor is covered with a woolen carpet, the bubble will bounce like a rubber ball when it strikes. Carpets are usually made of wool and wool does not easily become wet. Soap-bubbles will rebound without breaking, from a substance which is not readily wetted. If a bubble falls on a cotton rug or on the bare floor it will break. Cotton and wood are easily wetted and absorb part of the moisture in the bubble and cause it to break.

Smoke Bubbles are very pretty but will have to be made with the aid of a friend who smokes. The proper way to make a smoke bubble is to start the bubble first with a little air and then blow the smoke in.

Small smoke bubbles made with a straw look very much like pearls. When a smoke bubble bursts it will appear like an exploding shell.

Bubbles out of Doors. The soap-bubble is a beautiful and interesting object indoors but is still more so out of doors. The first thing which you will notice about a bubble which is out of doors, is the strange reflection of various objects which show in the walls of the bubble as though it were a mirror. Reflections can be seen on both the inside and outside surfaces and are curiously contorted. Those who have the advantage of a beautiful yard or surroundings will find it very interesting to photograph them as they appear in a bubble. It will be necessary to use a camera which can be focused so that the definition of the image will be sharp.

While out-of-door bubbles are very attractive, it is best not actually to blow them outside because there is seldom any time when there is so little wind blowing that bubbles of any size can be easily managed. To make them indoors near a window or a door and let them escape outside is the better way. Choose a day when there is a bright sun and little wind, and a window

out of which the air from the house is gently moving. This can be regulated to a certain extent by opening or closing other windows so as to make the right draft.

If you cannot succeed in finding or producing a current of air which will carry your bubbles out of doors you can waft them out with the aid of a fan.

When a bubble is just the right size and the air currents are just right, it will float away and last a surprisingly long

Fig. 86. — The first thing you will notice about a soap-bubble which is out of doors is the strange contorted reflection in its surface of various objects.

time, being blown hither and thither, skirting many objects but not touching them, now resting stationary for a moment and then being buffeted by a whirl of air and spun away again. Some bubbles will withstand the rough air currents and eddies

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in an amazing way. I have seen bubbles drawn out like a sausage and sometimes separated into two or three distinct bubbles by a sudden puff of wind.

Among trees, bubbles are very short-lived. They move through the branches with the wind and the first time they touch an object all is over.

Bubble Air-Ships. Soap-bubbles which are filled with hydrogen or illuminating gas, both of which are lighter than air will rise very rapidly and disappear in the sky. You can blow bubbles, inflated with illuminating-gas, by connecting one end of a piece of rubber tubing to the stem of the bubble pipe and the other end to a gas jet. Dip the pipe into the soap solution and turn on the gas. When the bubble is starting, hold the pipe with the mouth of the bowl downwards in the usual manner, but as the bubble gradually grows larger it will become very buoyant and rise on the pipe unless you turn it over so that the mouth of the pipe is upwards.

It will be necessary to hold the pipe very steady because the slightest motion will be apt to shake the bubble off before you are ready to launch it.

If you touch a gas filled bubble with the flame of a candle it will explode with a flash and a report. When your bubble is finished and freed from the pipe do not fail to shut the gas off immediately so that it will not escape in the room.

If you live in the country and there is no illuminating gas in your house and you wish to blow gas bubbles you may do so with the aid of a home-made hydrogen generator.

Place some scraps of sheet zinc in the bottom of a wide-mouthed bottle. Fit a cork, having a short piece of glass tubing passing through, to the mouth of the bottle. Slip one end of a rubber tube over the upper end of the glass tube and the other end onto the stem of the pipe. Pour a little dilute sulphuric acid on the zinc scraps and cork the bottle. The acid solution

should just be strong enough so that it attacks the zinc but does not do so with great violence. The bubbles which arise are hydrogen gas. The gas will pass out through the glass and rubber tube to the pipe. Dip the pipe into the soap solution while temporarily shutting off the flow of hydrogen by pinching

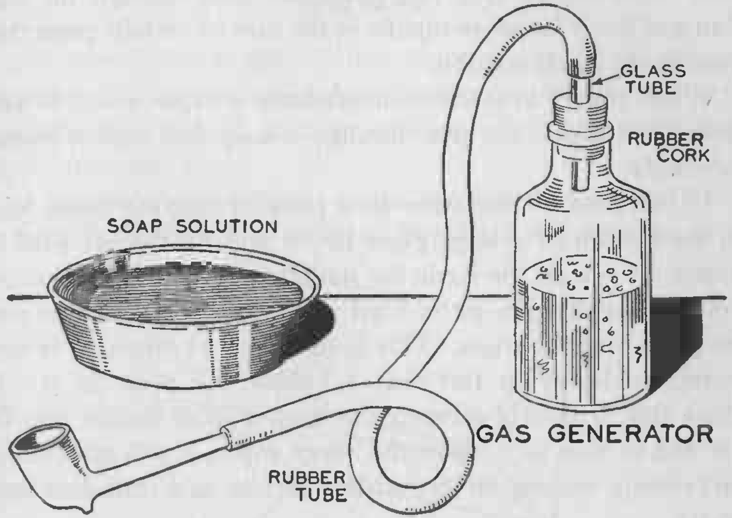

Fig. 87. — Bubbles filled with hydrogen are much lighter than the air which they displace. When released, they will rise like gas-filled balloons. You can fill bubbles with hydrogen by means of a home-made gas generator connected to a bubble pipe.

the rubber tube. When the tube is released, the pressure of the hydrogen will blow the bubble.

Keep all flames or fire away when making bubbles with hydrogen. When mixed with air in the right proportion, and ignited, hydrogen is explosive. If you observe this precaution there is no danger.

Ether Soap-Bubbles. The air inside of a soap-bubble is generally under pressure, as many of the experiments have shown. If this air could pass through the bubble from one

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side to the other, the bubble would soon shut up as it does when you take your mouth away from the pipe stem and allow the air to escape.

Apparently there are no holes in a soap film and you would not expect that a gas like air could pass through to the other side. However, it is a fact gases can pass through the soap film and do so far more rapidly in the case of certain gases than you would think possible.

When *ether* * evaporates, it produces a vapor which is very heavy and which can pass through a soap film almost instantaneously.

If you pour a little ether on a piece of blotting-paper lying in the bottom of a large glass jar, it will fill the jar with its vapor. If you set the jar in the sunlight and look at its shadow, you can see that the jar is filled with something which is running out over the edges. This is the vapor of ether. It is very heavy, so heavy in fact that a bubble will float on it. To show this, it is only necessary to drop a small bubble into the jar and as soon as it meets the heavy vapor, it will stop falling and remain floating on its invisible surface as a cork does upon water.

In order to show that ether vapor has the property of passing through a bubble, blow a bubble with the pipe. Hold your finger over the stem so that the air cannot escape and immerse the bubble in the jar of ether vapor for a couple of minutes.

Then remove the bubble from the jar and notice that it has changed and hangs like a heavy drop. The ether vapor has passed through the soap film and displaced the air inside of the bubble. Bring a lighted candle to the opening in the stem of the pipe, and the ether vapor inside, forced out by

* The *Ether* referred to in this instance is the chemical ether, used as an anaesthetic.

the elasticity of the bubble will catch fire and burn with a flame four or five inches long.

Ether vapor is very inflammable and so you must be very careful to keep fire away from the jar of vapor.

Soap Films

If a wire frame is made in the shape of any of the regular geometric solids, such as cubes, triangular prisms, etc., very beautiful figures will form upon them after they have been dipped in soapy water.

If you make a wire frame in the form of a triangular prism and dip it into the soap solution, the films will form on it in

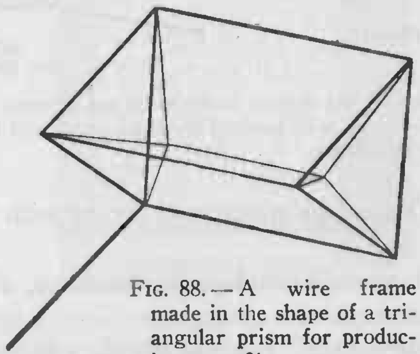

Fig. 88.—A wire frame made in the shape of a triangular prism for producing soap films.

a very peculiar fashion. The surfaces will all be flat, and at the edges where the films meet one another, there are always three meeting each other at equal angles.

After looking at the three-sided frame and noticing the three films meeting down a central line, you might expect that a square frame would have four films meeting each other down the middle. It is a curious fact however that, no matter how complicated or irregular the frame may be, there can never be more than three films meeting at an edge, or more than four edges or more than six films meeting in a point. Also, the films and edges can only meet each other at equal angles. If by any accident, four films happen to meet at the same edge or the angles are not exactly equal, it is only for the moment. The form, whatever it may be, is unstable. It cannot last and the films will slide over one another and never rest until they have set-

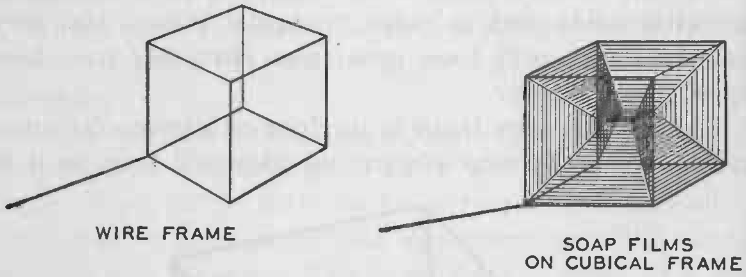

FIG. 89. — At the left is a cubical frame made out of wire. At the right is shown the same frame with some of the films which will form on it when dipped in soap solution.

tled down into a position which is in accord with the rule given above.

A cubical frame will produce twelve films, all adjusted to each other at an angle of 120 degrees.

Bubble Honeycomb. You can see the effect of this peculiarity of soap-films in a little better way by arranging a small box out of two pieces of window glass. The glasses need only to be about four inches wide and five or six inches high. They are about one-quarter of an inch apart. The sides and bottom of the box are formed by strips of wood and the cracks sealed with paraffin wax so that the box will not leak. Pour a little soapy water in the bottom. Blowing through a pipe of rubber or glass tubing immersed in the water will cause a great number of bubbles to form between the plates. If the bubbles are large

enough to reach across from one plate to the other, you will be able to see that there are not more than three films meeting each other, and that where they meet, the angles are all equal. The curvature of the bubbles may at first make it difficult to see that the angles are really all alike. If, however, you only look close to the point where they meet, the curvature will not mislead you and you will see that what I have said is true. If you are sharp and watch carefully while the bubbles are being formed, you

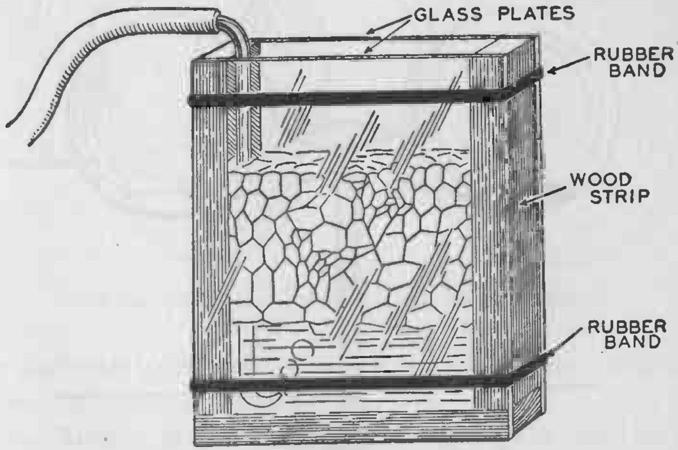

FIG. 90. — Bubble "honeycomb" formed between two panes of glass. The bubbles adjust themselves so that they meet each other only at equal angles.

will see that sometimes four do meet for a moment, but that they soon slide over one another and settle down into the only possible position of rest for them.

Fancy Bubbles

It would be possible to go on describing various soap-bubble experiments and explaining the peculiar things which happen at a much greater length than space will allow, and so in the following pages I am merely going to describe various sorts of "fancy" bubbles which are interesting to make, and leave it to the young experimenter to use his own powers of observation and reasoning in noticing and explaining the reason why things happen as they do.

The Bubble Stand will be found very useful for supporting a bubble on the wire rings so that both hands are left free to

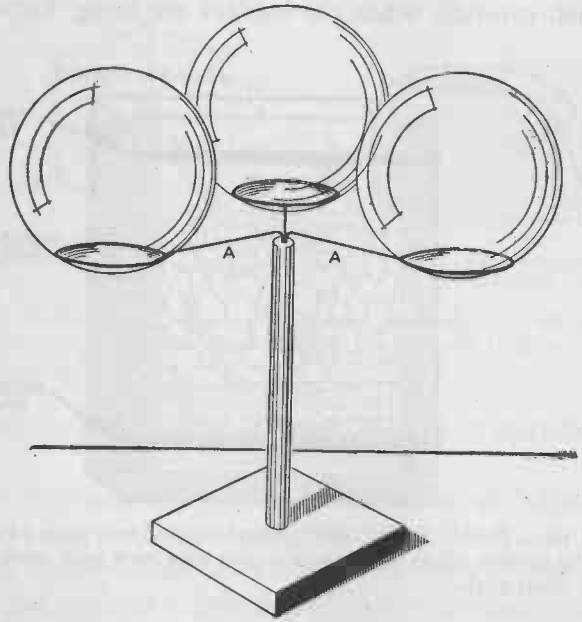

FIG. 91. — Three bubbles supported on the stand at the same time.

assist in the experiment. Before the bubble is placed in position on the ring, the latter must be thoroughly wet with the soap solution.

The Bubble Acorn is composed of two separate bubbles, a small one suspended from the bottom of the ring and a larger one resting on top.

A Bubble Basket is easily made by dipping one of the type "C" rings in the soap solution and then suspending a bubble from it.

A Bubble Lamp Chimney is formed by supporting a bubble on the ring "*A*" in the top of the stand and then touching a "*B*" ring which has been wet, to the top. Slowly lift the upper

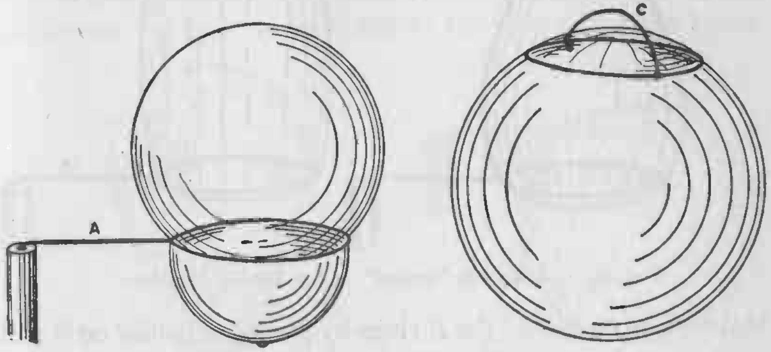

FIG. 92. — A bubble "acorn" and a bubble "basket."

ring until the bubble is drawn out into the shape of a lamp chimney as in the illustration.

The Bubble Bellows will give you a good idea of how elastic a soap film is. It is made by using two rings of the same size, "*A*" and "*C*." Place a bubble on "*A*." Wet the ring "*C*" and place it upon top of the bubble. You can then draw "*C*" up and down just like an accordion or a bellows.

The Bubble Lens will not magnify but looks very much like a reading glass lens. It is made by lifting the ring *C* up from the lamp chimney until the chimney breaks.

Bubble Domes. Wet the bottom of a saucer with the soap solution and then place a bubble on it and it will form a dome. If you wet the bubble horn or pipe thoroughly and push it through the dome, you can blow another bubble inside.

Pushing a Bubble through a Ring is not so hard as it might first appear. Blow a bubble and place it on the stand. It should be just large enough so that it will not fall through the ring.

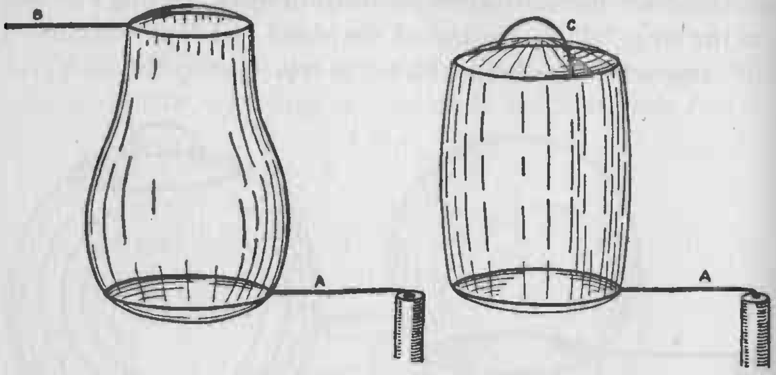

FIG. 93.—A bubble "basket" and a bubble "bellows."

Make a film on one of the *B* rings by placing a bubble on it and breaking it on one side. If you gently press the top of the bubble on the stand with the flat film you can push it through the ring to the other side. You can push it back and forth many times if you are careful.

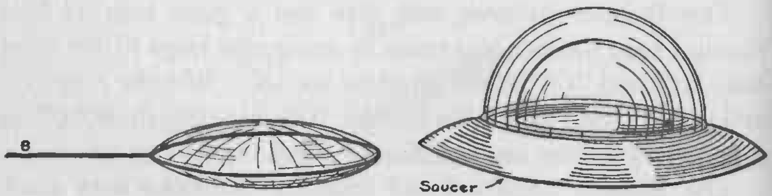

FIG. 94.—A bubble "lens" and bubble domes one within the other on the bottom of a saucer.

A Bubble within a Bubble. Blow a bubble and hang it on the stand on the under side of the ring. Wet the small ring, *C*, and hang it from the bottom of the bubble. Push the bowl of your pipe, which has been thoroughly wet in the soap solution

up inside from the bottom and blow another bubble inside the first.

Then pull the lower ring down gently, squeezing the inner bubble into a shape like an egg, or swing it around and around and carefully peel the ring *C* away so as to leave one bubble within the other.

A Bubble Balloon. You have already learned that illuminating gas and hydrogen are lighter than air and that a bubble

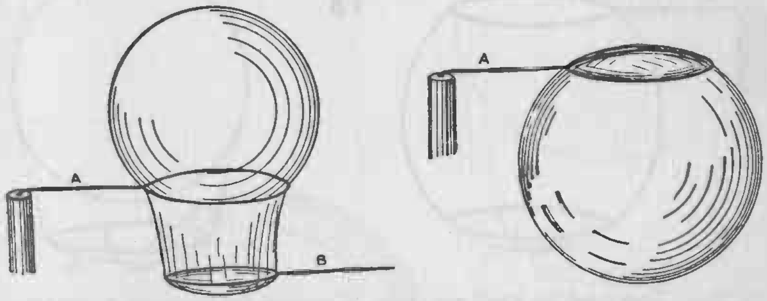

FIG. 95.—A bubble can be pushed through a wire ring without breaking as shown in the left-hand sketch. The first step in blowing a bubble within a bubble is to hang one from the wire ring as shown above.

containing either of these gases floats upward as soon as it is free.

Blow a large bubble with ordinary air and place it upon the ring stand. Blow a bubble inside of it using gas. The gas bubble will try to rise and will press against the top of the outer one with such force that it will stretch it out of shape.

In fact the buoyancy will probably be great enough so that it will carry up a very light wire ring having some light object such as a piece of thread and a feather attached.

Colored Bubbles

You can color bubbles a beautiful greenish yellow by means of a small amount of a chemical called *fluorescin* dissolved in the soapy water. If you look at a bubble or a soap film containing fluorescin, by ordinary light you will hardly notice anything different about it, but if you allow sunlight or the rays from an electric arc lamp to shine upon it, it will appear a brilliant green.

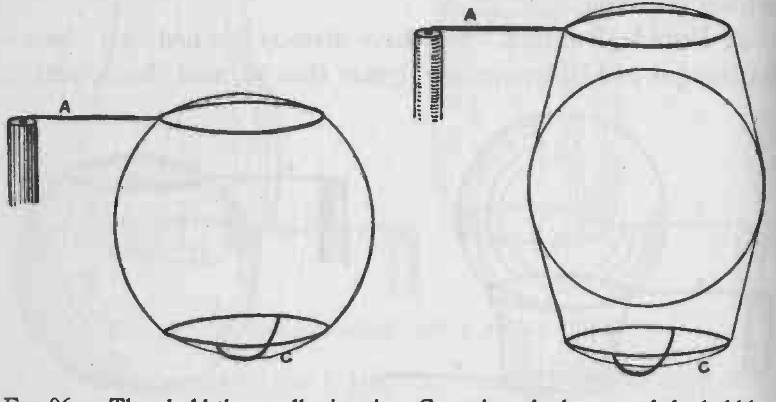

FIG. 96. — Then hold the small wire ring, C, against the bottom of the bubble, push the wet bubble pipe through and blow a bubble within the bubble.

A very pretty effect can be obtained by blowing one bubble inside of another and making the inner one with a soap solution containing fluorescin while the other one is made from an ordinary soap solution.

A Whimsical Bubble

Surprising and odd bubbles may be blown with a solution of *saponin.* Saponine may be bought as a white powder from a chemical house. A little dissolved in water will give the required mixture. A sufficiently good solution may also be obtained by cutting up horse-chestnuts in thin slices and soaking them in very little water. The slightly yellow liquid contains enough saponine to enable bubbles up to three or four inches in diameter to be blown.

Either method of preparing the solution will serve. It is well to have a pipe with a restricted stem so that the bubble cannot be blown rapidly. Bubbles blown with saponine do not show anything unusual while being blown or when contracting slowly

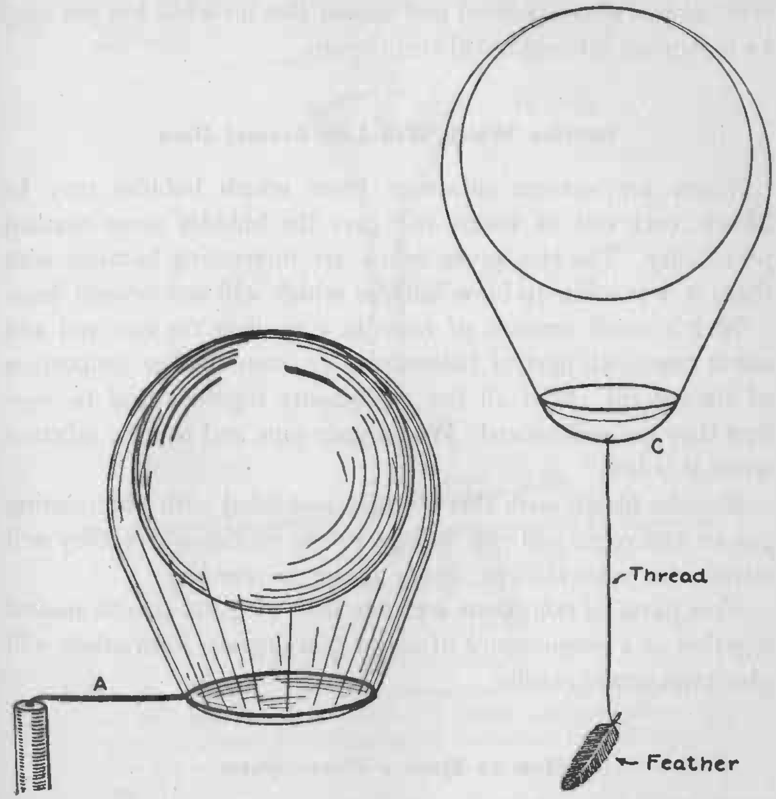

FIG. 97. — A bubble within a bubble is shown in the left hand sketch. At the right is a bubble balloon.

under their own tension and forcing the air back through the pipe, but have the peculiarity that when a bubble about an inch in diameter is blown, and a little of the air sucked back through the pipe, it does not follow the air as a soap-bubble does but forms a wrinkled bag, which if left to itself will slowly regain its smooth spherical form. They will do so at once, under compulsion, if air is forced in again. This process may be repeated several times. If sufficient air is drawn out, the wrinkled bag will become sharp pointed and appear like an icicle but yet may be blown out into spherical form again.

Bubbles Which Will Last Several Days

There are various mixtures from which bubbles may be blown, each one of which will give the bubbles some marked peculiarity. The two given below are interesting because with them it is possible to blow bubbles which will last several days.

Melt a small amount of resin in a shallow tin can and add about one-tenth part of beeswax or an even smaller proportion of linseed oil. Melt all the ingredients together and be sure that they are well mixed. Warm your pipe and use the mixture while it is hot.

Bubbles blown with this mixture and filled with illuminating gas or hydrogen will rise and go to the ceiling where they will remain for several days, finally going to powder.

Five parts of colophene and one part of gutta-percha melted together at a temperature of about 300 degrees Fahrenheit will give even better results.

How to Make a Water Motor

At one time in the history of the world water power was the only available source of energy to be had without prohibitive expense, in sufficient quantity for performing the work now accomplished by the modern steam engines and gasoline motors.

Almost all the older manufacturing cities owe their location to the fact that water power for manufacturing purposes existed

there. The principal uses for the power were grinding flour and sawing wood. A great many of the old-fashioned looms were also run by water power. Of course, in those days the amount of power required was very small compared with the

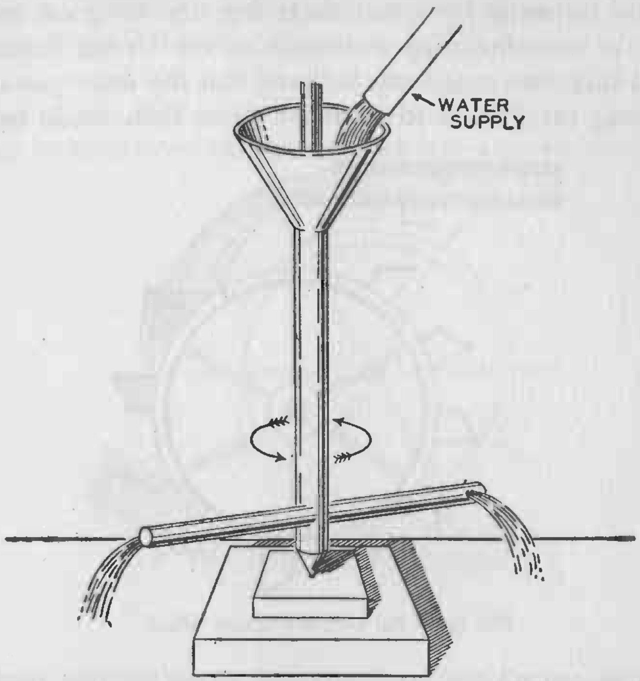

Fig. 98. — Barker's mill is a curious invention which operates on the same principle as Hero's engine but uses water in place of steam. It illustrates the important law of physics that the action and reaction of a force are always equal and opposite.

vast horse-power consumed in many of the industrial enterprises of today.

The modern way of using the energy in the waters of a river is to transform it into electricity. Many millions of horsepower are secured in this manner. The electricity can be transmitted to places far distant from the river. The United States is probably the most fortunate country in the world in the possession of rivers which can be used for power purposes.

It is curious to note that the city of Paterson, N. J. was founded distinctly for a manufacturing city, designed, indeed, to be the manufacturing metropolis of the United States. It was at that time confidently believed that the water power afforded by the Passaic River at the Great Falls would be suf-

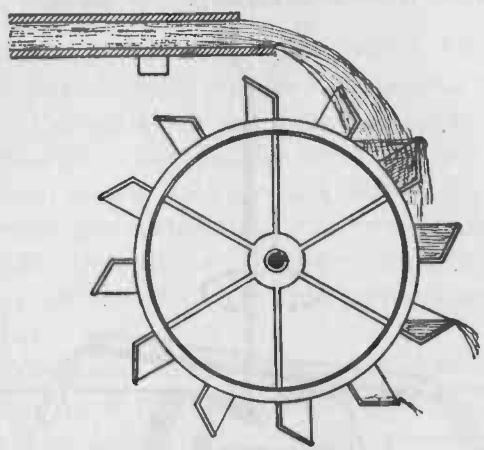

Fig. 99. — An overshot water wheel.

ficient to run all the machinery for manufacturing purposes in the country. This was in 1792, when the population of the United States was under 5,000,000 and its territory extended south and west respectively only to the Savannah and Mississippi Rivers.

There are several different methods of deriving the kinetic and energy of gravity from the water for power purposes. One of them, a most curious invention, called Barker's centrifugal mill is illustrated because it is an application of an important law of physics. The machine consists of an upright tube having

a funnel-shaped mouth for the admission of a stream of water, the lower end bearing two hollow arms closed at the ends but having two orifices or openings on the sides opposite to each other, so that the water spouting from them will fly in opposite directions. The lower part of the tube is solid, and turns on a point resting on a block of iron or stone.

Water is fed into the funnel at the upper end of the tube. As soon as the water runs down into the two arms and commences to spout from the openings the mill will revolve.

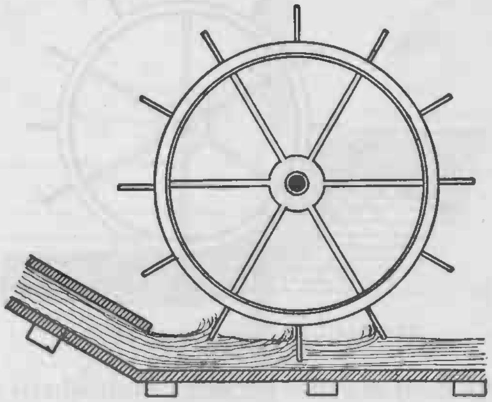

Fig. 100. — An undershot water wheel.

It is an invariable law of physics that the action and reaction of a force are always equal and opposite. Suppose that you hold your hand in the stream of water issuing from an ordinary garden hose. The strong pressure against your hand has a tendency to push the hand away. But upon investigating still further you will find that there is also an equal tendency to force the hose to move in the opposite direction, away from the hand. The tendency for the hose to move is the *reaction*.

It is the reaction of a fire hose which causes it to thrash about with such disastrous effects when it breaks away from the fire-men. If you should hold a finger in one of the little streams issuing from the "Barker's Mill," the pressure could be plainly felt. It is the reaction of this force tending to move in the opposite direction that causes the mill to revolve.

A "Barker's Mill" is of no practical use for power purposes. It is merely of interest as a laboratory instrument. The usual method until the advent of the water turbine was to employ a large wooden wheel carrying on its circumference a series of

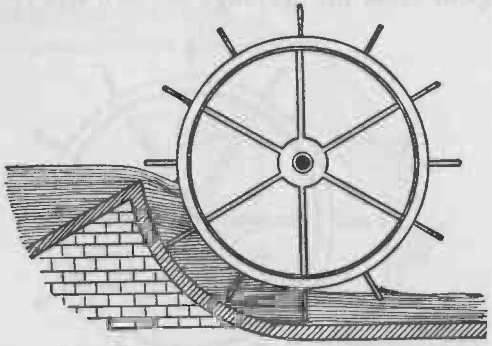

FIG. 101. — A breast water wheel.

flat boards or cavities called buckets. Such wheels are of three kinds, namely: overshot, undershot, and breast wheels.

The buckets on an overshot wheel are so constructed that they retain the water until the wheel has made about one-third of a revolution, when it escapes as from an inverted vessel and the wheel ascends with empty buckets while on the opposite side they are filled with water. It is chiefly by the weight and not the momentum of the water that the overshot wheel is turned.

The undershot wheel is so-called because the water passes under instead of over as in the overshot wheel. Instead of tight buckets to retain the water it has flat boards.

A breast wheel might be called "half overshot and half under-

shot." In this, the water, instead of passing over or entirely under the wheel is delivered at the side first and then it passes

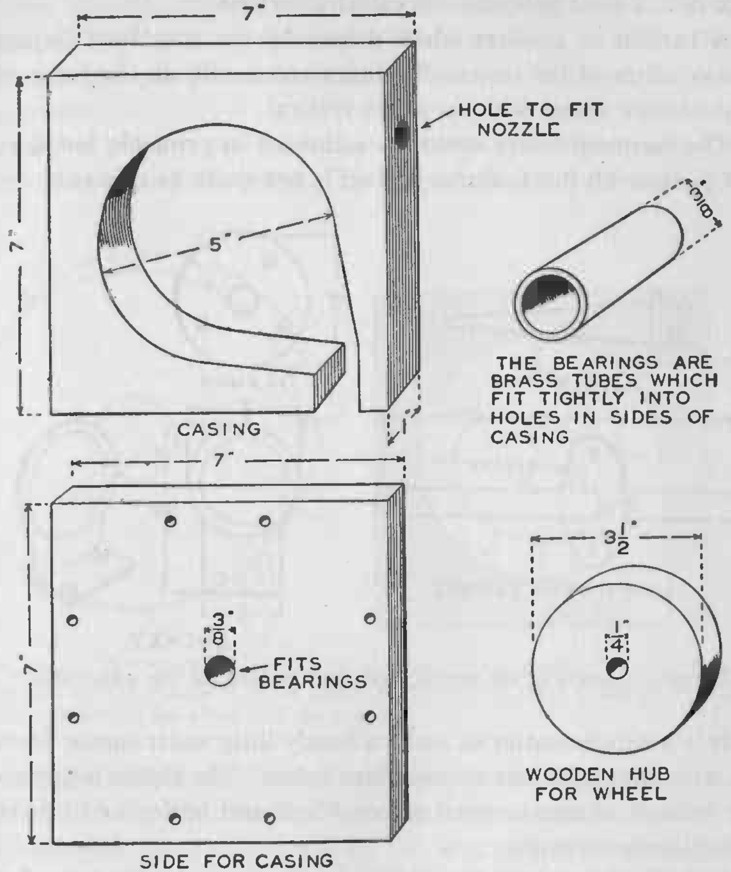

FIG. 102. — These parts for the water motor are easy to make. The casing and the sides for the casing are made of wood.

under. The breast wheel is moved partly by the weight or gravity and partly by the momentum or kinetic energy of the water.

Old-fashioned water-wheels such as those just described are no longer built for power purposes except in very isolated places or where power is required for temporary service only. The device used nowadays is called a turbine.

A turbine is a water-wheel driven by the combined impact and reaction of the water. Turbines are usually in the form of a horizontal wheel with the shaft vertical.

The common water motor is a turbine in principle but does not possess all the features and so is not quite as efficient.

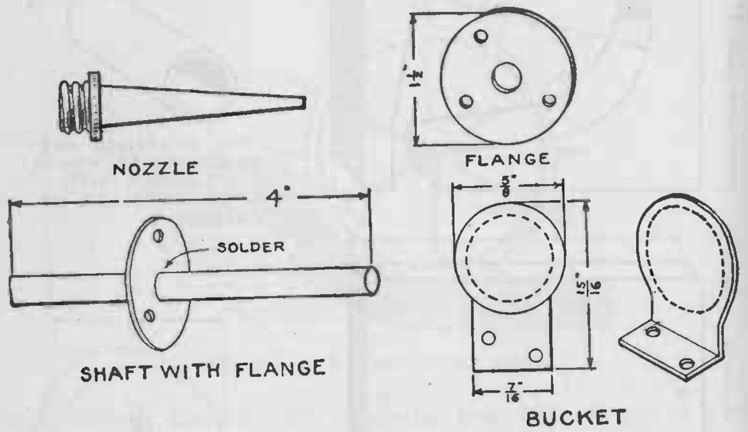

Fig. 103. — Details of the nozzle, shaft and buckets for the water motor.

It is a simple matter to make a handy little water motor from the drawings and instructions given below. The motor is powerful enough to turn a small emery-wheel and buffer or to drive a miniature dynamo.

Make a round hole five inches in diameter, by the use of a scroll saw or in any convenient manner, in a pine board seven inches square and one inch thick. Then enlarge the hole at one corner so as to make a pear shaped opening out of the circle. This forms an outlet for the spent water.

Fit two pieces seven inches square and one-half-inch thick

to the sides. Bore a three-eighths-inch hole in the centre of the side pieces.

The wheel is formed out of a circular piece of pine three and one-half inches in diameter and one-half of an inch thick. A hole, one-quarter of an inch in diameter is bored through the centre.

Twelve brass buckets are fastened equidistantly around the circumference of the wheel. These are cut out of No. 18 B. &

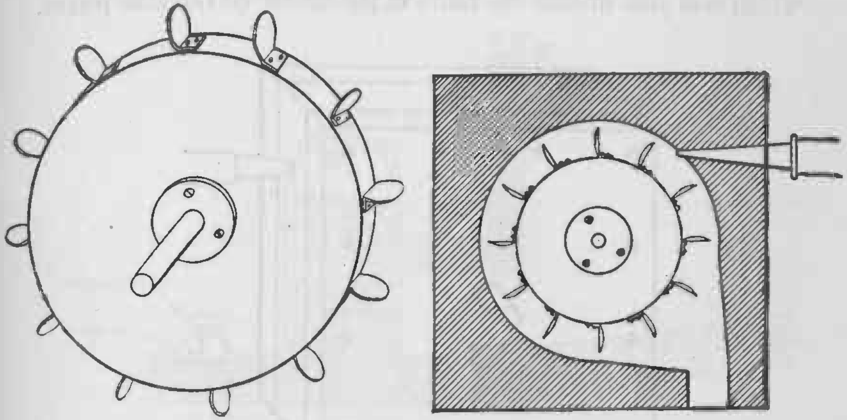

Fig. 104. — The completed wheel with the buckets and shaft in place is shown at the left. Alongside it is the motor with one side piece removed to show the position of the wheel and the nozzle.

S. gauge sheet brass. To make them cup-shaped, take an iron rod and file the end round. Place one of the buckets on a block of lead with the rounded end of the iron rod in the center of the bucket. A few blows of a hammer on the rod will form a small cup shaped depression in the bucket.

The small flaps on the buckets are bored and bent forward at right angles so that two small round-headed brass screws passing through into the wood will fasten them securely.

The shaft is a piece of five-sixteenths brass rod four inches long. A round piece of sheet brass, one inch and one-half in diameter is soldered near the center. The wheel is fastened to the shaft by means of several round-headed brass screws passing through the disk.

The nozzle for the wheel may be secured from an old oil-can. It is driven through a hole in the wooden casing as in the illustration.

The bearings of the motor are two pieces of brass tubing which will just fit into the holes in the center of the side pieces.

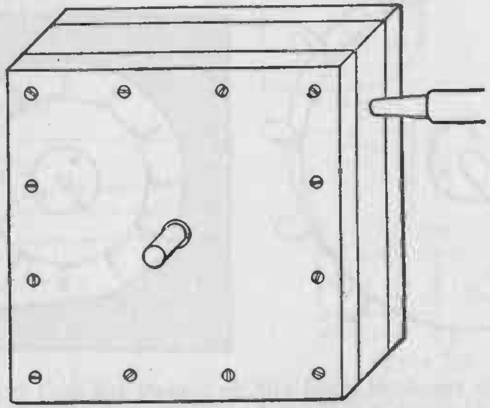

Fig. 105. — The completed water motor.

Several round brass washers should be placed on the shaft on both sides of the wheel to keep the latter from striking the sides of the case. The side pieces should be fastened firmly in position by means of several round-headed brass screws.

The motor has a very high speed, and so in order to realize its full power, the shaft should be fitted with a very small pulley. In order for the motor to develop sufficient power to be of any practical use the water pressure should be at least thirty pounds.

The motor should be fastened over a sink or basin by a couple

of iron brackets. The water is led to the nozzle by means of a rubber hose.

The Hydraulic Ram

The hydraulic ram was invented by Montgolfier, a French mechanician and inventor (the same who first ascended in a balloon) in about 1796.

This useful machine affords the most efficient, cheap, and convenient means of raising water ever devised. A small brook

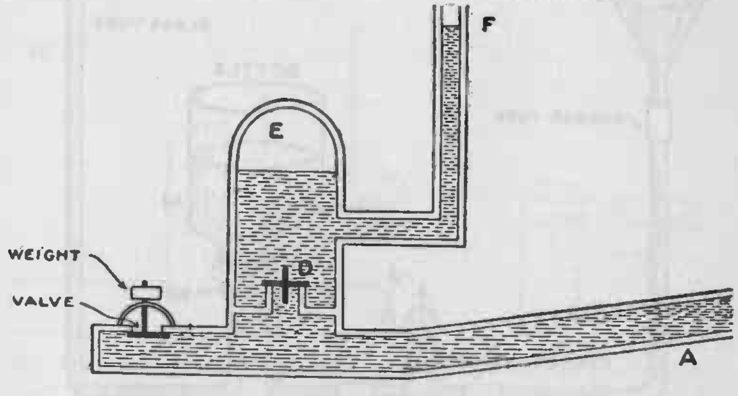

Fig. 106. — Cross-section of a hydraulic ram.

or a spring with an elevation of only a few feet is all the power that is required to furnish an abundance of water. Perhaps many of the readers of this page are familiar with this useful machine and some of those who live in the country may even obtain their water supply in this manner.

The hydraulic ram is very simple in all its parts and makes a very interesting and instructive model for the young experimenter to construct.

Its operation is very easily understood. Suppose the pipe *A*, comes from a spring or brook elevated a few feet above the base of the ram. The water flows from the spring down through the ram to that part called the "spindle valve." This spindle valve closes the opening forming the outlet of the ram when drawn upward by the current of water.

On the spindle are several small weights so adjusted that the valve is made to open and drop down again as soon as the flow is stopped and the water is still. But as soon as the valve is opened the water is permitted to flow through the ram. Its

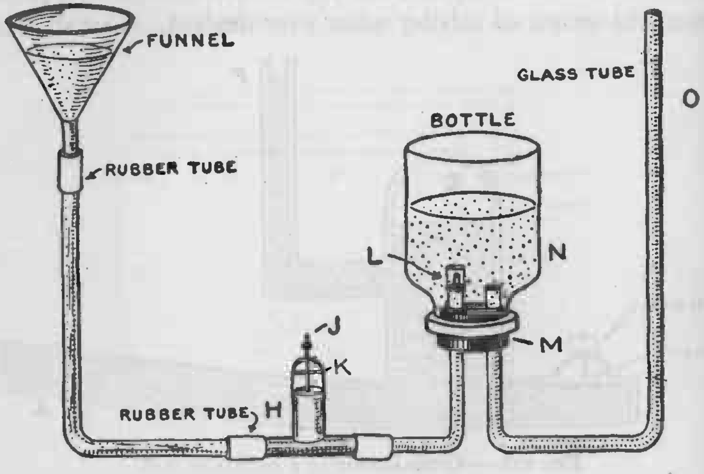

FIG. 107. — A model hydraulic ram.

movement, however, again closes the valve stopping the discharge.

The whole operation of the ram is dependent upon the proper adjustment of the weight of the valve so that it is just sufficient to permit the valve to rise by the force of the stream of water flowing through the opening and to sink again as soon as the water has ceased to flow after the opening is closed. This results in an intermittent stream of water flowing for an instant, stopping, and then again renewing its motion.

Now water in motion acquires a property called momentum

or kinetic energy. Momentum might be termed quality of motion. The water exerts a tendency to continue in motion after the opening has been closed.

When the valve opens by dropping down, all the water in the pipe instantly moves forward to supply the place of that which has escaped through the outlet. The valve is then immediately closed again by the action of the stream and the water shut off. But the water, as explained above, tends to keep on moving, in fact, if the pipe were long and the spring high so that the water

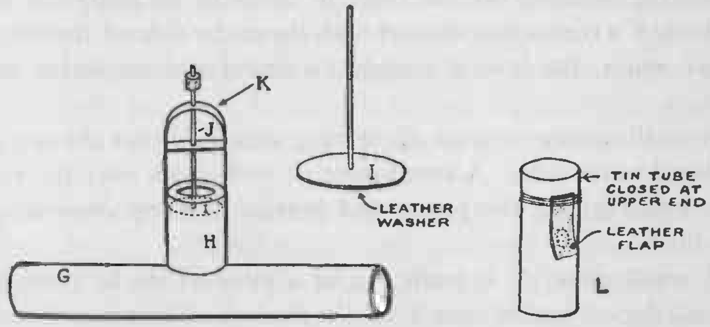

FIG. 108. — The sketch at the left shows the details of the spindle valve for the hydraulic ram. At the right is illustrated the valve L which prevents the water that is pumped upwards into the bottle from flowing back again.

acquired considerable momentum, the pipe or the ram itself might be easily burst by the force of the shock when the stream was interrupted unless of course some outlet for the water were provided. The second outlet is the valve *D*, opening upward into the air vessel *E*, and out through the pipe *F*. As soon as the momentum of the water is expended, the valve *D* closes and prevents the water from flowing back again. The process is then repeated.

A working model of a hydraulic ram may be easily constructed with the help of some metal and glass tubing, a bottle and one or two other "odds and ends." All dimensions have purposely been omitted so that the experimenter is free to use whatever material he may have on hand, it only being necessary to observe a reasonable degree of proportion.

Two pieces of tin or brass tubing, *G* and *H*, are joined by soldering together. The short tube *H*, is closed with a cover which has a hole cut in it so as to allow the piston *I*, and rod *J*, forming the "spindle valve" to work freely up and down. The piston is made up of a circular piece of sheet tin about two-thirds the diameter of the tube. It must be perfectly flat so that when it comes into contact with the under side of the cover under water, the hole is completely closed and no water can pass.

A small stirrup or yoke, *K*, serving as a guide for the rod is soldered to the tube. A small piece of cork stuck over the rod serves to regulate the piston and prevent it from descending too far.

A small valve, *L*, is made out of a piece of tin by riveting a small flap of leather over a hole in the side. The valve is then passed through a cork, *M*, fitting tightly into an inverted bottle, *N*. The valve is connected to the tube *G* by a piece of thick rubber tubing.

CHAPTER V

SOUND

WHENEVER you start on a scientific adventure, it is usually not possible to proceed very far without hearing much about "waves" and "vibrations." Our old friend *Energy* takes many different forms and does many strange things, but it apparently always likes to keep things moving when possible and to move them both back and forth with perfect regularity so that the motion is called a *vibration,* which is just another word for shaking.

Whenever energy shakes anything or causes it to vibrate, some widely different results are produced, depending upon how fast the shaking takes place and what it is that gets shaken up. If energy shakes the air, it produces *Sound,* if it moves the *molecules* of a piece of iron, it generates *Heat,* while if the vibrations occur in the Ether, *Light* and *Electric Waves* are produced.

All these vibrations are very interesting, but in order to understand some of them, we must first learn something about them in their simplest form—*Sound.*

Sound is a sensation peculiar to the ear caused by vibration of the nerves of hearing. These vibrations generally have their origin in the motion of the air produced by some vibrating body such as a bell, a whistle, etc.

How we Hear. Lodged in a cavity on either side of the head and situated in the midst of a dense and solid mass of bone are two little membraneous bags, called the *membraneous* *labyrinth* and the *scala media of the cochlea.* Each bag is filled with a liquid, and is also surrounded and supported by a fluid which fills the cavity in which the bag is lodged. Certain small, hard bodies, much like sand and called *otoconia,* lie in the liquid in the bag. The ends of the *auditory* nerve of hearing are dis-

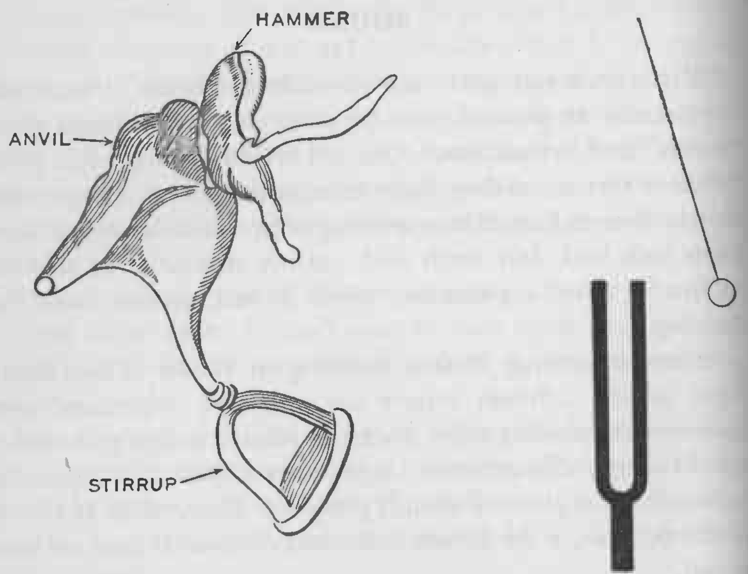

Fig. 109. — The left-hand sketch shows the three bones in the ear called the ossicles. They are the hammer, anvil and stirrup. At the right is a tuning fork. If a small ball of cork tied to a fine silk thread is touched to the prong of a vibrating tuning fork, the ball will be violently repelled.

tributed around the walls of the bag in such a manner that they are struck by the little particles whenever the fluid in the bags is disturbed.

The walls of the bag on which the ends of the auditory nerve are spread are virtually a miniature beach, and the little *otoconia* showers of little pebbles or sand which are raised and let fall by each succeeding wave of sound.

This wonderful mechanism constitutes the inner ear.

The ear, as a whole, consists of three parts; the *outer* ear on the outside of the head which serves as a sort of horn to collect the sound waves and pass them on through the *auditory canal* to a small membrane called the *ear drum;* the *ossicles,* which are three little bones caller the hammer, the anvil, and the stirrup; and the inner ear just described.

The foot of the stirrup is connected with an oval membrane which closes a hole in the inner ear. Sounds passing through the auditory canal cause the ear drum to vibrate or tremble and and send tremors through the bones to the liquid in the little bags. The tumbling of the pebbles against the filaments of the auditory nerve sends the sound impressions to the brain.

These impressions which the mind receives through the organ of hearing are what we know as sounds. All bodies which produce sounds are in a state of vibration and they communicate their vibrations to the surrounding air and thus set it into waves, just as a stick, moved back and forth in a pool of water creates ripples.

Sound implies vibration, and whenever a sound is heard, some substance, a solid, a liquid or a gas is in vibration and is sending out waves in the air which conveys it to the ears.

If you strike an ordinary tuning fork or a bell and cause it to produce sound, the vibrations are too small to be seen with the eye, except sometimes in the case of the tuning fork, the prongs will appear blurred on account of their motion. You can however detect the motion by touching your finger nail to the edge of a large bell when it is ringing.

You can also perform this experiment in a different way. Tie a small ball of cork about the size of a pea on the end of a very fine silk thread. Ring a bell or set a tuning fork into vibration and while it is still sending forth its sound, touch the edge of the bell or the prong of the tuning fork, as the case may be, with the cork suspended from the thread. The little ball will be quite violently repelled, because the bell or fork is in vibration and moving back and forth so rapidly that the ball is knocked away by a succession of little blows.

Sound waves cannot usually be felt and cannot be seen. The movement of the air which takes place is usually too delicate for our sense of touch. The very lowest sounds can be felt sometimes as well as heard however. It is possible to make a large heavy tuning fork which will vibrate back and forth about fourteen times a second. If a person has a good ear, the sound can be heard as a very deep, faint note. The air waves from a

FIG. 110. — These straight lines are a pictorial representation of a sound wave. Where the lines are close together they represent the compression on the air, where they are far apart the air is rarefied.

large tuning fork of this sort vibrating at such a low rate of speed can be felt by our sense of touch.

The nature of a sound wave may be easily represented by a series of straight lines. The portions where the straight lines are close together indicate the air as being crowded or compressed at that point and the portions where they are farthest apart show how the air is slightly rarefied halfway between the compressed areas.

The Velocity of Sound. The vibrations causing sound are transmitted through the air at a speed of about one thousand feet per second. If you are about one thousand feet from a locomotive when it whistles, you will see steam blowing out of the whistle for one second before you hear the sound of the whistle. The exact speed at which sound travels through the air is 1,090 feet per second at a temperature of 32 degrees Fahrenheit. With every rise in temperature of one degree, the velocity

of sound increases one foot. Sound therefore travels more rapidly in the summer when it is warm than on a cold day in the winter.

Other substances besides air conduct sound waves. Water, wood, glass, steel, and practically all materials are conductors of sound.

If, while bathing you hold your head under water for a moment, you will be able to hear distinctly, a sound produced below

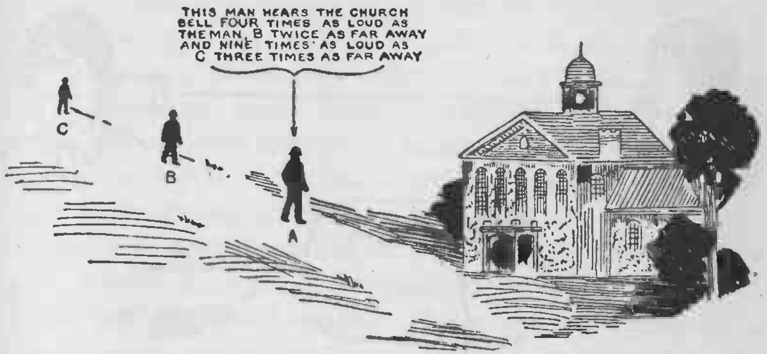

FIG. 111. — If you stand 100 feet away from a tolling bell you will hear it *four* times as loud as a person 200 feet away and *nine* times as loud as a person 300 feet away.

the surface of the water by the knocking together of two stones at a considerable distance away.

In fact, this property of water to conduct sound is made use of by submarines in communicating with each other or with the mother ship while they are submerged below the surface. There are several different forms of submarine signalling devices, but one of the most commonly used consists of two thin metal diaphragms set in opposite sides of the ship and connected together by a taut steel ribbon stretching between. A small felt wheel, revolved by an electric motor is arranged so that it will swing down and rub against the steel ribbon whenever a key is pressed.

The felt wheel revolving against the steel ribbon causes it to vibrate and emit a loud sound just as the bow rubbing against a violin string causes it to sound. The vibrations of the steel ribbon are transmitted to the metal diaphragms in the sides of the hull and so sent out into the water in the form of sound waves. The listening apparatus which picks up the sounds so sent out into the water, consists of a sensitive telephone transmitter attached to the side of the hull and connected to a tele-

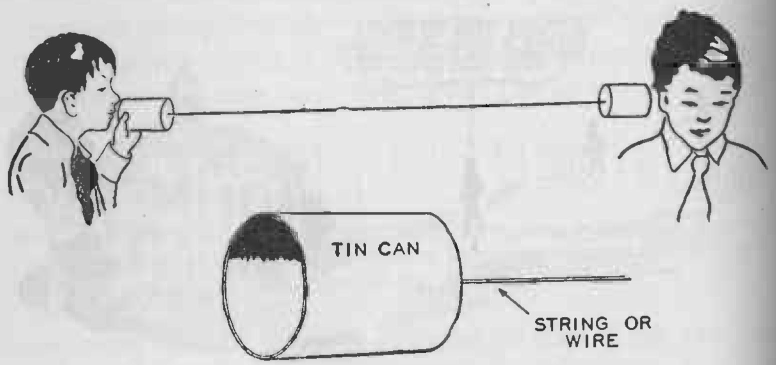

FIG. 112.— The tin can telephone is an illustration of how sound waves may be transmitted through a wire or string.

phone receiver. In this manner two submarines several miles apart and entirely under water can telegraph to each other.

Many dangerous points along the coast are provided with huge bells arranged to ring under water. Ships provided with a listening mechanism like that employed by submarines described above, can hear the sound of the bell ringing under water at a much greater distance than if the sound waves traveled through the air and are so enabled to avoid the danger point.

The Tin Can Telephone is a good illustration of how sound waves may be transmitted through a metallic wire or a string.

Punch a hole in the centre of the bottom of two tin cans.

Run a wire through the holes and twist a knot inside so that the wire cannot slip out again. The wire should be fifty feet long.

If the wire is drawn tight and does not touch anything a conversation may be carried on between two persons at each end of the line, by using one can as a mouthpiece to speak into and listening at the other.

Make certain that you do not have your fingers on the bottom of the can. Hold it as near as possible to the front edge.

If you hold your fingers lightly against the bottom for a second while you are talking you will feel it vibrate against your finger-tips. When you make the can vibrate by talking into it, the sound waves travel through the wire to the can at the other end and cause it to vibrate. These vibrations set up sound waves in the air which you can hear when your ear is held at the opening of the can.

The Velocity of Sound in very Dense Substances is very much greater than in air. Sound travels at a velocity of 16,500 feet per second in steel. If you stand alongside of a railroad track, and a few hundred feet away from a workman driving spikes or hammering on the rails, you will have an opportunity to see how much more rapidly the sound of the hammering travels through the steel rails than through the air.

The velocity of sound is much less than that of light, and you will be able to see the hammer strike the rail before you hear any sound. Almost immediately however will come the "click" of the blow transmitted by the steel rails, followed shortly by the sound through the air.

How Sounds Differ

Sound has been likened to a picture, painted not in space and color but in time and motion. We may have a red and an orange-colored light, both of the same intensity, but the eye is able to distinguish one from the other. So may we have sounds of the same *intensity* and *pitch,* one from a piano, the other from a violin. When the same note is struck on a violin and on a piano, the ear is still able to distinguish between the sounds and name the origin in each case. What is the difference?

Sounds may be divided into two kinds, noises and music. If the vibrations are irregular and *non-periodic* the sound is a *noise.* If they are regular, the sound is *musical.*

Sounds are further distinguished by three qualities—pitch, intensity or loudness, and timbre.

The Pitch of a sound is that quality by which we distinguish its position in the musical scale. Thus, we speak of sounds being *higher* and *lower* than one another. Pitch depends upon the number of vibrations made by the sounding body in a certain length of time, usually a second. The higher the pitch, the greater the number of vibrations.

The ordinary ear is sensitive to sounds running as high in pitch as 20,000 vibrations per second. The limits vary slightly in different persons. The power of hearing very high notes is usually lost with advancing age. Just as there are many objects which are invisible to the unaided eye; so there are sounds such as those produced by some insects which are above the range of the human ear.

A Homemade Siren Wheel will enable you to perform a number of experiments showing that the pitch of a sound rises with the number of vibrations.

Make a cardboard disk about nine inches in diameter and mount it on a pulley connected to a larger driving pulley by a string belt so that turning the crank will cause the disk to revolve at a high rate of speed. Make four series of holes in the disk, each series being equally spaced on its respective

circle. On the inner circle make 24 holes, on the second 30, on the third 36, and on the outside 48.

If you revolve the disk at a uniform speed and blow through a small glass tube placed close to and opposite the inner series of holes, a sound having the character of a musical note will be produced. This sound will be caused by the vibrations made by puffs of air which pass through the holes each time one of the latter crosses in front of the tube. If you pass the tube from the inside to the second, third, and outside row of holes, while the disk is still revolving at the same speed, there will be a rise in the pitch of the sound produced at each new position of the tube because the number of vibrations per second is increased.

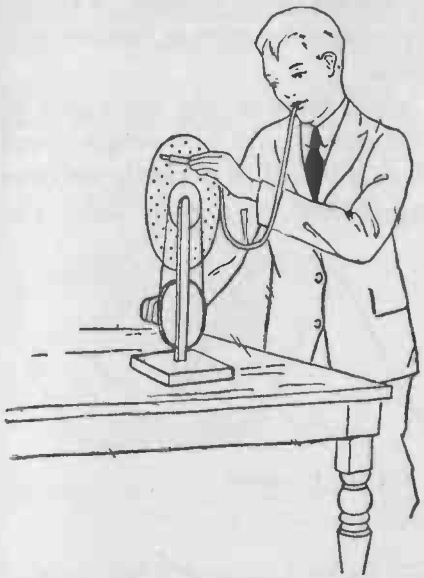

FIG. 113.—A simple siren wheel. If you blow through the holes in the revolving disk, a sound having the character of a musical note will be produced. Changing the speed of the disk will change the pitch of the note.

If you hold the tube stationary before any one of the series of holes, you will find that the sound rises in pitch as you increase the speed of the disk and falls as you slacken it.

The Intensity of a sound depends upon the energy or power of the air vibrations which strike the ear. The loudness of a sound diminishes very rapidly as the distance from the source of the sound increases. If you stand 200 feet away from a bell which is ringing, the sound is only one-quarter as loud as it would be if you were 100 feet away. At a distance of 300 feet it will only be *one-ninth* as loud as at 100 feet.

Timbre is the quality of sound by which we are able to distinguish the notes of a piano from those of a violin or a clarinet. It may be likened to certain colors in light. The different timbres of sound are produced by mixing various proportions of red, blue, and yellow.

A simple sound is one in which there is only one sound of one pitch. If you could see the sound wave of a simple sound such as that from a tuning fork it would be perfectly uniform and regular. It could be represented by a wavy line. The

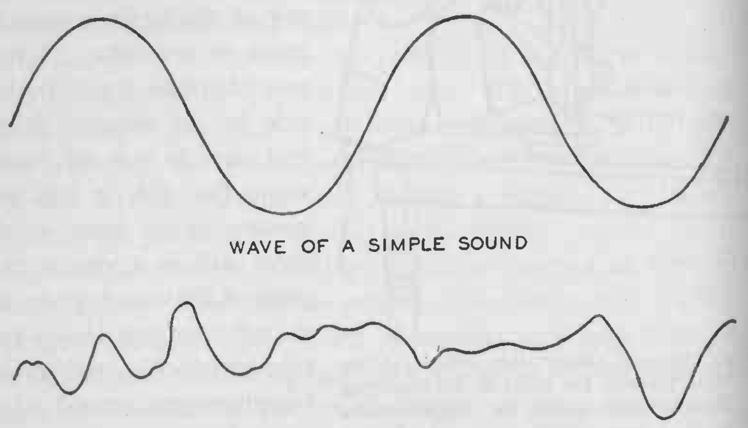

FIG. 114.—The wave of a simple sound is somewhat like a uniform waving line as shown at the top of this illustration. A composite sound such as one made by the human voice is like the irregular line at the bottom of the illustration.

sounds of a violin, the human voice, and most musical instruments are *composite,* or made up of several simple sounds which mingle.

How We Speak and Sing—The wonderful musical instrument by means of which we speak and sing is composed of two

flexible membranes called the *vocal cords,* stretched across a small cylindrical box, known as the *larynx* and located at the upper end of the windpipe. The cords are arranged so that their tension may be changed at will. In breathing, the air passes freely between the cords on its way to and from the lungs. When however, the muscles controlling the cords are tightened, the edges of the latter are brought parallel and quite close to each other. If the air from the lungs is then forced

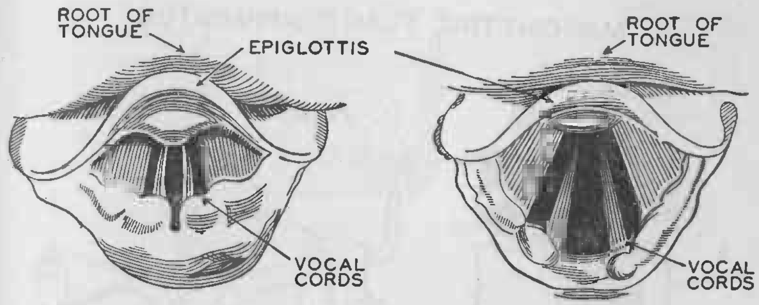

FIG. 115.—At the left is a sketch of the human larynx producing a sound. The sketch at the right shows the larynx at rest.

through the narrow slit between them, they vibrate like the reed of a musical instrument and produce sounds. The wide range of sounds which it is possible for a human being to produce are the result of varying degrees of tension of the vocal cords together with various movements of the mouth, lips, and tongue. The sounds called consonants are made by movements of the tongue and lips obstructing the sounds at their beginning or end, while the vowels are formed by a steady sound modified by the different shapes or sizes given parts of the mouth.

Manometric Flames

Many interesting and instructive experiments showing the nature of the sounds of the human voice may be performed by means of a simple apparatus called Koenig's manometric flame apparatus which consists of a device for transmitting the motion of the sound waves to a gas flame.

It is easly constructed and will prove to be one of the most interesting pieces of apparatus the young scientist could possibly desire.

A box is separated into two compartments by a thin sheet of rubber. Illuminating gas is led into one of these compart-

MANOMETRIC FLAME APPARATUS

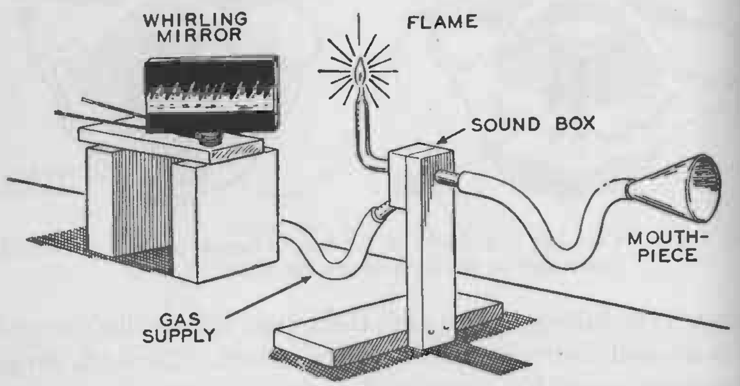

FIG. 116. — The manometric flame apparatus for transmitting the motion of sound waves to a gas flame. The nature of the sound waves is revealed by the image of the flame in a revolving mirror.

ments by a rubber tube, and then allowed to issue to a burner. The other compartment is connected to a mouthpiece.

Two pieces of mirror are arranged so that they may be revolved in front of the burner. When the burner is lighted and the human voice is projected into the mouthpiece, the sound waves strike the rubber membrane and cause rapid changes in the pressure of the gas. The height of the flame

varies with each change in pressure, and when viewed in the revolving mirror, resembles a band of light having a toothed edge like a saw. The tooth-shaped edge is a faithful representation of the vibrations in the voice and immediately assumes a new appearance when a new sound is emitted.

An upright piece of wood, *A,* two inches wide and three-quarters of an inch thick has a recess, one and one-quarter inches in diameter and three-eighths of an inch deep bored in it

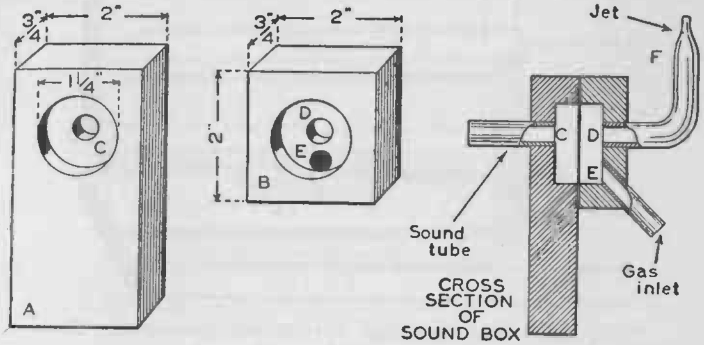

FIG. 117. — Details of the wooden sound box for producing manometric flames.

near the upper end. Another small hole, three-eighths of an inch in diameter, is bored through the strip in the centre of the recess. Similar holes are bored in the block, *B,* which is two inches square and has a three-eighths inch hole, *E,* bored obliquely near the bottom of the recess. A piece of thin sheet rubber such as that used in toy balloons is placed over the recess in the block, *A,* so as to cover it and is secured to the block by glue or cement. The block *B* is then placed on *A,* as shown, and the two pieces glued together.

The result is a box, separated into two compartments by a sheet of thin rubber. Fasten a glass tube into the oblique hole, *E.* Slip a rubber tube connected to a gas jet over the end of the glass tube so that gas may be led into the compartment. The gas issues from the box through a glass tube, F, bent at right angles and inserted into the hole D. The upper end of F is softened in the flame of a Bunsen burner or an alcohol lamp and drawn out so as to form a jet. The gas is

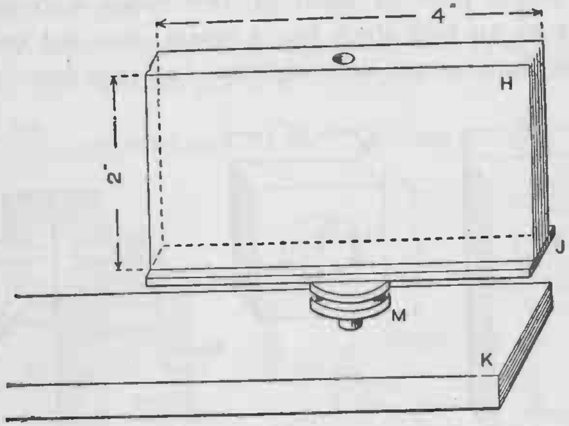

FIG. 118.—The revolving mirrors are fastened to the arrangement shown above.

lighted where it issues from the jet at F and then lowered until it burns with a small bright flame.

Insert a glass tube into the hole A in the other compartment and attach a short rubber tube having at its other end a cone made of cardboard.

The glass tubes must be firmly fastened in the wooden blocks and all joints made tight with the aid of a little sealing-wax.

Cut out a flat piece of wood according to the shape and dimensions shown by H. Drill a one-quarter-inch hole, I, through from top to bottom. Be certain that the hole goes through perfectly straight and parallel with the faces and ends of the block or the mirrors which are to be mounted on it will wobble and not run true.

Fasten a small strip of wood like J on the bottom of the block and glue a small grooved pulley to the bottom. The holes in H, J, and M must all line up so that a shaft formed of a piece of brass rod will slip through.

The lower end of the shaft is forced into a hole in a wooden block, K, so that it sits upright in a vertical position.

The two pieces of mirror should be four inches long and two inches wide. They are fastened to H by means of two rubber bands. The apparatus should move easily without friction.

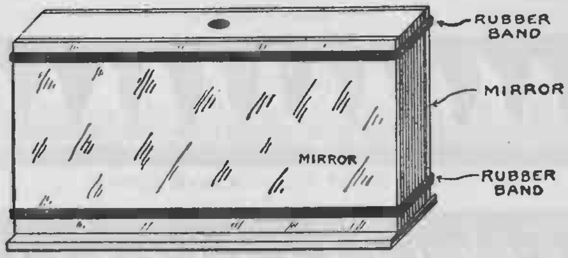

FIG. 119.—The mirrors are cemented to the wooden block with cement or glue. The rubber bands are added for safety sake to prevent the mirror from flying through the air if it should become loosened while rotating.

The block, K, is fastened to a piece of board having a grooved wooden pulley provided with a handle, mounted at the other end so that when the driving-wheel and the pulley on the mirrors are connected by a string belt, the mirrors may be rapidly revolved by turning the handle.

If you place the mirrors in front of the lighted gas jet and sing into the mouthpiece while the mirrors are revolving, the reflection of the gas flame, as seen in the mirrors, will have the appearance of a band of light with its upper edge toothed like the edge of a saw.

When the mirrors are rotated and no sound vibrations enter the mouthpiece, the reflection of the flame is drawn into a brilliant band or ribbon. On singing into the mouthpiece, the flame will vibrate and the upper edge of the band becomes serrated. Each tooth indicates a sound wave striking the

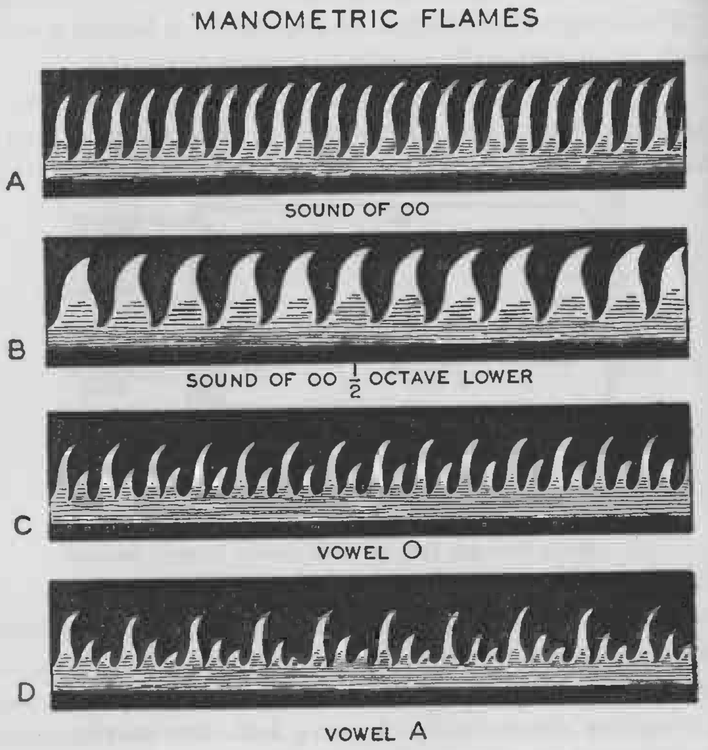

FIG. 120. — The manometric flame produced by the sound OO is shown at the top. The same sound an octave lower is also illustrated. The flames in the two bottom rows were produced by the sounds of the vowels O and A.

membrane and thus you have a faithful representation of the vibrations of your voice.

A shows the flames prdouced by singing the sound *oo,* as in *tool.* The same sound sung an octave lower in pitch will

show as in B, where there are just one-half as many vibrations and consequently one-half as many teeth in the flame. The sound *o* possesses an *overtone* and if sung into the mouthpiece, the image in the mirror will appear like that shown by *C,* being made up of alternating large and small teeth.

A band of flame like *D* will appear in the mirror if you sing the vowel *A* into the mouthpiece.

The illustrations show only a few of the unlimited different bands you will be able to produce with this interesting piece of apparatus.

The Sonometer

If you stretch a thin steel wire or a rubber band between two nails driven into a board and the wire is tight, it will give

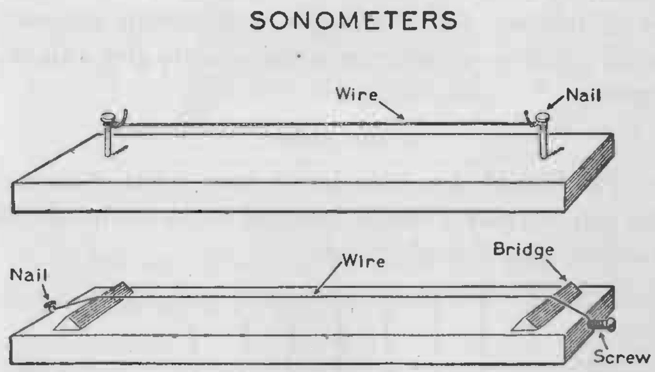

FIG. 121. — At the top is a simple sonometer and below a more elaborate form provided with bridges and tension screw.

forth a loud musical note when vibrated by being struck or plucked.

You can try a number of different experiments with an arrangement of this sort if you care to make one which is slightly more elaborate. Take a wooden strip about three feet long, four inches wide and one inch thick. Make two little wooden bridges as shown. Drive a nail, *A*, in one end of the board and fasten the end of a thin steel wire to it. Fasten the other end to a screw, *C*, in the opposite end of the board. Slip the bridges under the wire near the ends and tighten the wire until it gives a musical note when plucked at its center.

If you tighten the wire, the note will rise in pitch. Likewise if you move the bridge, *B*, so that the portion of the wire between the two bridges is short, the note will rise in pitch.

By varying the tension of the wire and the length of the portion which vibrates, that is, the part between the bridges, you will be able to obtain a great range of different sounds.

This is the principle made use of in musical instruments such as the mandolin, piano, harp, etc. The different notes are secured by steel wires of different lengths under varying degrees of tension. Such "stringed" instruments are really a number of special sonometers arranged so as to give a timbre to the sounds.

A Pin Piano

The "Pin Piano" is a little device upon which with a little practice, you can play a simple tune and which shows the effect which *length* has in changing pitch.

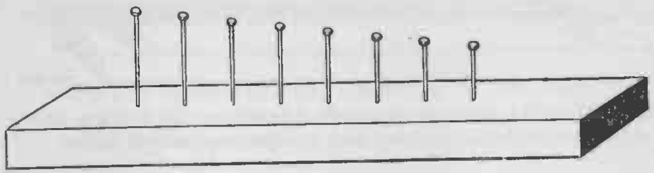

FIG. 122. — The "pin piano" shows the effect which length has in changing pitch.

Drive a number of ordinary dressmaker's pins into a block of wood placing them in a row and about a quarter of an inch apart. Drive the point of the first pin into the wood only a

very short distance. Drive the second one a little farther and the third one still farther so that you have eight pins with their heads in a sloping line as in the illustration. If you pluck the pins with the point of a pin they will each emit a clear musical note. The longest pin will emit the lowest note and

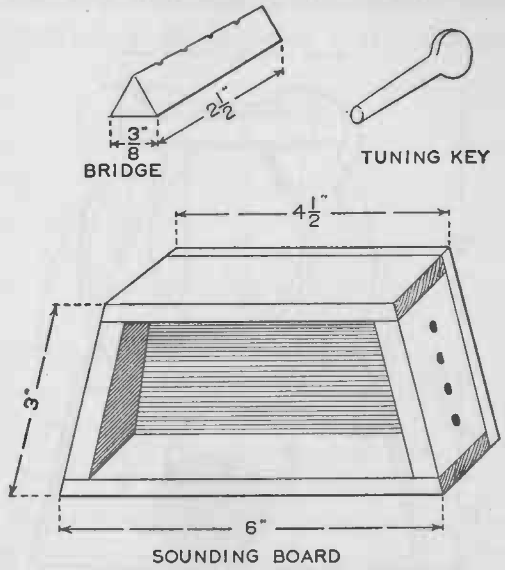

FIG. 123. — The sound box of the door zither is made of wood. At the top are shown the bridge and the tuning key.

the shortest pin the highest note. You can easily play a tune.

Some experimenters may care to make a somewhat more elaborate musical instrument than the "Pin Piano" and so the following description of a "door zither" will prove interesting.

How to Make a Door Zither

You will be able to get a great deal of amusement out of this device. When your friends come to see you and you open the door upon which the zither is hanging, they will hear a faint and apparently far-away strain of music which for a moment is almost impossible to locate.

The effect is produced by a little sounding board or box over which are stretched several little steel strings. Hanging down in front of each string is a little lead ball suspended

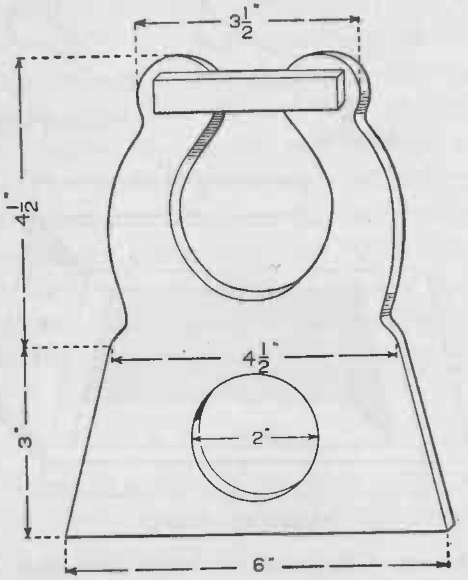

FIG. 124. — The sounding board which closes the front of the box is a lyre-shaped piece of wood as shown in the sketch above.

from a thread. The box is fastened to the back of the door and when the latter is moved, the balls tap against the steel wires and make the music.

First make a little box or sounding board like that shown in the drawing. Make the sides of the box out of wood which is three-eighths of an inch thick and the front and back out of wood a little less than one-quarter of an inch thick. Use only

straight-grained material and when you assemble the box do not use any nails to fasten it together but *glue* all parts. Do not leave any cracks where the parts fit together or the sounding-board will not have a good tone.

The Bridges are three-cornered strips of hardwood with four small notches cut one-half an inch apart. They should be fastened in position on the sounding board with glue.

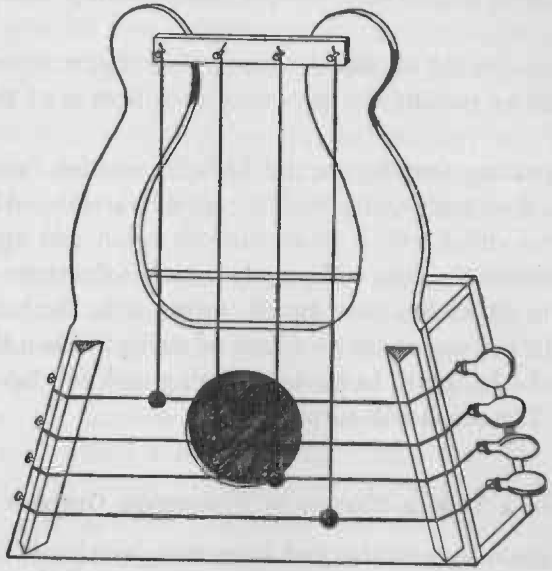

FIG. 125. — The completed door zither.

The Tuning Keys are made of hard wood and are patterned after those used on musical instruments such as banjos, mandolins, etc.

The strings should be steel banjo strings. You will need four of them. One end of each is fastened to a small wire nail in the side of the zither. The other end passes around the tuning keys and through the small hole near the handle. The ends of the keys fit snugly into tapered holes. The keys should fit very tightly so that when the wires are pulled up taut, they will not loosen.

The strikers which set the wires into vibration are four large split shot which have been squeezed on to the ends of four separate silk threads. The upper ends of the threads are tied to small nails at the top of the zither. Adjust the threads so that there is a lead ball opposite and touching each one of the wires.

The wires should be tuned to suit your fancy or to some minor chord by turning the keys until each note is of the right pitch.

Before putting the strings and balls in position, sandpaper the zither off smooth and give it a coat of varnish. After the first coat has dried, rub it down smooth again and apply one or two more coats. This will greatly improve the tone.

After the zither has been tuned, fasten it to the back of a door by a little strap of tin or a loop of string. When the door is opened, the balls will be set to swinging and will tap against the wires. The result will surprise you.

How a Talking-Machine or Phonograph Operates

One of the most valuable and interesting results of the facts which we know about the nature and behavior of sound and its waves is the "talking-machine" or phonograph. Not so very long ago, a machine which would reproduce music and the human voice was wholly unknown but nowadays a home is often considered incomplete without one.

In 1877, Mr. Charles Cross, a Frenchman, deposited a sealed packet with the Academy of Sciences, Paris, in which he disclosed the idea of reproducing sound by means of a metal record upon which a sound line had been traced. Thus, he anticipated

Berliner and Edison as far as the idea went but he cannot be said to have disclosed the means of carrying his ideas into practice. In 1878, Mr. Thomas A. Edison patented the first practical talking-machine.

The principle of all the modern machines is exactly the same, although there is some difference in the mechanical details. The process of producing and manufacturing the records used on the modern phonograph is exceedingly interesting but it is not possible more than to outline the method here.

How Phonograph Records are Made. The person who is making a record, sings or plays in front of a microphone. The sound waves cause a needle or "cutter" to move back and forth. A wax disk revolves underneath the needle and the latter cuts a spiral wavy line corresponding to the sound waves into the the wax.

When the record in wax has been made, it is placed in an electroplating tank and heavily plated with copper. The copper "negative" thus made, forms a "master" from which many commercial records may be pressed. These are the records which we are familiar with. They are made out of a special composition which is more durable than wax. The master is placed in a hydraulic press capable of exerting a tremendous pressure and squeezed down into the composition while the latter is kept plastic by heat. When the composition cools it hardens. The finished record contains a wavy line which is a faithful reproduction of that carved on the original wax record by the sounds. If you examine the surface of a record with the aid of a magnifying glass you will be able to see this wavy line or "sound picture."

How the Record reproduces the Sounds. Now if the record is placed on a turntable and revolved at the same speed as the original wax record and a needle arranged so as to follow the wavy line, the needle can be made to vibrate a diaphragm and reproduce the sounds which originally recorded the wavy line on the wax record. So you see that although it has required a great deal of time, hard work and money to perfect the details of the machines and records and the methods by which they are manufactured, the phonograph or talking-machine is in reality a very simple affair.

There is no Mystery about a Talking-Machine. The needle which travels in the sound line on the record and the diaphragm to which it is attached together with the little box

FIG. 126.—A simple experiment which shows that there is really no mystery about a talking machine. If you hold your finger nail in the sound track on a revolving phonograph record your finger nail will vibrate and reproduce the sounds recorded on the record.

upon which they are mounted constitute the "sound-box" or reproducer. There is nothing mysterious about this sound-box or reproducer, the horn or any of the other parts of a talking-machine and in order to prove it, I am going to tell you how to perform a very interesting and simple experiment.

Get a manicure file and file one of your fingers nails down to as sharp a point as possible. Put a disk record on a talking-machine and start the turntable revolving. Do not place the reproducer on the record but put your pointed finger-nail in the groove on the record and hold it there lightly, letting the record run underneath. The wavy line on the record will cause

your finger nail to vibrate and produce sound waves. You will hear faint music and although it will not be as loud it will be just as sweet as the regular music from the machine.

You can vary this experiment by holding a hat pin or a large darning-needle in your teeth and letting the point run in the groove on the record. The needle will transmit the vibrations to the bones in your head and you can hear the music quite distinctly although it is not audible to any one else in the room. It will be best to use an old record for this experiment so that the pin or needle will not scratch and spoil a good record.

A Home-made Talking-Machine

You can easily build a toy phonograph which will play real music. It will be necessary to buy the records and the needles but all of the rest of it you can make yourself.

The machine will play ten-inch records as well as records of smaller diameter. Unfortunately, it is not suitable for twelve-inch records.

The Reproducer is the most difficult part of the machine to build and the portion which will require the most careful workmanship.

The box is a flat cylinder of hard wood turned into the shape and according to the dimensions shown in the upper left-hand part of the illustration.

The diaphragm is a circular piece of thin mica, two and one-quarter inches in diameter. The mica must be solid all the way through and not split at the edges or your machine will "squawk" very badly on certain notes.

The diaphragm is clamped to the front end of the box by a brass ring and six small round-headed wood screws. A blotting-paper ring, two and one-quarter inches in diameter

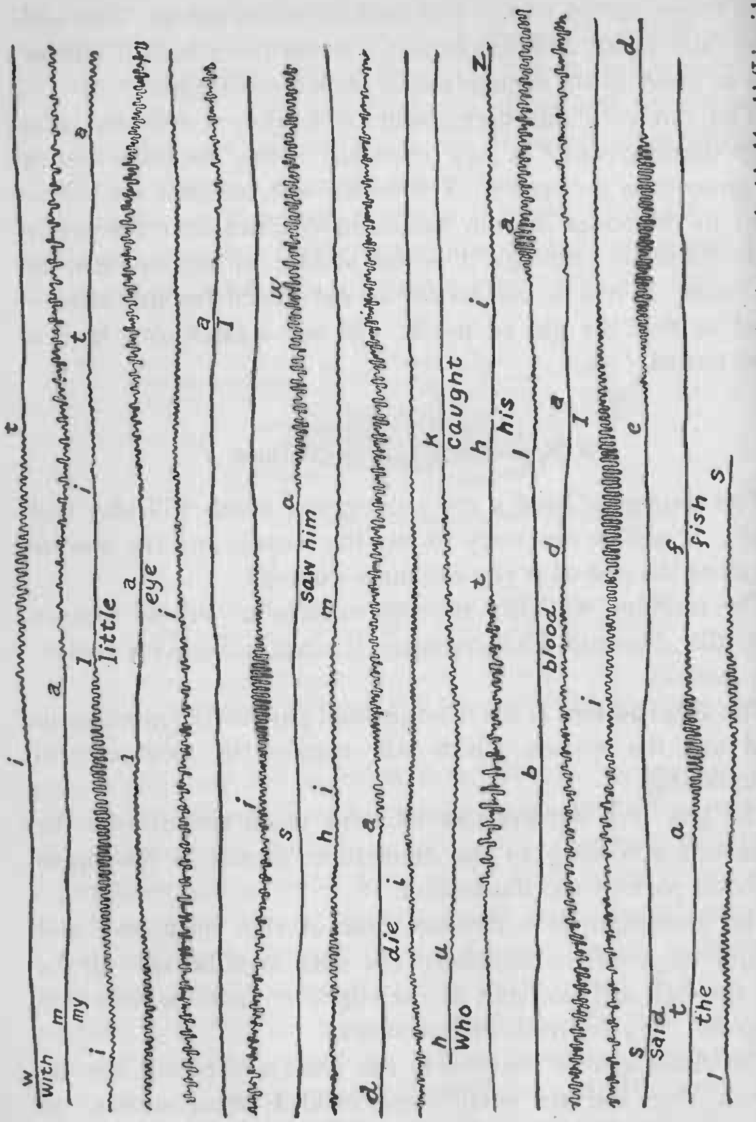

FIG. 127. — A sound picture of the words, " 'with my little eye, I saw him die,' 'who caught his blood,' 'I,' said the fish from "Cock Robin." It required about six and one-half seconds for the recording needle to register these words. The needle had to vibrate back and forth hundreds of times. This picture will give you a good idea of how complicated and varied are the vibrations of the human voice. Think how complicated the sound [illegible] must be to register and reproduce all the sounds of a full orchestra.

outside and one and three-quarter inches inside is placed on each side of the mica diaphragm so that one is between the diaphragm and the box and the other between the diaphragm and the brass ring.

The lever is a piece of one-quarter inch square brass rod, *A*, seven-sixteenths of an inch long which has a piece of brass wire, *C*, one-sixteenth of an inch in diameter soldered in a small hole in the top. The wire is just long enough to reach to the centre of the mica diaphragm when bent and the end is flattened as illustrated. The lower end of *A* is drilled with a hole just large enough so that an ordinary phonograph needle will slip in. A small set-screw, *D*, is provided to clamp the needle, *E*, in place. A small strip of thin sheet brass, *B*, about three-quarters of an inch long and one-eighth of an inch wide is soldered across the back of *A*. The strip is then riveted to the brass ring, a small washer being placed between the ring and the strip at each end. The spring acts as a pivot so that the lever can swing back and forth slightly.

The upper end of the wire, *C*, is fastened to the centre of the mica diaphragm by means of a small rivet. If a drop of hot beeswax is smeared over the diaphragm around the rivet, it will help to eliminate some of the "squawky" sounds which will be produced if the rivet is loose when the machine is played.

The Turntable is a circular disk of wood eight inches in diameter and three-eighths of an inch thick. The turntable is glued to the top of a small spool having a two-inch diameter grooved pulley fastened to the under side. A small peg, just large enough in diameter to slip through the hole in the centre of the record, is set in the centre of the turntable. The top surface of the table is covered with a layer of felt, glued to the wood. The felt furnishes a soft surface for the record to

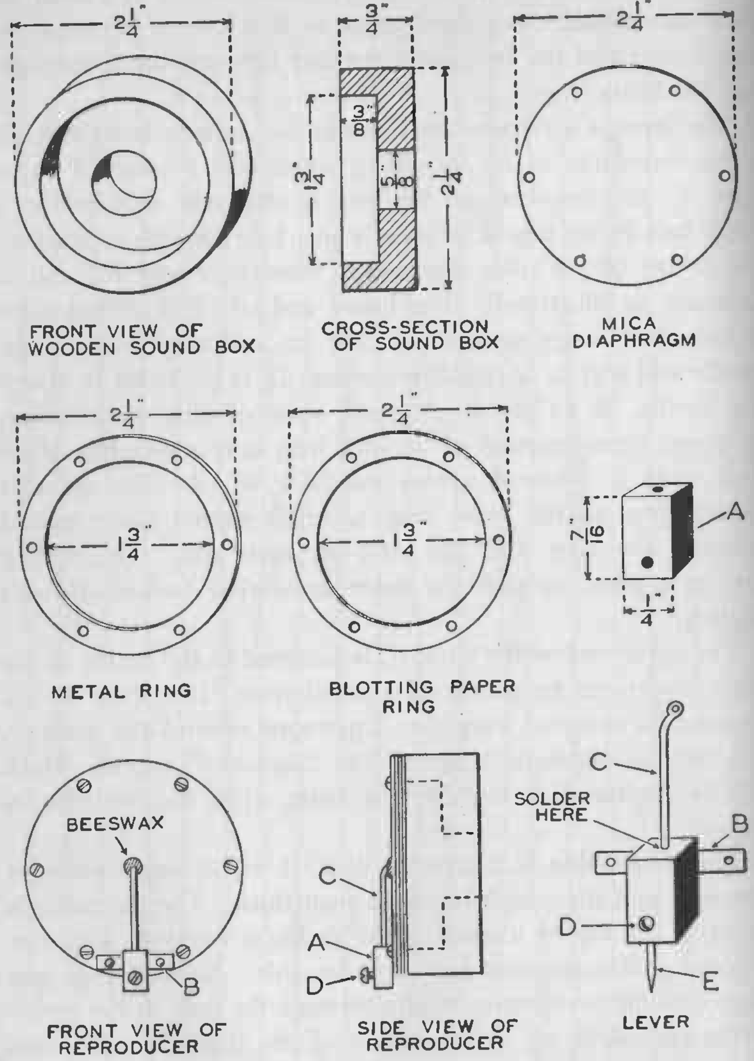

Fig. 128. — Details of the home-made phonograph reproducer.

lie on and provides enough friction so that the record revolves with the turntable without slipping.

A hole through the pulley, in line with the hole through the axis of the spool, will permit a piece of brass or steel rod, just large enough to make a smooth-running fit, to be used

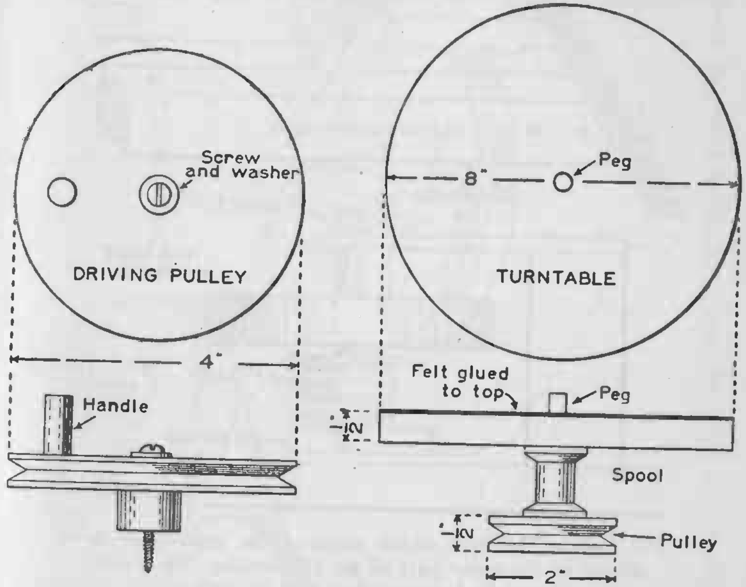

Fig. 129. — Details of the wooden turntable and driving wheel for the phonograph.

as a bearing. The rod is driven tightly into a hole in the base and should be perfectly perpendicular to the base. It should be made just long enough so that when the upper end rests against the under side of the turntable, the pulley will clear the base.

The Driving Pulley is a wooden circle, four inches in diameter and three-eighths of an inch thick. A "V"-shaped groove is turned in the edge.

A circular wooden boss is fastened to the under side so as to raise the pulley off the base a distance of five-sixteenths of an inch. A round-headed wood screw, provided with a washer, passes through the centre of the pulley into the base. The pulley should turn without friction. The handle is a short piece of dowel, glued into a hole near the outer edge of the pulley.

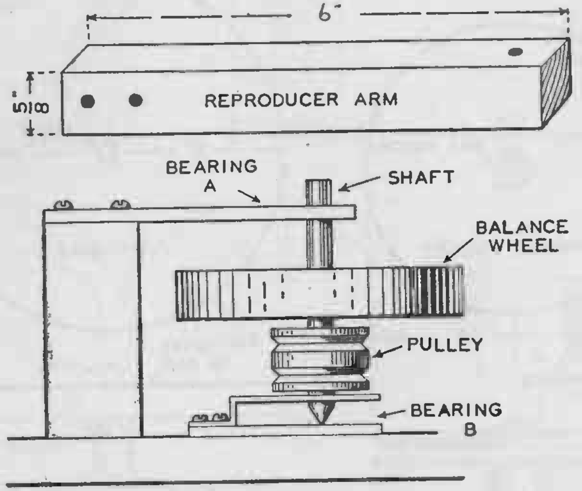

FIG. 130. — The arm which supports the reproducer is shown in the upper part of the illustration. The lower sketch shows the balance wheel and its pulleys.

The Balance Wheel is a circular piece of lead or cast iron about three to three and one-half inches in diameter and one-half to three-quarters of an inch thick. It is mounted upon a shaft which is pointed at the lower end and rests in a small hole in a bearing-plate, *B*. The upper end of the shaft passes through a hole in a brass bearing-plate, *A*. The lower part of the shaft is fitted with a double grooved wooden pulley about three-quarters of an inch in diameter.

The purpose of the balance-wheel is to absorb any jerks and

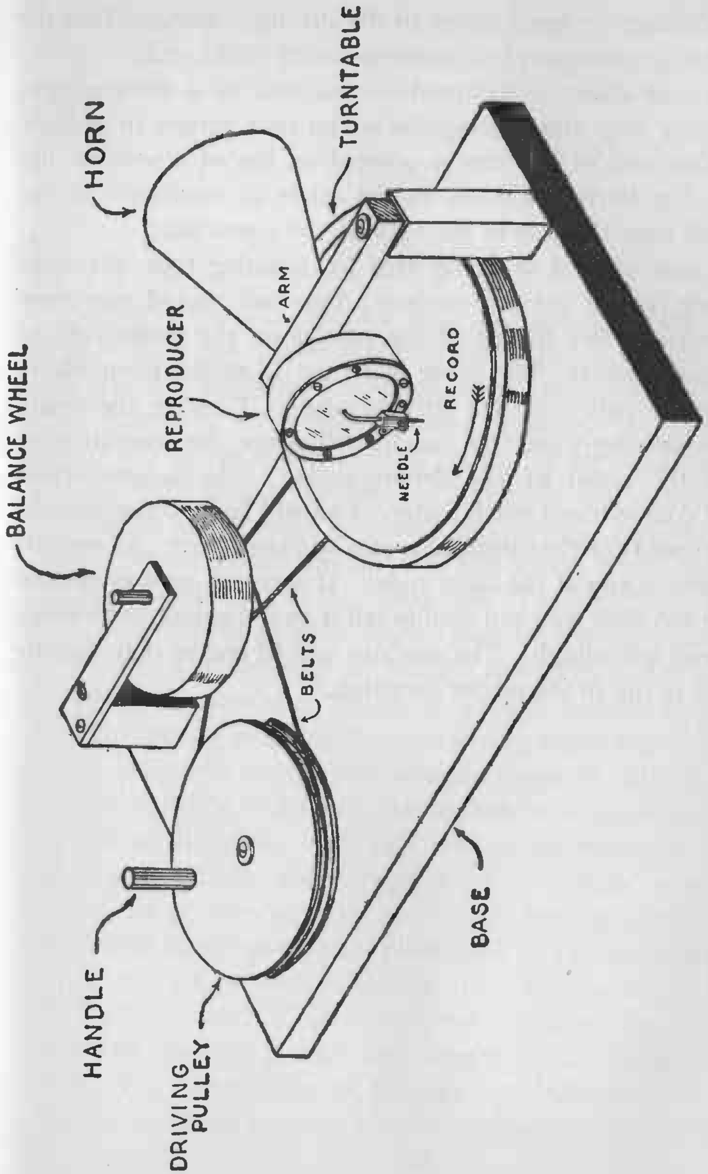

FIG. 131. — A talking-machine driven by hand power which a boy can make.

small changes in speed given to the driving wheel, so that the record will consequently operate smoothly and evenly.

The reproducer is mounted on one end of a wooden arm six inches long and five-eighths of an inch square in section. The other end of the arm is pivoted on top of a wooden upright. The horn is a small funnel made of cardboard or tin fastened over the hole in the back of the reproducer.

The sort of cord or string used for spinning tops will make excellent belting for the machine. One belt should run from the driving-pulley to one of the pulleys on the under side of the balance-wheel. The other belt runs from the turntable to the second pulley on the driving-wheel. Turning the crank on the driving-wheel by hand, will drive the turntable at double the speed of the driving-pulley. The balance-wheel will of course travel much faster. You will have to find out the proper speed for the turntable to run by experiment. All records are made to run at the same speed. If a record runs either too fast or too slow, you can readily tell it by the sound and change the speed accordingly. The machine will of course only operate when it is run in the proper direction.

CHAPTER VI

HEAT

What is Heat? That is a hard question to answer. Its real character is not perfectly understood and it is very difficult to give the explanations which have been made by learned men regarding the probable nature of heat in simple language which would be understandable by the young scientist.

You have already learned in Chapter V that a body giving out sound is vibrating in a very regular and systematic manner. The molecules swing back and forth, nearly all in the same direction and at the same rate. The regularity of these vibrations which produce sound may be compared to that of the steps of a company of soldiers marching in perfect time.

But the molecules of all bodies possess another and entirely distinct motion whether they are giving forth a sound or not. They are never completely without some of this motion although it exists to a much greater extent in some bodies than in others. It differs from that of a sound vibration in being very unsystematic and irregular. The motion producing a sound can be detected with the fingers but the motion we are concerned about now takes place only in the molecules themselves and no movement can be felt. The molecules are flying back and forth in different directions, slowly for a moment, then fast, jostling against their neighbors and being jostled in turn. The irregularity of this motion, instead of being like that of marching soldiers, may be compared to the footsteps of a great crowd of people, no two of whom are trying to move at the same rate of speed or in the same direction.

Any body which is moving possesses energy. Molecules which are moving also possess energy. The energy of molecules which are moving in the irregular manner described above is called *heat*.

The Sources of Heat may be divided into two great classes, those which are *natural* and over which mankind has no con-

SOUND VIBRATIONS ARE REGULAR

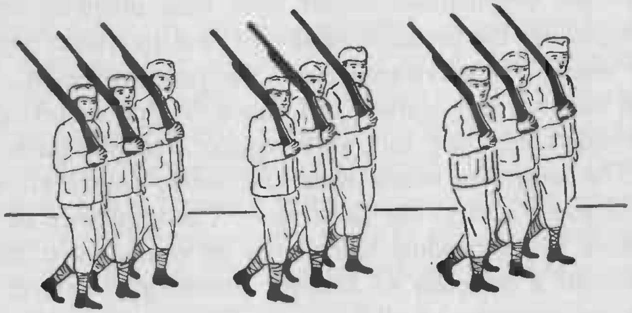

FIG. 132. — The vibrations which produce sound take place with perfect regularity, like the steps of a company of well-trained soldiers.

trol and those which are *artificial* because they have been devised by man. Among the former we may mention the sun and the earth's interior.

Most of our heat comes from the sun. Without it there could be no life on this earth. It would be a frozen wilderness.

The sun is a dense ball of blazing gas nearly a million miles in diameter and located 93,000,000 miles distant from the earth. It is inconceivably hot, probably having a temperature of at least 10,000 degrees Fahrenheit. Only a very small part of this heat reaches the earth but it is still so great that if that

which falls on the deck of a steamer sailing on a tropical ocean could be used to heat the steam boilers in place of the coal, it would drive the ship at a speed of fifteen miles an hour. A

HEAT VIBRATIONS ARE IRREGULAR

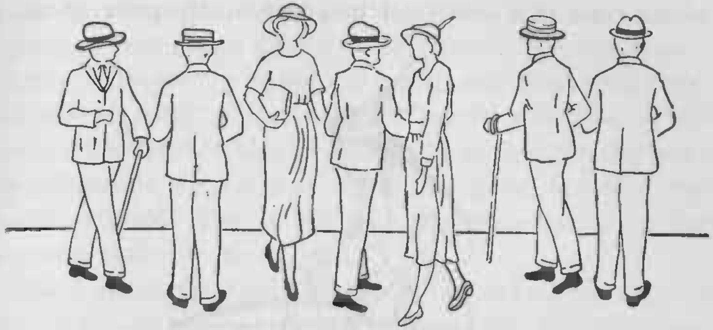

FIG. 133. — Heat vibrations are irregular and may be likened to the motion of a crowd of people moving in different directions at different speeds.

practical method of converting the sun's heat into mechanical energy will be one of the great inventions of the future.

There are many kinds of artificial heat such as

Heat due to collision,
Heat due to compression,
Heat due to friction,
Heat due to fires,
Heat due to electricity,
Heat due to chemical action.

If you strike a piece of flint or hard stone a glancing blow with a piece of steel, sparks will fly. Little pieces of flint and steel are broken off by the blow and the *collision* heats the little particles blazing hot.

When air is squeezed or compressed, the crowding of the air molecules produces considerable heat. You will be able to notice this the next time you are pumping up your bicycle or automobile tire. Feel the rubber hose before and after pumping and notice how warm it has become through the *compression* of the air.

Savages kindle fire by rapidly twirling a dry stick, one end of which rests in a notch cut in a second dry piece of wood.

FIG. 134. — Indians used to kindle fires with the spark produced by the friction of two dry sticks rubbed together.

The *friction* between the two sticks produces enough heat to ignite tinder.

The bearings of machinery, the axles of carriages, etc., have to be carefully lubricated so as to eliminate friction or they would soon be heated to a high temperature. The "hot boxes" sometimes occurring on railway cars are due to the heat caused by *friction* in bearings not properly lubricated.

Any burning substance produces heat, as is well known. The heat produced by *fire* is really due to a chemical change, but has been separately listed in the little table above so as to distinguish it from the heat produced by a chemical change where no flame and smoke may be distinguished.

Many chemical substances produce heat when they combine

with each other. If you pour a little surphuric acid into water the mixture will immediately become warm. You may have noticed this when you were preparing the electrolyte for the experiment in decomposing water.

When a current of *electricity* passes through a coil of wire it also produces heat. You can prove this for yourself by connecting a few inches of very fine wire to the terminals of a battery. The wire will become warm and may even melt. If the wire is made of some of the special mixtures of metals which offer considerable resistance to the electric current and the volume of electricity is sufficiently great, the wire may be heated red hot. This is the principle made use of in electric flatirons, toasters, etc.

There are many important things for us to learn about heat. The principal thing we should understand is the difference between *heat* and *temperature.*

Temperature. When a body feels hot or cold we are likely to think that this is because its temperature is respectively higher or lower than that of the hand. But we cannot always correctly judge the temperature of a body by our sense of touch. The temperature of an object must not be confused with the *quantity of heat which it possesses;* it may have a low temperature and yet possess a large amount of heat, and conversely a high temperature and yet have a very small amount of heat. If, for instance, a piece of iron and a block of wood are left in an oven for a considerable length of time, the iron will feel very much hotter than the wood when touched with the hand. The temperature of the wood and the iron may be very nearly the same but the iron will feel hotter because it *contains more heat.* This interesting fact brings to our attention what the scientist calls

Specific Heat. When equal weights of mercury and water are placed in two similar vessels and are heated for the same length of time over the same burner, it will be found that their temperature will vary considerably at the end of a few minutes. The mercury will be much hotter than the water. Inasmuch, however, as they have each been receiving the same amount of heat from the burner, it is clear that the quantity of heat which is required to raise the temperature of the water one degree is greater than the quantity required to raise the mercury to the same temperature.

Hence, water gives out more heat in cooling a certain number of degrees than mercury does. Water requires thirty-two times as much heat as mercury does to produce the same increase in temperature.

If other substances are tested in the same manner, it will be found that the quantity of heat required to produce the same change in temperature is different for almost every substance.

Scientists have experimented with all sorts of materials and substances and calculated the amount of heat required to raise the temperature of a certain quantity, one degree. This is called the *specific heat* of the substance. The specific heat of a number of substances is given below.

Water	1.000	Copper	0.093
Ice	0.489	Silver	0.057
Iron	0.113	Mercury	0.031

The fact that water has a high specific heat has important consequences in practical life. It accounts for the equable character of ocean climates. The water of the ocean may part with a large amount of heat in winter without becoming very cold, and on the other hand receive a large amount in summer without becoming warm.

Why Water Puts out a Fire. The fact that water has such a great capacity for absorbing heat and is also noncombustible makes it ideal for putting out a fire.

When water is thrown on a fire, part of the quenching action is due to the fact that the water smothers the fire by preventing the oxygen in the air from reaching the burning material, but its greatest value as a fire extinguisher is undoubtedly due to the fact that it absorbs so much heat that it cools the burning substance down to a point where it cannot burn.

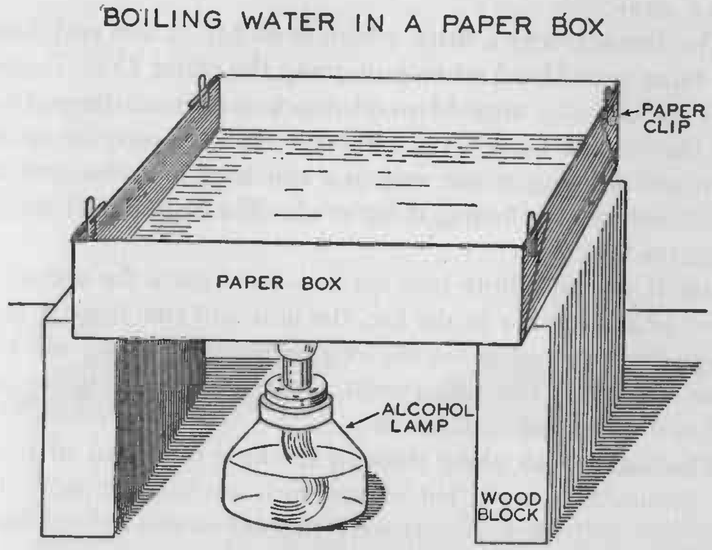

FIG. 135. — Water may be boiled in a paper box over the flame of an alcohol lamp or a Bunsen burner. The water draws the heat away from the paper so rapidly that it cannot become hot enough to ignite and burn until the water has boiled away.

How and Why Water may be boiled in a Paper Box. This is an experiment you can perform yourself. Take a piece of heavy writing-paper about six inches square and fold it up so as to form a shallow box about one inch deep. Set the box on a ring made of stiff wire and support it over an alcohol lamp. Fill the box half full of cold water and light the alcohol lamp. You may allow the top of the flame to touch the bottom of the paper box provided that it is in the center. In a short time the water will commence to boil.

If the water were not in the paper box, the paper would catch on fire and burn up. The water, however, absorbs the heat so rapidly that the temperature of the paper cannot rise high enough to become ignited and burn until all the water has boiled away.

The Reason why a Stick which is on fire at one end does not burn your Hand when you grasp the other End. If you poke the end of a stick of wood into a fire, it will become so hot that it will burn. And although the stick may be quite short and burning at one end, you can hold the other end in your hand without finding it hot at all. The heat doesn't travel along the stick.

But if you substitute iron for wood and place the end of a poker or an iron bar in the fire, the heat will run along it and if you leave the end in the fire long enough, the handle will become very hot. The heat travels along the iron from the hot end to the cold end.

The heat travels along through the little molecules of iron, not because they move, but because each one hands it on to the next just as if the molecules were stepping-stones and the heat walked from one to the other.

This process is called *conduction,* and the iron is said to be a *good conductor* of heat. All metals are good heat conductors. Some are, however, better than others. Silver conducts heat the best of all.

If you should hold a bar of iron in one hand and a bar of copper of the same size in the other and place the ends in the fire, you will find that the heat travels along the copper much more rapidly than along the iron. This is because copper is a better conductor.

The following table is interesting because it shows the

relative ability of various metals to conduct heat. If the conductivity of silver is represented by 1,000, the relative conductivity of the other metals may be indicated by the numbers opposite each, as,

Silver	1,000	Zinc	190	Lead	85
Copper	736	Tin	145	Bismuth	18
Gold	532	Iron	116		
Brass	231	Steel	116		

The great heat-conducting power of copper may be illustrated by an experiment.

If a piece of copper wire gauze or fine screen is held in the flame of a Bunsen burner or alcohol lamp, the flame will burn

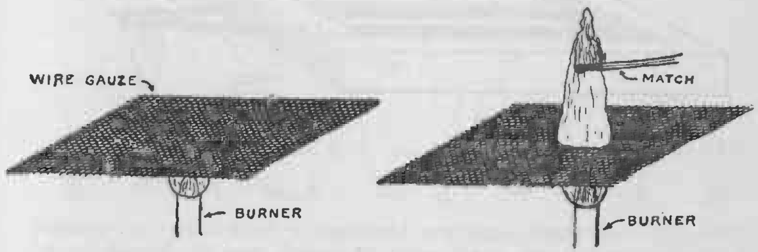

FIG. 136. — If a piece of copper gauze is held in the flame of an alcohol lamp, Bunsen burner or candle, the flame will burn below and not above the gauze, unless a lighted match is held above.

below but not above the gauze. The heat of the flame is carried away so rapidly by the copper that the temperature above the gauze does not rise sufficiently so that the combustible gas can burn. If a light is applied above the gauze, the gas will take fire and burn.

This experiment explains the action of what is known as the Davy safety lamp used by miners, which consists of a small oil lamp burning inside a copper-gauze cylinder. The lamp burns quietly inside the cylinder and owing to the great conductivity of the copper gauze may be taken into a dangerous mixture of air and "fire damp" without danger of an explosion. The temperature does not rise sufficiently outside of the cylinder to ignite the explosive gas because the copper gauze carries the heat away.

Wood and other organic substances, that is, tissues made by living things, are *poor conductors* because heat does not travel through them easily. To this class also belongs minerals, resins,

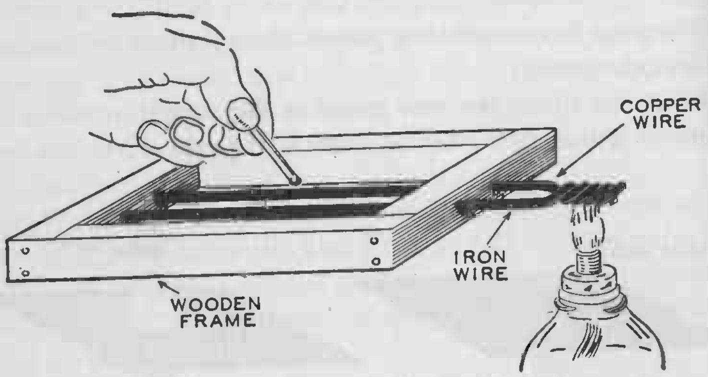

FIG. 137. — A simple apparatus for showing the relative heat-conducting power of iron and copper. A match may be ignited on the copper wire at a much greater distance from the flame than it can on the iron wire.

glass, clay, most liquids and gases. Boilers are often covered with a coating of asbestos because the asbestos is such a poor conductor of heat that it prevents the heat escaping from the boilers and being wasted.

You can test relative heat-conducting abilities of iron and copper if you twist together the ends of two wires about a foot long, one of iron and the other of copper, and mount them in a wooden frame. Set an alcohol lamp under the twisted part. After the wires have been heated for several minutes, find the point on each wire farthest from the flame which will ignite

an ordinary match when touched against it. This point will be found to be some distance farther along on the copper than on the iron, showing that the copper is a much better conductor of heat than the iron.

The Three different ways in which Heat travels. Heat has three different modes of traveling, namely by *conduction,* by *convection,* and by *radiation.* You have already learned how heat passes along an iron rod by

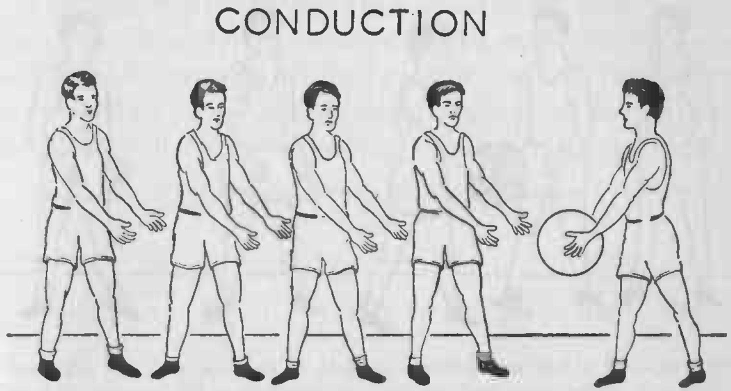

FIG. 138. — If the ball represents heat and the boys represent molecules and the ball is passed down the line from one boy to another, it shows the manner in which heat is *conducted* or passed from molecule to molecule.

Conduction. This method might be likened to a number of boys standing in a row. The boys correspond to an iron bar. One of the boys at the end of the line has a ball in his hand which corresponds to the *heat.* If he should pass the ball to the next boy and each one in turn should hand it to his next neighbor, the ball would pass along the line in very much the same manner as heat travels along a metal rod by *conduction.*

Convection. If you place a tall glass jar full of water over a fire and sprinkle a little bran or sawdust into the water, the ascending and descending currents of water which are produced by the heat will be indicated by the bran or sawdust which rises and descends with the currents. It is mainly by these currents that heat is distributed through a liquid, and not by its conductivity. They are due to the heating and expansion of the bottom layers of water, which are nearest the fire and become heated first. Warm water is lighter than cold water

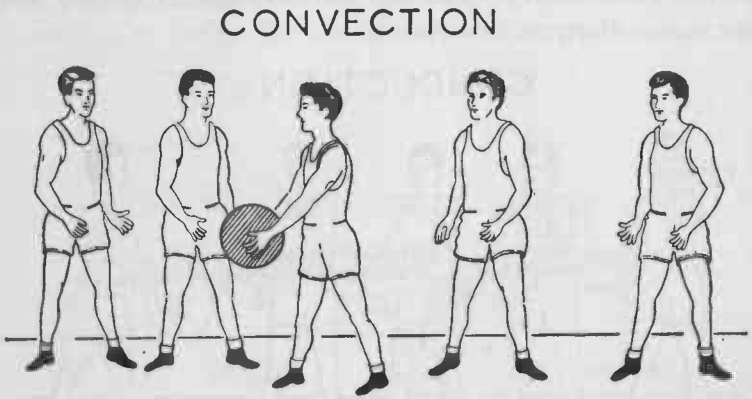

Fig. 139. — If a boy starts from one end of the line with the ball and carries it to the other end, we have an example of the passage of heat by convection.

and so rises in the liquid, carrying its heat with it and being replaced by colder and heavier layers.

The mode in which heat is thus propagated in liquids (and it also happens in air and other gases) by circulating currents is said to be by *convection.*

We may also explain convection by a row of boys and a ball. Instead of passing the ball along the line however, as in the case of conduction, the boy at one end *walks* down to the other end of the line with it.

Radiation. Heat can be transmitted from one body to another without greatly altering the temperature of the intervening medium. If you stand in front of a fire you can feel the

heat but if a screen is suddenly interposed, the sensation immediately disappears. This would not be the case if the air between you and the fire was the means of conveying the heat, for then the air itself would be very warm and when the screen were placed in front of the fire, you would still feel the heat.

Hence hot bodies can send out rays which excite heat and which penetrate through air without greatly heating it, just as a ray of light can pass through a transparent substance.

The heat travels to you from the fire by what is termed *radiation.* In order to understand this more clearly we will again use the example of the boys and the ball. Imagine two boys standing a short distance apart and one of them as corresponding to the fire and holding a ball in his hand which we

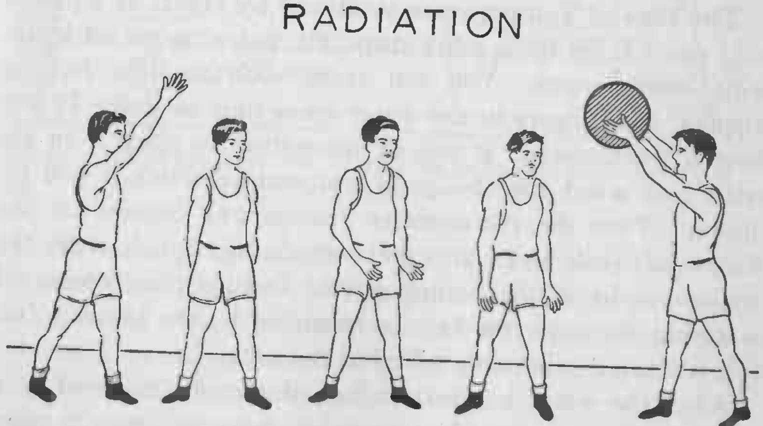

Fig. 140. — Radiation is similar to the action which takes place when the ball is thrown from one end of the line to the other.

will liken to the heat. Consider the other boy to be yourself standing in front of the fire.

If instead of passing the ball along a line of other boys or walking across to you with it, the boy *throws* the ball or heat, you will have an illustration of the principle of radiation.

The Effects of Heat. When heat is applied to an object the effect produced varies with the nature of the substance. It may only cause a rise in temperature so that the body becomes warmer or in the case of some objects which are solid when cool, cause them to melt or liquefy. Many other bodies such as wood and most organic compounds do not melt but decompose and separate into the different compounds or elements of which they are composed. We had a good example of this in the experiments of decomposing soft coal and wood.

Most liquids vaporize under a continued application of heat.

When heat is removed from bodies, the changes are exactly the reverse. Vapors condense into liquids, liquids solidify, and the temperature falls.

The Rise of Temperature produced by Heat. If a pan of cold water is set upon a hot stove, the water, as we all know, will become warm. You can easily ascertain this fact by dipping your fingers in the water from time to time. If you have a thermometer, it will be interesting to place it in the water and watch the change in temperature which it will indicate. When the thermometer reaches 212 degrees on the Fahrenheit scale and 100 degrees on the Centigrade scale, the water will be at the boiling point. During this process of warming the water the heat is furnished by the burning fuel and is being continuously added to the water.

After the water has become hot, it may be removed to a cold room where it will serve as a source of heat, because when it cools, it imparts the heat which it received from the fire to the room. Buildings are often heated by a system which makes use of the heat furnished by hot water conveyed in pipes.

Expansion produced by Heat. Nearly all objects expand when heated. As a general rule, air and gases expand the most, then liquids, and solids the least.

The expansion of solid bodies is very important to the engineer and due allowance must be made for it in a great many instances. Molten metals occupy a much greater space than after they have cooled and solidified. It is therefore necessary to make the molds for castings slightly larger than the size desired for the finished castings because the metal *shrinks* when it cools.

Car rails are always left with a little space between their ends, in order to allow for the expansion and contraction which takes place due to changes in temperature. The expansion and contraction of the rails when the weather varies is so great

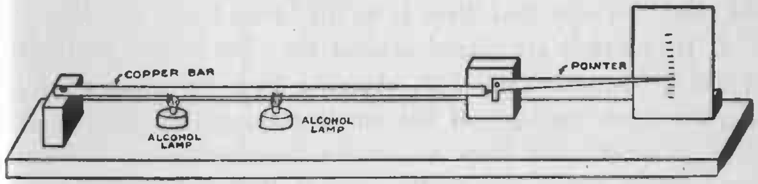

FIG. 141. — Simple apparatus for showing the expansion of a copper rod when it is heated.

in a railway track many miles long that they would be torn from ties if the little spaces between the ends were not provided.

The tie-rods of bridges have been known to expand or contract to such an extent under the influence of extreme heat and cold as to pull the structure badly out of shape.

The Expansion of Solid Bodies is often illustrated in schoolroom laboratories by a large metal ball which will just slip through a metal ring when both are of the same temperature. If the ball alone is heated in the flame of an alcohol lamp or a Bunsen Burner, it will expand to such a degree that it cannot pass through the ring.

You can easily rig up an apparatus which will show the expansion of a copper rod when heated.

A long copper rod is fixed at one end by a screw, while the other end presses against the short arm of a pointer which moves over a scale. If an alcohol lamp or a Bunsen burner is placed below the rod and moved back and forth so that the whole of the rod is thoroughly heated, the pointer will be pushed over the scale by the lengthening of the rod.

The Expansion of Liquids, when heated, may be strikingly shown by means of a common glass bottle holding at least one quart of water. Fill the bottle with cold water and close it with a rubber cork through which passes a glass tube. The tube should be drawn out fine just above the cork. The level of the water should be about half-way up the narrow part of the tube. Be sure that there is no air in the bottle or tube.

If both hands are placed against the sides of the bottle, the liquid in the tube will fall, showing that the glass expands slightly from the heat of the hands making the bottle larger.

If, however, you place an alcohol lamp or a Bunsen burner far enough below the bottle so that there is no danger of cracking the glass and the water in the bottle gradually becomes warmer, the level of the liquid in the fine tube will rise showing that the water has expanded under the influence of heat.

The Expansion of Air and Gases is very great under comparatively small changes in temperature. The enormous expansive power of hot gases is made use of in driving gas and oil engines and in firing bullets from a rifle and shells from a cannon.

An air thermometer will show how sensitive the atmosphere is to small changes in temperature.

It consists of a small glass tube having a large bulb blown on the upper end. The lower end of the tube passes through a cork in the neck of a small bottle about half filled with colored water. The lower end of the tube should dip into the water.

The tube is supported in a vertical position and has a cardboard scale attached, as shown in the illustration. The cork in the bottle will serve as a support for the tube. The cork should have a groove cut in the side so that it is not air-tight.

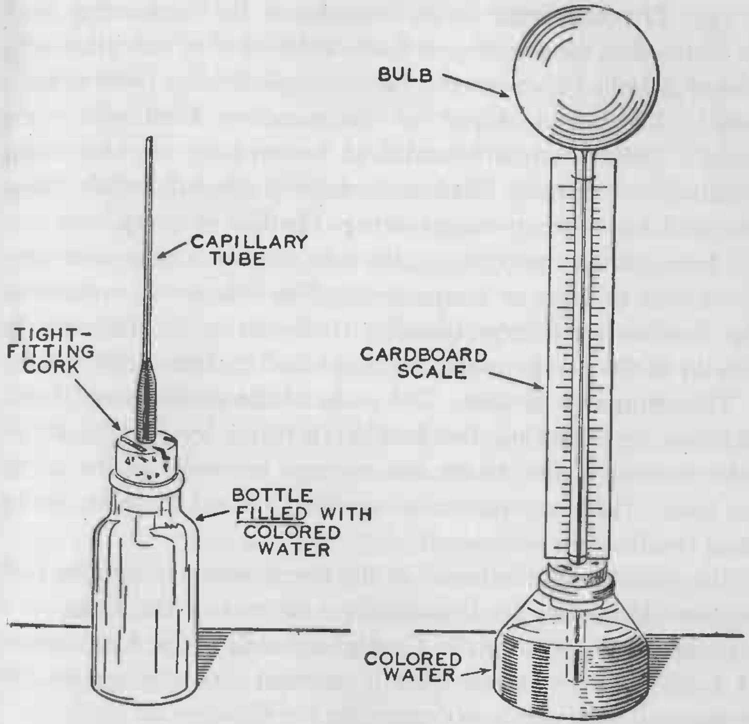

FIG. 142.— The left-hand sketch shows a bottle filled with colored water and provided with a capillary glass tube passing through a tight-fitting cork. At the right is shown an air thermometer.

If the air in the bulb is warmed by grasping it with the hand or holding a lighted match near by, the air will expand and some of it will escape from the bottom of the tube in the form of bubbles. Upon cooling, some of the colored water will be drawn up into the tube. Any slight change in the temperature, such as that produced by the hand on the bulb will change the height of the column of colored water in the tube and show the great expansion which air undergoes under a small change in temperature.

The Thermometer is an instrument for measuring temperature. The most common form consists of a fine glass tube having a bulb blown at the bottom and the top hermetically sealed. The bulb and part of the stem are filled with some liquid. Thermometers intended to be used at very low temperatures are usually filled with colored alcohol, while those designed for ordinary temperatures contain mercury.

The alcohol or mercury, as the case may be, expands or contracts with changes in temperature. The changes in volume of the comparatively large quantity of liquid in the bulb at the bottom of the thermometer are magnified by the capillary tube.

Thermometer Scales. The scale of the thermometer is established by inserting the bulb in melting ice and in steam from boiling water, under the average pressure of the air at sea level. The temperatures of melting ice and of steam under these conditions are constant.

The position of the liquid in the thermometer when the bulb is placed in melting ice is marked 32 degrees on the *Fahrenheit* scale and 0 degrees on the *Centigrade* scale. The temperature of boiling water at sea level is marked 212 degrees on the *Fahrenheit* scale and 100 degrees on the *Centigrade.*

There are two kinds of thermometers in common use. The difference between them lies in the way in which the scales are marked. The Fahrenheit scale is the one which we are most familiar with. The Centigrade thermometers are principally used by scientists and for laboratory purposes.

Boiling water is something which you have no doubt seen a great many times. But do you know what the word "boiling" means? *Boiling* is the phenomenon which takes place when a liquid becomes so hot that it starts to vaporize and bubbles of the vapor are produced in the mass of the liquid itself.

It is interesting to watch a pan of cold water grow hotter and hotter until it commences to boil. If you dip a thermometer in the water you will notice that the temperature gradually rises and that bubbles of air become visible on the sides of the pan. These bubbles appear at a comparatively low temperature and are caused by the air which is dissolved in the water. Finally as the temperature becomes hotter and hotter, bubbles of *steam* begin to form at the bottom of the vessel. The water is commencing to boil. The first bubbles of steam rise through the water and collapse with a sharp snapping sound. The upper portion of the liquid is slightly cooler than that at the bottom of the pan and *condenses* the steam or changes it back into water. The walls of the bubbles come together with a snap when the steam condenses.

The "singing" of a teakettle is due to the collapsing of the little bubbles when the kettle commences to boil. It ceases when all of the water in the kettle becomes hot enough to boil.

In a few minutes the bubbles cease to collapse but grow larger and rise to the surface. The water is then boiling freely. If your thermometer has a scale which registers high enough, it will indicate 212 degrees on a Fahrenheit scale and 100 degrees on a Centigrade scale.

Boiling Points Differ. If you substitute some other liquid or chemical for water, you will probably find that it boils above or below 212 degrees Fahrenheit. For example, alcohol boils at a very much lower temperature than water and oils at a higher temperature. As the melting points of solids vary, so do the temperatures at which liquids boil. The following table shows how greatly the boiling points of many common substances vary.

Table of Boiling Points on the Centigrade Scale

Ether	35 degrees	Water	100 degrees	Sulphur	447 degrees
Alcohol	78 "	Mercury	350 "	Zinc	940 "

Vaporization. If you allow a pan of water to continue boiling the amount of water in the pan will gradually grow less until it has finally entirely disappeared.

The water has all changed to steam or become *vaporized.* Liquids which boil or vaporize at low temperatures are said to be *volatile.*

If you could provide the pan with a tight-fitting cover so that the steam could not escape, the large amount of steam which would soon be crowded inside would exert a tremendous pressure and blow the cover off. It is this pressure which is exerted by steam when it is confined that drives the steam engine.

A Metal which Melts in Water

Alloys of metals generally melt at a much lower temperature than any of the metals of which they are composed. It is possible to make several mixtures of metals which melt at a temperature which is very much lower than the lowest melting point of any of the metals in the mixture.

Tin melts at 450 degrees Fahrenheit, lead at 617 degrees Fahrenheit, and bismuth at 507 degrees Fahrenheit, yet an alloy of all three, known as Rose's fusible metal which consists of four parts of bismuth, one part of lead, and one part of tin melts at 94 degrees Centigrade.

There used to be trick spoons on the market which were made of an alloy known as Wood's metal. These would melt in hot water and could be made the means of an amusing joke. Imagine the surprise of an unsuspecting friend, who

stirring his tea with one of these spoons, suddenly finds that the bowl has melted off.

Wood's metal is put to practical use nowadays in mounting the crystals used in radio telegraph detectors. The crystals are placed in a metal cup full of the molten alloy and then set away to cool. It is necessary to mount the crystals in this manner so as to make a good electrical connection with them. If a metal such as lead or tin were used, the high temperature required to melt these substances would destroy the sensitiveness of the crystals.

You can make Wood's metal by melting together,

1 or 2 parts of Cadmium
2 part of Tin
4 parts of Lead
7 or 8 parts of Bismuth

You can obtain these metals from a chemical supply house or can buy the Wood's metal already prepared.

If you make it yourself, melt the lead first, the bismuth next and the tin and cadmium last. Be very careful to weigh out the metals accurately so that the proportions are correct or the mixture will not have a low melting point. Perhaps if you are acquainted with a druggist, he will do the weighing for you.

Turning Heat into Electricity

One of the most cherished dreams of many inventors and scientists is to succeed in devising a means of "harnessing the energy of the sunlight." Day after day, light and heat come streaming down to us from the sun. The amount of energy represented in this heat which is received daily by our planet is almost inconceivable. If we knew how to avail ourselves of this power, it would run all our factories and railroads, light our cities, warm our houses, and there would still be so much in reserve that we should not be able to tell that any had been used.

Harnessing the sunlight is not an idle dream. It is perfectly possible, and there only remains to be found out the means for doing it efficiently and without too much expense. Perhaps the secret lies in some method of generating electricity from the sun's rays. Then large storage batteries could

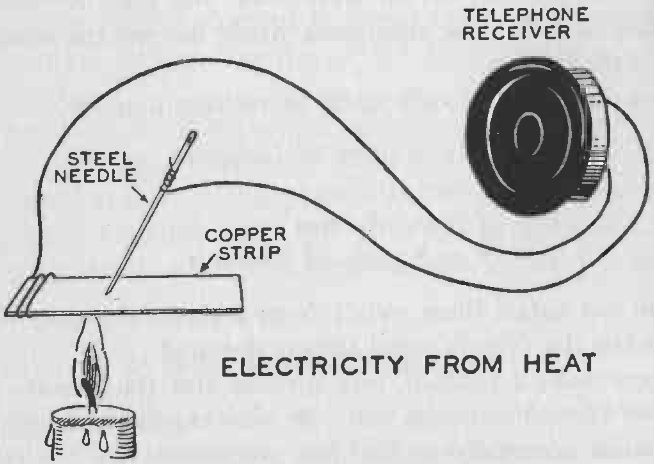

FIG. 143. — An experiment showing how electricity may be generated directly from heat.

be charged during daylight, and the power used to drive electric motors, light lamps, etc.

Heat will Generate Electricity. The usual method of utilizing heat to generate electricity is to boil water and drive a steam engine with the steam pressure thus created. The engine is then made to turn a dynamo and so electricity is produced. It is however possible to generate electricity *directly* from heat. The present method of doing this is not efficient and so not yet useful for practical purposes.

An alcohol lamp, candle, or source of heat, a piece of sheet

copper, a steel needle, and a telephone receiver are all that are necessary to prove that electricity may be generated directly from heat.

Connect the needle and the sheet of copper to the telephone receiver. Hold the copper sheet over the flame of the alcohol lamp until it is quite hot and then touch the hottest part with

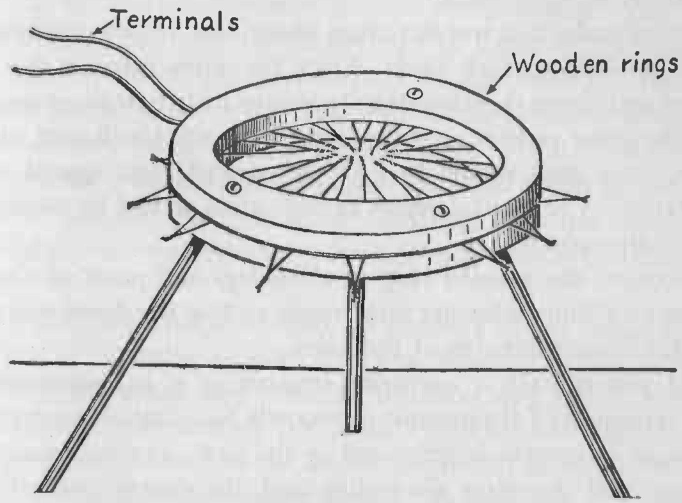

FIG. 144. — Complete thermopile. An alcohol lamp should be placed underneath the thermopile so that the flame heats the inside ends of the wires in the center of the wooden ring.

the point of the needle. Enough current will be generated to produce a click in the telephone receiver. The needle should be pressed against the copper tightly enough so that the point cuts through the scale or oxide on the surface and makes a good electrical contact with the metal underneath.

You can make a more elaborate apparatus than this for generating electricity from heat, which while not giving enough current for any useful purpose, will serve as an exceedingly interesting and instructive experiment.

Cut thirty or forty pieces of No. 14 to 20 B. and S. gauge copper wire four or five inches long. Cut an equal number of pieces of German silver wire of the same size and length. Iron wire may be used in place of German silver wire but is not as good. Twist each German silver wire together with one copper wire so as to form a zigzag arrangement made up of thirty or forty pairs.

Next make two wooden rings about four inches in diameter and one-half an inch thick. Place the wires between the two rings and clamp them together by means of two or three screws.

The inner junctures of the wires must not touch each other. The outer ends should be bent out straight and spaced equidistantly. The two terminals or end wires should be connected to binding-posts.

Support the wooden ring on three legs and place an alcohol lamp or a Bunsen burner underneath so that the flame will play on the inner junctures of the wires.

If you connect a telephone receiver or a galvanometer to the terminals of the apparatus, you will find that an appreciable amount of current is generated by the heat. If the flame is removed and the wires allowed to cool, the electric current will cease, thus showing that it is actually generated by the heat.

An arrangement of this sort is called a *Thermopile.*

The Invention of the Steam Engine

The first practical steam engine was made over two hundred years ago.

For a long time, men all over the world had been trying to make use of steam as a source of power. Each man in his turn made some slight improvement but none succeeded until Thomas Newcomen, an English blacksmith, made a steam engine which pumped water out of mines. Considering that

this was one of the first engines, it was a wonderful device; but of course, far from perfect and capable of many improvements which were to come later.

On a certain Sunday afternoon, in the early spring of 1765, over one hundred and fifty years ago, a poor, sickly mechanic was taking a walk in one of the parks of Glasgow, Scotland. He was an instrument-maker by the name of James Watt and kept a very small shop on the grounds of Glasgow University. He had set up in business without having served a regular apprenticeship to learn his trade and so his brother mechanics were not very friendly toward him. In fact, but for the special favor of the professors at the University from whom he derived a great part of his income by repairing their philosophical apparatus, he could not have carried on his trade in Glasgow at all.

On this particular afternoon he was in a brown study as he walked in Glasgow Green. He was thinking about a very puzzling job which had come to his shop and trying to find a method of overcoming the difficulty. The job was not of any great importance as far as the amount of money in it for Watt was concerned, it being merely the repairing of a working model of the steam-engine belonging to the University and for which he received about twenty-five dollars. But the idea which occurred to that poor Scotch mechanic on Glasgow Green, one hundred and fifty years ago, resulted in the first real step toward the perfection of the steam engine and has produced more changes in the world than any other single invention.

The model of a steam engine which had been brought to his shop to repair, was a copy of the engine invented by Newcomen and used in pumping water out of mines. Steam engines were then used for no other purpose. They were such clumsy machines and were run at such an enormous expense for fuel that they could not be applied to furnishing power for manufacturing.

Watt had worked and worked at the model but it could not be made to go to his satisfaction, but now finally the idea had occurred to him that the real defect of this sort of a steam engine was that *the greater part of the steam was wasted.*

The steam rushed into the cylinder, did its work of driving the piston out and then had to condense in the cylinder and run off in the form of water. The cylinder was exposed to the air and always cool so that the new steam began to condense before it had done its work, and hence a large part of it was wasted.

The thought occurred to Watt that the steam, after doing its duty, might be made to rush into another vessel kept cool by jets of water, and thus be instantly condensed, while the cylinder if surrounded by some substances which would not conduct heat could be kept at a uniform heat, equal to that of steam.

This improvement made the steam engine practical for all purposes, because not only did this make it more powerful, but instead of it wasting most of its steam it now turned it into useful energy.

The Energy which Drives the Steam Engine

When we speak of steam and refer to the power which drives steam engines, we mean water vapor which is really *water in the form of gas.*

Water *evaporates* at all temperatures. It makes no difference whether it is hot or cold, it slowly *leaks* away into the air in the form of a gas. If the water is hot, however, it passes into a gas so quickly that the air cannot hold all and it cools and turns into the little drops of water in the air that we sometimes wrongly call steam. Water vapor ought not to be called steam because the gas or vapor only becomes steam when it has ceased to be a gas and becomes water again.

We can see steam but not water vapor. Steam is what we see escaping from an engine. This would never drive an engine. The kind which drives an engine is called "dry-steam." It is really not steam at all but water vapor. It is formed under pressure in the boiler and has the power to expand. It is this expansive power that does the whole work and makes it so useful. When it has escaped into the air and expanded, which is to say that it has taken as much room as it needed, it has no more force. The force is not in the white cloud of steam coming out of the spout of a teakettle but in the vapor inside of the kettle trying to raise the lid.

The expansive power of dry steam is due to the tiny little molecules of water of which it is made.

Each of these molecules is flying about in all directions trying to get loose, and so striking against whatever holds it in. The force in one of the molecules alone is of course very small, but as there are billions of them flying around in a very small space the combined result is tremendous and gives "steam" its wonderful power.

The steam engine is a device for transforming this energy into mechanical motion. It consists of a strong cylinder in which a piston is made to move to and fro by applying the force of the steam to first one side and then the other.

When "dry-steam" is admitted to the cylinder of the engine, the billions of little water molecules bombard the inside of the cylinder and the piston in an effort to expand and find more room. The walls of the cylinder are strong and immovable but the piston is made so that it can move and the hard and fast bombardment of the little molecules is so great that it moves it forward and so turns the wheels of the engine.

Afterwards the gas escapes into the air, becomes cool and condensed, so that we can see it, and that is what we usually call steam.

The engine is provided with valves so that the steam pressure is admitted alternately to first one side of the piston and then the other, and so moves it back and forth.

The Steam Turbine, strange as it may seem, considerably antedates the steam engine and is probably the oldest known source of mechanical power.

The aerophile, sometimes also called Hero's engine after the Greek scientist who is supposed to have invented it ages ago, is the forerunner of the modern steam engine. It did not of course possess sufficient power so that the energy could be applied to any useful purpose, but the germ of a valuable idea was represented there.

Turbines may be divided into two groups, known respectively as the *impulse* type in which a jet of steam at high velocity is caused to strike against a number of paddles set around the rim of a wheel, free to rotate, and the *reaction* type in which the motion is caused by steam passing through the vanes or paddles so that they move in an opposite direction to the flow of steam.

Steam turbines give much more power for their size than reciprocating engines. They are also free from vibration, and for these reasons are now being widely used to drive the propellers of ships and in power stations for operating dynamos.

How to Build a Small Steam Turbine

A steam turbine is exceedingly simple and is well adapted to form a boy's first steam model. Of course a little machine such as that described below is not an exact counterpart of those used in power stations but is very similar in principle.

The boiler is a tin can of the variety in which syrups and fine molasses are packed. The most common size measures about four and one-half inches long and four inches in diameter. The cover fits into the top of the can so that it is air-tight.

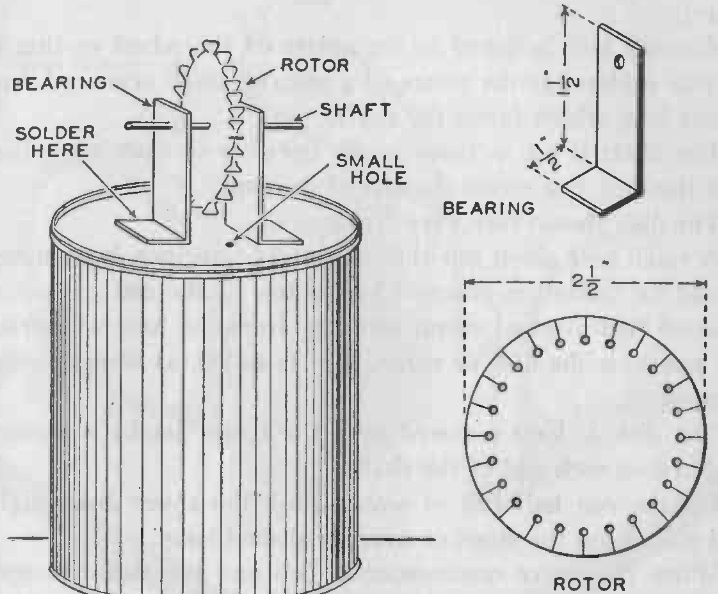

FIG. 145. — A simple steam turbine made from a tin can.

Two pieces of tin about two inches long and one-half inch wide are bent so as to form two L-shaped pieces. These are soldered on the top of the can.

The turbine wheel is formed from a circle of sheet tin, two and one-half inches in diameter. Thirty small holes, one-sixteenth of an inch in diameter, are bored at equal distances around the circumference of a circle two inches in diameter and having the same centre as the wheel.

Slots are then cut from the circumference of the wheel to the holes so that when all the separate teeth thus formed are twisted around at right angles with a small pair of pliers, the result is a wheel two and one-half inches in diameter having a series of little blades around the circumference like a paddle wheel.

A small hole is bored in the centre of the wheel so that it may be soldered to the centre of a piece of small brass rod, two inches long which forms the shaft.

The shaft is set in holes in the uprights in such a position that the disk just clears the top of the can.

The disk should turn very freely.

A small hole about one-thirty-second of an inch in diameter should be drilled or punched in the top of the can in such a position that a jet of steam escaping from the hole will strike the vanes on the disk or *rotor,* as it is called, as shown in the illustration.

The disk is kept centered over the steam jet by a washer soldered on each end of the shaft.

Fill the can half-full of water, push the cover down tight and place it on the stove or over an alcohol lamp.

When the water commences to boil and the steam escapes under pressure from the hole, the disk will revolve at a high rate of speed.

If the disk were enclosed in a casing the turbine would greatly resemble one of the common types of machines used for power purposes. A small model steam plant consisting of a boiler and turbine, may be constructed out of waste material which usually goes into the ash-barrel.

The boiler is also a tin can of the variety in which corn syrups are usually packed. This type of can may be used to make an excellent small boiler, owing to the fact that the cover fits very tightly and does not leak.

The firebox is made from a strip of tin or stovepipe iron, sixteen and one-half inches long and three inches wide. That shown in the illustration was made from a strip of old stovepipe which had been hammered out flat. It was used because it is

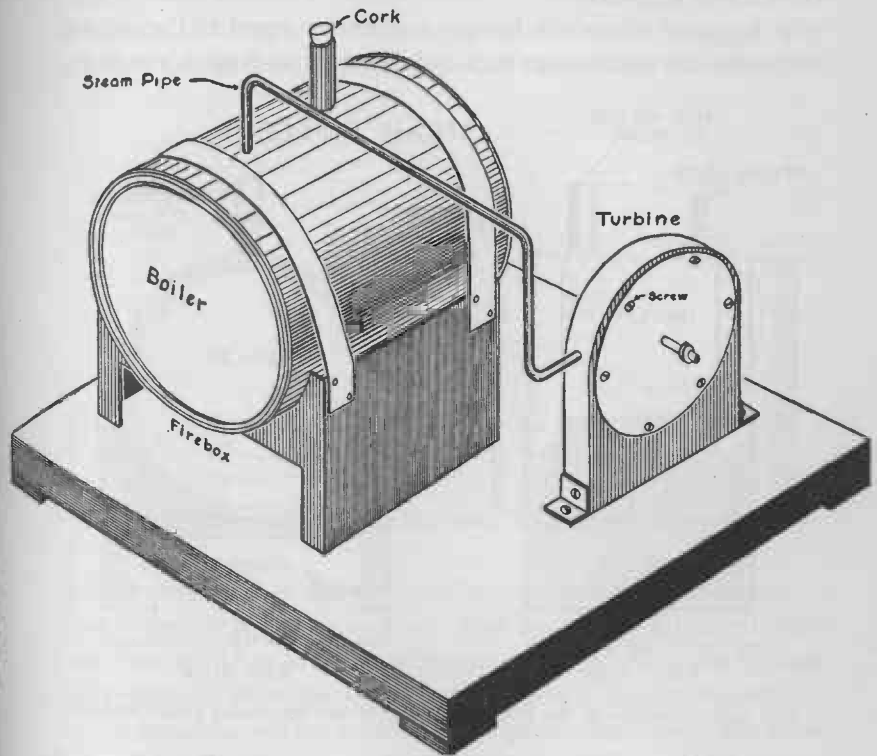

Fig. 146. — The model steam turbine and boiler.

black and the contrast with the bright boiler gives the little plant a better appearance. Ordinary tin will, however, serve the purpose of a firebox just exactly as well. The sheet tin used in cans and for roofing purposes is really tin plate, that is, sheet iron coated with tin.

The strip is bent at right angles in four places so as to form a bottomless box four and one-half inches long, three and one-half inches wide and three inches deep. One end of the strip is bent over for one half an inch so as to form a flap for riveting the firebox together.

A segment of a circle having a diameter equal to the outside of the tin can but only an inch and one-quarter deep, is cut in the

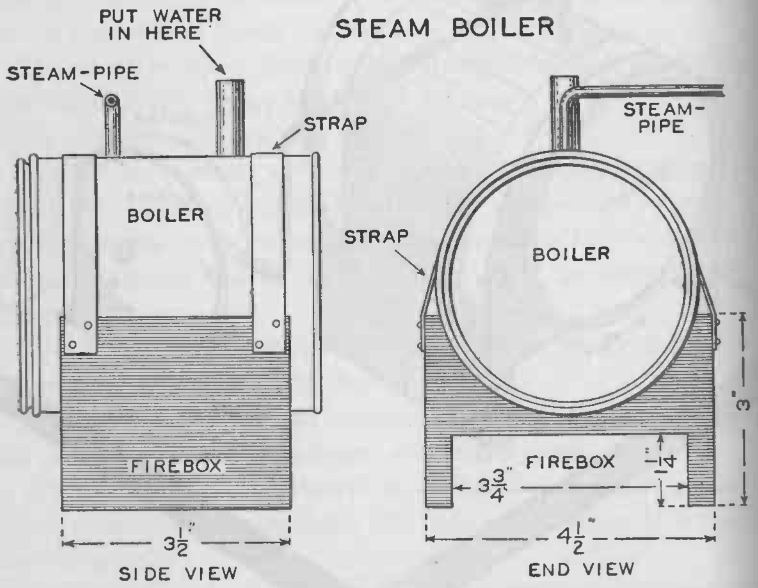

FIG. 147. — Details of the firebox and boiler for the model steam turbine.

top of the two narrow faces of the firebox so that the boiler will rest in them.

A rectangle one and one-quarter inches high and three and three-quarter inches long is cut out of the bottom of one of these faces so that an alcohol lamp will pass through the opening and under the boiler.

The boiler is held to the firebox by two straps of tin five-

eighths of an inch wide which pass over the top. The ends of the straps are riveted to the sides of the firebox. If a small wire nail having a flat head is cut in two with about one-eighth of an inch of the shank remaining with the head, it will make an excellent rivet for the purpose.

The turbine wheel is formed from a circular piece of sheet tin two inches in diameter. Twenty-four small holes one six-

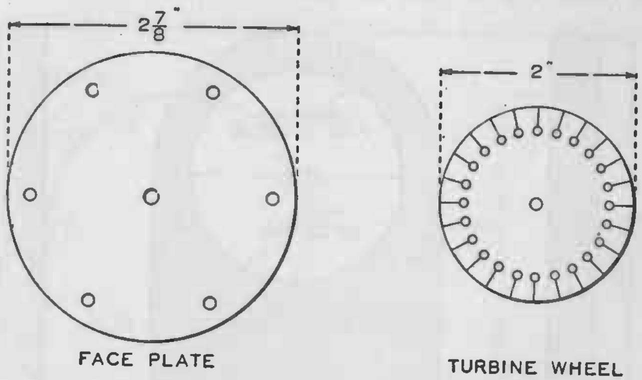

FIG. 148. — The turbine wheel and the face plate.

teenth of an inch in diameter are bored at equal distances around the circumference, one quarter of an inch from the edge. Slots are then cut from the circumference of the wheel to the holes so that when all the separate teeth thus formed are twisted around at right angles with a small pair of pliers, the result is a wheel two inches in diameter, having a series of little blades around the circumference like a paddle wheel.

The shaft is a piece of round brass rod, two inches long and three-thirty-seconds of an inch in diameter. Drill a hole in the centre of the wheel and solder it to the middle of the shaft. Be very careful to mount the wheel so that it is perfectly true and does not wobble any.

Solder a small washer to the shaft on each side of the wheel. The distance from the wheel to the washers should be three-sixteenths of an inch. The purpose of these washers is to center the wheel in the bearings so that it will not scrape against the sides of the casing.

The casing of the turbine is made from a piece of hard wood three and three-quarter inches high, three inches wide and one-half an inch thick. The space in which the wheel revolves is two

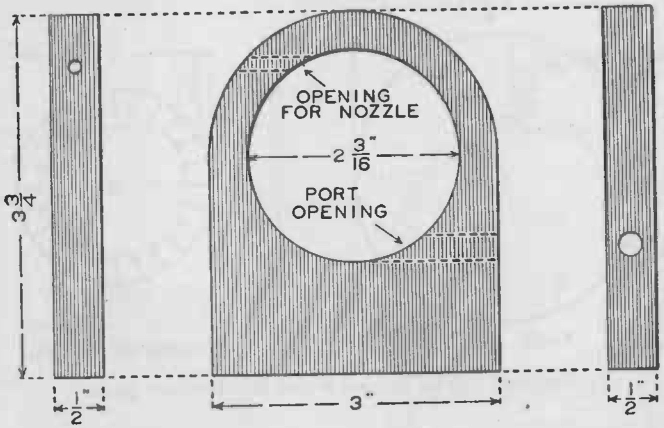

FIG. 149. — The turbine casing is made of wood in the shape and according to the dimensions shown above.

and three-sixteenths of an inch in diameter. A hole five-sixteenths of an inch in diameter is bored through one side of the casing so as to form an exhaust port through which the spent steam may pass.

A smaller hole, on the opposite side of the casing, near the top provides a passage for the steam nozzle. The nozzle in this case is simply the end of the steam pipe. It should fit tightly and be driven into place.

The steam pipe is a piece of one-eighth inch copper tubing. This tubing is inexpensive and may be purchased at almost

any garage. The end of the pipe forming the nozzle should be closed down until the opening is about one sixteenth to three-thirty-seconds of an inch in diameter. This is best done by tapping lightly with a hammer and twisting the tube at the same time.

The sides of the casing are formed by two circular pieces of tin, two and seven-eighths inches in diameter. Bore six holes in each, at equal distances around the edge so that small round headed screws may be passed through to fasten the plates to

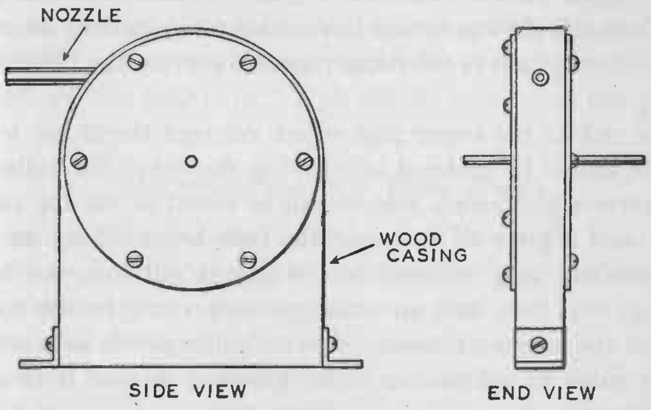

FIG. 150. — The completed turbine.

the wood. The bearings are formed by a hole bored in the center of each face plate, through which the shaft will just pass but still revolve freely.

In order to assemble the turbine, first screw one face plate in position. Put the wheel in place in the casing and then slip the other bearing on and put in the screws.

The boiler and the turbine should both be fastened to a suitable wooden base.

After the turbine has been assembled, bore a hole about one-eighth of an inch in diameter in one face plate near the bottom so that it will drain off any water formed by condensed steam in the casing.

The base should be three-quarters of an inch thick, and about ten inches long, and eight inches wide.

The turbine can be fastened in position by means of two screws passing upwards through from the bottom of the base or by two small brackets.

The firebox will have to be secured by two small braces riveted to the sides of the firebox and screwed to the base.

If a small piece of tin is bored and fitted to the casing to form a nozzle plate as shown in the illustration, a drop of solder will serve to join it to the steam pipe and prevent the latter from pulling out.

One end of the steam pipe which conveys the steam to the turbine should be soldered in a hole in the top of the boiler.

A three-eighths-inch hole should be bored in the top of the boiler and a piece of three-eighths inch brass tubing an inch and one-half long soldered in. Water is put into the boiler through this hole and an ordinary cork stuck in the top to prevent the escape of steam. The cork also serves as a sort of safety valve to relieve the steam pressure in case it becomes very great.

The heat which generates the steam is furnished by one or two small alcohol lamps. These lamps are easily made from shallow metal pill-boxes. Make two holes, three-eighths of an inch in diameter in the top of each, about three-quarters of an inch apart. Solder a short piece of brass tubing in each of the holes. The pieces of tubing should be about one inch long and should project about one-half inch above the top of each can. The wicks are formed by a bundle of cotton cords, inside of each tube. The fuel used in the lamps is alcohol. Do not attempt to use kerosene or gasoline.

Fill the boiler about one-third to one-half full of hot water

from a teakettle and place the lighted alcohol lamps in position underneath. It will require only a few minutes to generate steam if the water you fill the boiler with is hot.

There is no danger of an explosion, because such small fires cannot generate steam fast enough for the pressure to rise to any great extent. Considerable pressure would be required to burst the can, if the steam pipe were stopped up, but the cover will loosen or the cork blow out long before there could be any such danger.

As soon as there is steam in the boiler it will commence to blow out through the nozzle and drive against the blades of the wheel. If the steam strikes the blades properly it will drive the turbine at a surprisingly high rate of speed.

How to Build a Small Steam Engine

After building the steam turbine just described, it is but a natural step for the young mechanic to turn his attention to the construction of a *reciprocating* steam engine.

The word "reciprocate" means *to move back and forth* and this name is usually applied to the common form of steam engine in which a piston moves back and forth, in order to distinguish it from rotary engines or turbines having a revolving "piston."

The only difficulty involved in building engines of this sort is that usually some of the metal parts require turning on a lathe in order to make them fit perfectly.

Access to a lathe for turning the piston, etc., is desirable when possible, but it is perfectly practicable to build the engine described below without the aid of anything but hand tools.

The engine is mounted on a wooden base or bed. The bed of the engine is a piece of hardwood, four and one-quarter inches long, an inch and one-half wide and one-half an inch thick.

Maple or birch are the best because they do not become water soaked as easily as a softer wood. A strip two and three-quarter inches long and one-half an inch wide is cut out of one side to provide room for the piston rod and crank to move in. A slot two inches long and one-half an inch wide is also necessary in order to accommodate the fly wheel. The bed is mounted upon two wooden feet, three-eighths of an inch high and one-

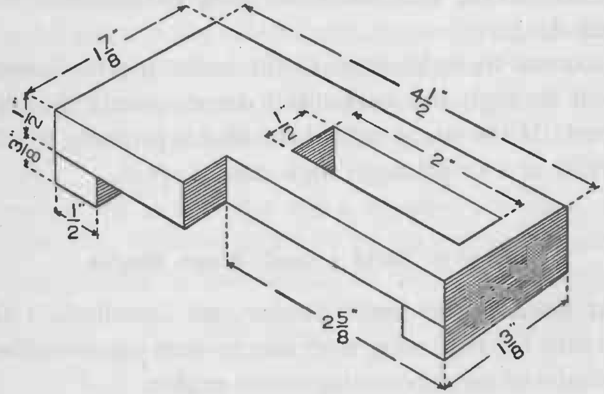

FIG. 151. — The wooden bed for the steam engine.

half an inch wide. The illustration shows just how the engine bed should look when completed.

The cylinder, in which the piston moves, is a piece of brass tubing having an inside diameter of one-half an inch and an inch and three-eighths long. One end of the cylinder is entirely open. The other end is closed save for a small hole in the centre, one-eighth of an inch in diameter. The easiest manner in which to accomplish this is to solder a circular piece of brass, having a hole in the centre, into the end of the cylinder.

A piece of one-quarter inch brass tubing, an inch and one-half long, having a one-eighth inch hole bored through its wall three-quarters of an inch from one end should be soldered

across the end of the cylinder in such a position that the hole coincides exactly with that in the cylinder. This tube forms the inlet and exhaust valve through which the steam passes in and out of the cylinder.

The cylinder is clamped to the base by means of two brass straps fastened at each end by means of a round-headed wood screw.

The piston is made out of brass and should fit the inside of the cylinder snugly so that the steam will not leak past, but at the same time not so tightly that it binds and will not move freely. The groove turned in the centre of the piston is not

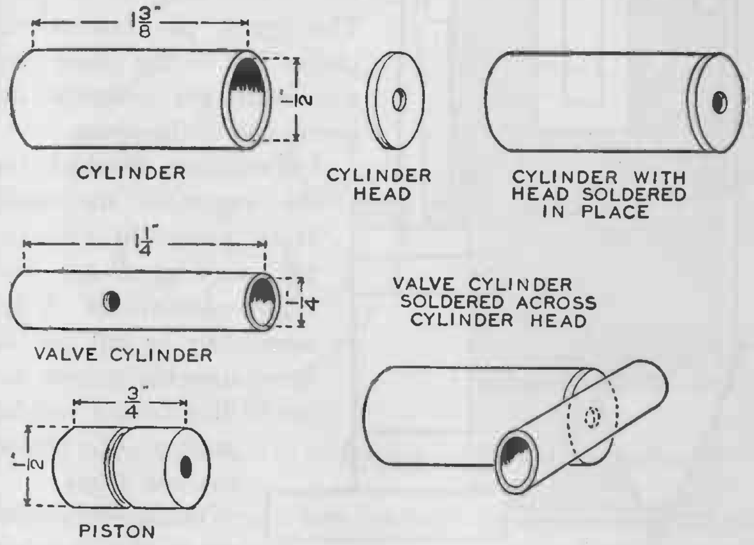

FIG. 152. — Details of the main cylinder, the valve cylinder and the piston.

necessary but if used will probably aid in making it "steam tight" so that it does not leak. The end of the piston can be easily cut into shape with a hack-saw and a file. If care is used in selecting a piece of one-half-inch rod which will fit the cylinder, a lathe will not be necessary in order to turn the piston down to size and the fitting can probably be done with a file and a piece of emery paper.

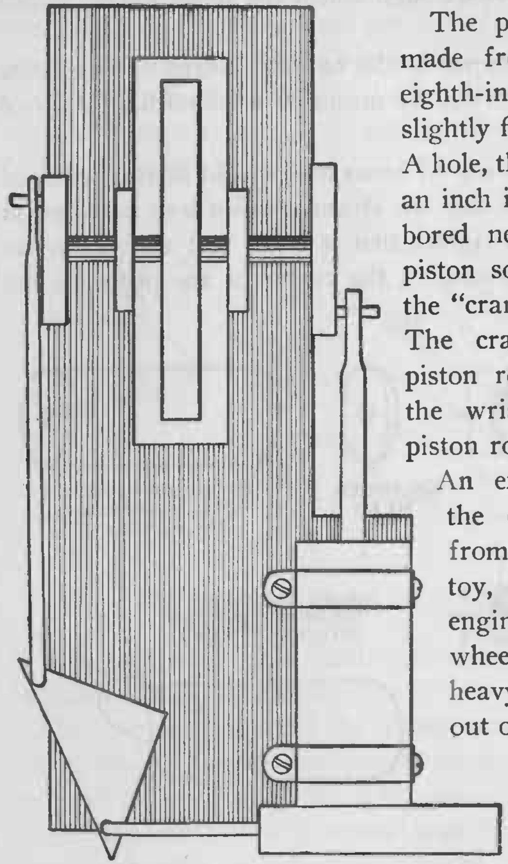

FIG. 153. — A full-size top view of the complete engine.

The piston rod should be made from a piece of one-eighth-inch brass rod which is slightly flattened at both ends. A hole, three-thirty-seconds of an inch in diameter should be bored near each end of the piston so as to accommodate the "crank" and "wrist" pins. The crank pin fastens the piston rod to the crank and the wrist pin connects the piston rod to the piston.

An excellent flywheel for the engine is the wheel from some old cast-iron toy, such as a toy fire-engine or coal-cart. A flywheel can be cut out of heavy sheet lead or even cast out of lead from a wooden pattern of similar size and shape.

The flywheel does not need to be over an inch and three-quarters in diameter. It is mounted so as to be directly in the centre of the slot.

The bearings are cut out of one-eighth inch sheet brass. They are fastened in the proper position to the two sides of the base

by means of two small round-headed wood screws. The shaft is a piece of one-eighth inch brass rod about an inch and one-half long.

The crank is formed by a circular piece of brass, seven-eighths of an inch in diameter soldered to the end of the shaft.

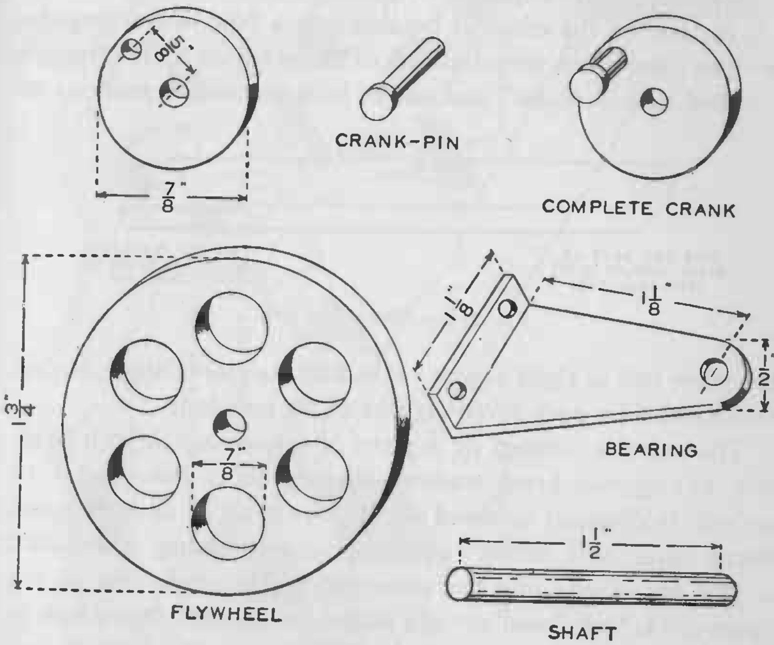

FIG. 154. — Details of the flywheel, crank, shaft and bearings.

The crank pin is riveted into a hole in the crank, five-sixteenths of an inch from the centre so as to give the engine a five-eighths inch stroke.

The opposite end of the shaft is fitted with a second disk similar to that forming the crank but only three-quarters of an inch in diameter. The disk is bored to receive a small crank pin, one-quarter of an inch from the centre of the shaft so as to give a one-half-inch stroke to the "valve rod" which is mounted on the pin.

The valve rod is a piece of one-eighth inch brass rod, two and five-eighths inches long. One end is flattened slightly and drilled to receive the pin. The other end is bent down at right angles for a distance of one-quarter of an inch.

This end of the crank is hooked into a hole in a triangular piece of sheet brass, one-sixteenth of an inch thick. This triangle is called a "bell crank" and serves to transmit the motions of

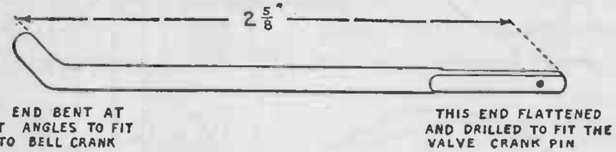

FIG. 155. — The valve rod.

the valve rod at right angles. It is an *isosceles* triangle having two equal sides each seven-eighths of an inch long.

The valve is formed by a piece of one-sixteenth inch brass rod, having two brass washers slightly under one-quarter of an inch in diameter soldered about one-eighth of an inch apart. Wrap some soft cotton twine in the intervening space until it just fits snugly into the valve tube. The other end of the valve rod is bent down at right angles and hooked into a hole in the bell crank. The triangle is mounted on the base at one corner. It is set on a small block of proper height so that the valve parts all line up properly and work without friction.

The steam boiler for supplying steam to the engine should be made in the same manner as that described for use with the steam turbine. The boiler should be mounted to one side of a wooden base and the engine to the other.

The steam is led from the boiler to the engine by means of a copper tube. The steam is led in the open end of the valve tube.

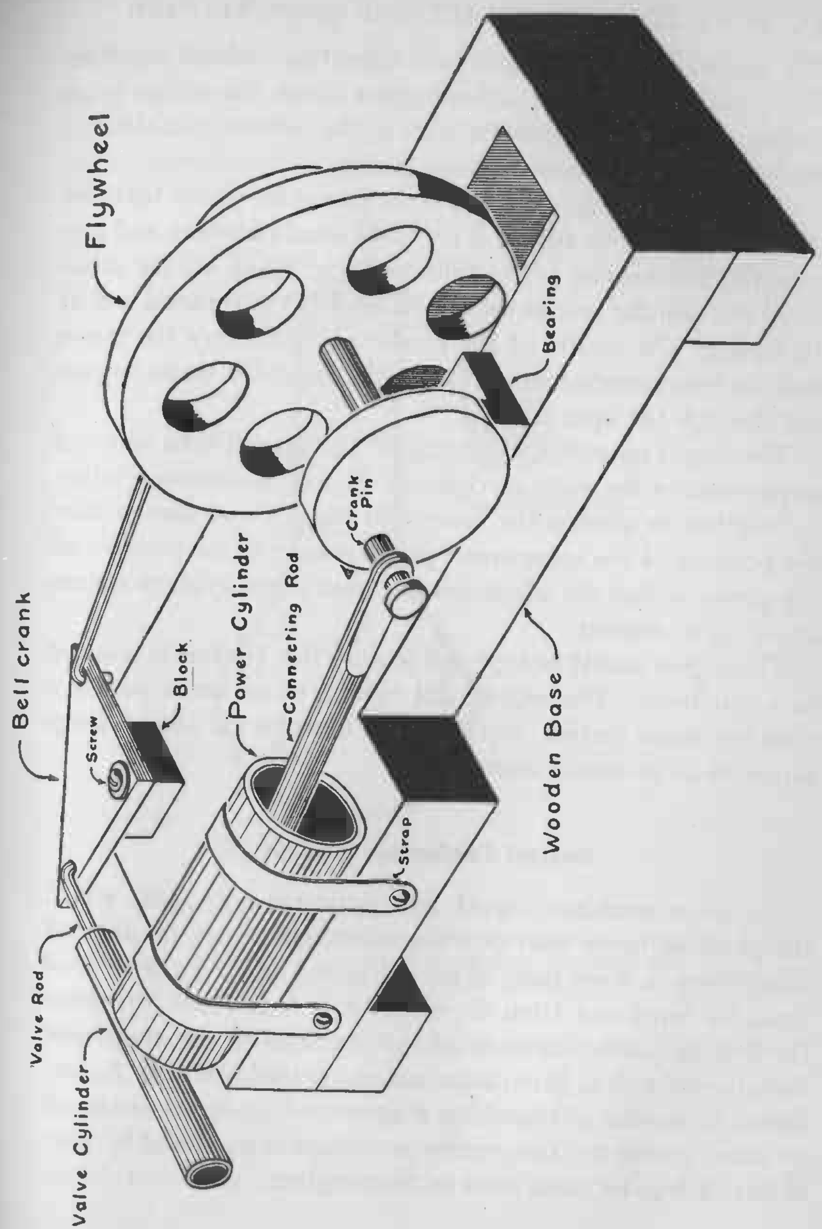

FIG. 156. — The completed model steam engine.

The steam pipe and the valve tube should be soldered together. The valve should be so adjusted that when the piston is on such a position that it is at the back of the cylinder and about to move forward, the valve is just opening.

The steam passing into the cylinder moves the piston forward. As the piston moves forward, the valve should advance and pass over the hole leading to the cylinder thus cutting off the steam from the cylinder just as the piston reaches the forward end of its stroke. The inertia of the flywheel should carry the piston back on the return stroke and allow the expanded steam to pass out through the open exhaust.

The proper operation of the engine will depend upon an exact adjustment of the valve mechanism. It will be necessary either to lengthen or shorten the valve rods slightly and also to alter the position of the valve crank pin in respect to the position of the piston so that the admission of steam to the cylinder occurs at the right moment.

The engine should be kept well oiled so that friction is reduced to a minimum. The engine will require more steam pressure than the steam turbine, and it is well to make the alcohol lamp larger so as to supply more heat.

Internal Combustion Engines

No other machines are of such importance as those which the physicist terms *heat engines.* Although power is obtained from rivers in many parts of the world and may even be secured from the wind and from chemicals, it is *heat* which furnishes the driving power for most of the machines in our shops and factories as well as for transportation on land and sea. A considerable amount of electricity is generated by dynamos turned by water power but the greater percentage is produced by generators driven by some form of heat engine.

Of course the steam engine is a heat engine. However, the heat engine with which we are most familiar nowadays is the gasoline engine. The essential difference between a steam engine and a gasoline engine is that in a steam engine the fuel is burned

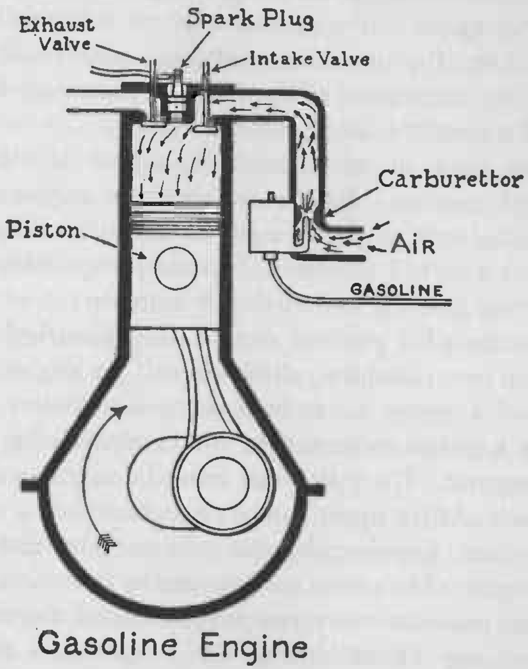

FIG. 157.—Diagram of an internal combustion engine of the type used in automobiles and commonly called a gasoline engine. Compare this with the diagram of a Diesel engine.

under a boiler apart from the engine itself while in a gasoline engine the fuel is burned in the cylinder of the engine. Therefore a gasoline engine is called an internal combustion engine.

The internal combustion engines used in automobiles are called four-cycle engines because there is a push or thrust of power once in every two revolutions or every four strokes of the piston. In order to understand how a four cycle gasoline engine works, think of it for a moment as a muzzle-loading cannon. There are four cycles in the operation of a muzzle-loading cannon—loading, ramming, firing and cleaning. There are also four cycles in the operation of an automobile engine. They are called the intake, compression, power and exhaust strokes. They correspond to the loading, ramming, firing and cleaning of a muzzle-loading cannon.

The fuel used in an automobile engine is the volatile liquid called gasoline. Before entering the engine cylinders, it is converted into a gas in a device called a carburetor. A carburetor is a sort of atomizer. It is simply a mixing chamber for vaporizing gasoline and mixing it with air.

The cylinder of a gasoline engine is a cylindrical hole in a block of cast iron called the cylinder block. An engine is usually made up of a group of four to sixteen cylinders. In each cylinder is a piston connected to the crankshaft by means of a connecting rod. The piston can move in only two directions, up and down. At the upper end of the cylinder are a spark plug and two valves. One is called the exhaust valve and the other the intake valve. The valves are operated by cams on a camshaft which turns once for every two revolutions of the crankshaft. Both valves are closed during the compression and power strokes. The intake valve is open during the intake stroke and the exhaust valve is open during the exhaust stroke. The purpose of the spark plug is to ignite the gasoline-air mixture by means of an electric spark or flame at the proper time.

During the intake stroke the piston moves downward into the cylinder, sucking gasoline vapor and air into the cylinder. The operation is like loading a cannon. During the compression stroke, the piston moves upward in the cylinder and compresses the mixture of gasoline vapor and air. It is like ramming the

powder charge in a cannon. The gasoline vapor and air are compressed to about one fifth of their original volume. The pressure is about 95 lbs. per square inch. At the beginning of the power stroke the mixture of compressed air and gasoline vapor is ignited by an electric spark. It is commonly supposed that an explosion occurs in the cylinder when the mixture is ignited. The burning of the gasoline vapor is swift but somewhat slower than an explosion. The rapid steady burning of the gasoline-air mixture which takes place in the cylinder is much more desirable than an explosion would be. An explosion in the cylinder would be equivalent to trying to drive the piston down by hitting it with an enormous hammer. It would be moving the piston with blows instead of pushes. On the other hand the heat of the burning air-gasoline mixture causes it to expand enormously, creating a push or *pressure* of about 400 pounds per square inch on the top of the piston.

When the piston has travelled to the bottom of the cylinder during a power stroke it reverses its direction and moves back up, pushing out the burned gases through the exhaust valve. This cycle of operations is repeated, each cylinder first sucking in the gasoline-air mixture, then compressing, firing and cleaning out the burned gases. In an eight cylinder engine running even at a moderate speed the power strokes occur several thousand times a minute. Considering that the pressure on each piston during part of the power stroke may amount to more than *one and one-half tons* it is no wonder that a comparatively small engine can develop 100 horsepower.

Diesel Engines. An internal combustion engine called a Diesel is used in many large trucks, tractors, busses, ships and power plants. Diesel engines are also used to power railway cars and locomotives. They are more efficient than gasoline engines, they produce more power per pound of fuel. Diesels burn heavy fuel oil which is not as inflammable as gasoline and is lower in cost. In proportion to the power they develop, Diesel engines are heavier than gasoline engines. At the present time it is not possible to make a small Diesel engine which is light enough and "fool-proof" enough to replace gasoline engines in small trucks and passenger automobiles.

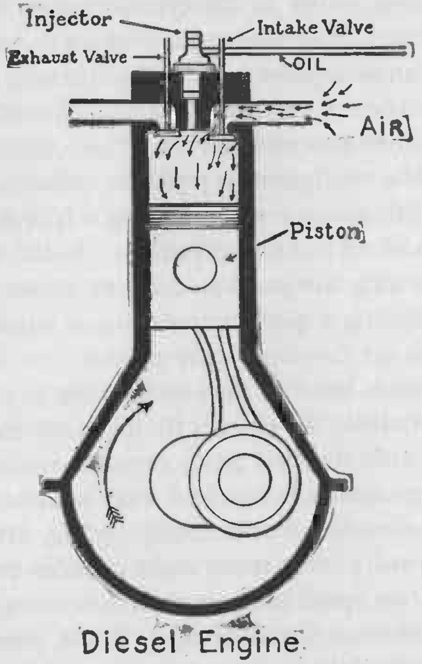

FIG. 158. — Diagram of a Diesel engine. Compare this with the gasoline engine shown in Fig. 157 and notice the absence of carburetor and spark plug.

The Diesel engine was invented by Rudolph Diesel, a German engineer. It was described in his original patent dated August 27th, 1892. The first successful Diesel engine was constructed in 1897 at the Maschinenfabrik, Augsburg, Germany.

The easiest way to understand the principle used in building

and operating a Diesel engine is to compare a four-cycle Diesel with a four-cycle gasoline engine.

Diesel engines have no spark plug; they are self-igniting. They also have no carburetor. Instead, each cylinder is provided with an injector and a fuel pump which measures and injects a small amount of fuel oil in the cylinder at the proper time.

Instead of a mixture of gasoline vapor and air, a Diesel draws pure air into its cylinders. During the compression stroke, the air is compressed to 400 to 500 lbs. per square inch. When air is suddenly highly compressed it becomes very hot. The temperature of the compressed air in a Diesel engine cylinder may reach 1000 degrees Fahrenheit. At the end of the compression stroke a small amount of fuel oil (refined petroleum) is injected into the hot compressed air above the piston. The oil is broken up into a fine mist and when the oil particles meet the hot air they burn. The heat of the burning oil further expands the air. A large volume of hot gas is produced by the combustion. An enormous pressure is built up in the cylinder and forces the piston down on its power stroke. During the return or exhaust stroke the hot air and gas from the burned oil are pushed out through the exhaust valve.

The pistons, cranks and connecting rods of a Diesel engine are like those used in a gasoline engine but are heavier and stronger. Diesel engines must be very heavily and strongly built to withstand the heavy pressures developed in the cylinders. They weigh more than gasoline engines of the same horsepower.

CHAPTER VII

LIGHT

We have now come to another interesting subject, that of *Light.*

We have already learned that sound is produced by vibrations and consists of waves moving through the air. Heat also is produced by vibration, the motion not being that of a body as in the case of sound but the movement of the little *molecules* composing the body.

The long and painstaking investigations of patient scientists have shown light also to be due to certain kinds of vibrations and to consist of electromagnetic waves.

A knowledge of what light is and how it behaves under certain circumstances will enable you to understand many things, which may now be a puzzle; also to perform many interesting experiments. There is an old saying that "seeing is believing" but the person who knows much about the phenomena of light also knows that no other of our senses is so very easy to fool as that of sight and that the old saying is far from being true.

What is Light? In the chapter on Heat it was explained that the molecules of all substances are continually in motion, moving back and forth and jostling their neighbors and being jostled in turn, like a lot of marbles being shaken in a bag. Some of the energy of these moving molecules sets up vibrations in the surrounding space and produces *waves* just as the motion of the bathers in a swimming pool produces waves in the water.

The *energy* of these restless little molecules, we have learned is *heat.* The *waves* which they produce in the ether possess another form of energy which we are most familiar with as *Light.*

Light Waves may vary in their rate of vibration just as those of sound. Just as the rate of vibration or number of waves made in a second varies, so does the size of the waves. The proper name for the size of the wave is *wave length.* When the rate of vibration of a sound wave is changed, we hear a sound of different *note* or *pitch.* When the rate of vibration of a light wave is changed *we see a light of different color.*

Just as the ordinary ear is only sensitive to sounds of a limited range of vibration, so can the eye only see light produced by a limited range of vibration. Light produced by a wave length of approximately three-one-hundred-thousandths of an inch is of a dull red color. Light waves of a longer wave length can be produced *but they cannot be seen.*

When light waves become so long that they can be measured in feet instead of extremely small fractions of an inch, *they become the electromagnetic waves of radio telegraphy.* "Radio" waves vary in length from a few feet to one hundred thousand feet. *Otherwise they are simply light waves which are invisible.*

When the speed of vibration of a wave is increased, the wave length becomes shorter.

If the vibration of a red light is gradually increased, the color of the light will change, becoming first orange, then yellow, green, blue, and violet as the vibrations increase. When the color has become violet the wave length is about fifteen-one millionths of an inch. If the vibrations increase so that the wave length becomes still shorter, the light can no longer be seen with the eye.

When the number of vibrations is increased above that which produces a violet color, until what we might term a very shrill pitch several octaves above the violet, is reached, the famous X-Rays are produced. These rays are themselves invisible but by means of them it is possible to photograph the interior of the body.

You should now have an understanding of how heat, light, and electricity are related. In order to make this a little clearer let me suggest that you imagine a huge piano with a long keyboard in front of you, arranged so that if you press any of the keys, waves in the ether would be set up instead of sound waves in the air.

If then you press a key near the bass end of this piano, electric waves—the waves that run in the ether inside of a copper wire and the waves needing no wire, which are used in wireless telegraphy—will be produced.

Then if you move up the keyboard a short way and press a few notes you will feel warm because the shorter higher pitched waves of *Radiant Heat* will have been produced.

Moving farther along the keyboard to the proper place and pressing a key would make a bright red light. Pressing the other keys in the same octave would produce orange, yellow, green, blue, and violet lights.

The notes high up along the keyboard, would produce X-Rays when they were pressed.

Before telling you how to build any of the apparatus described farther on in this chapter I am going to explain a few more facts about light and ask you to perform some simple experiments which would give you a good idea of the principles governing the action of light.

One of the most remarkable things about light is the speed at which it travels.

The Velocity of Light. Until 1675, it was believed that light traveled instantaneously. In that year, Roemer, a Danish astronomer, made the discovery that light travels in space at

the enormous speed of approximately 186,000 miles per second. That this figure is correct has been proved in a number of different ways. Some idea of this tremendous speed may be gained from the fact that while pronouncing its name, light might travel a distance equal to eight times around the world.

All Light Travels at the Same Speed regardless of the number of waves in a second, just as a small boy with very short legs might be running along aside of a tall man with long legs at exactly the same rate even though the boys legs were making three strides to the man's one.

Light Moves in Straight Lines. One of the most important facts about light is that it naturally travels in straight lines. This does not mean that the light from a lamp travels only in one direction but that it travels equally straight in all directions. Since it is the property of light to travel in straight lines, of course it cannot turn a corner by itself and that is the reason why there are shadows. If light could of itself bend and pass around an object there would be no shadows. It would be impossible accurately to aim a bullet if light did not travel in a straight line through the sights of a rifle to the eye.

Fortunately there are ways in which light can be compelled to pass around corners and even to bend. These we shall learn about later.

Law of Intensity of Illumination. One of the things that you have no doubt noticed is that light grows rapidly weaker as the distance from its source is increased. A lamp is much brighter when you are close to it than when you are at a distance. But did you know that the light is only one-fourth as strong two feet away from the lamp as it is one foot away and only one-ninth as strong three feet away?

The diagram will make this clear. The light from a candle is shown illuminating a square card, *A*, one foot away. The same light if not intercepted by *A* would go on to *B* at a distance of two feet. It would there illuminate four squares of the same size as *A*. If allowed to proceed to *C*, three feet away, it would illuminate nine such squares and have but one-ninth of its original intensity.

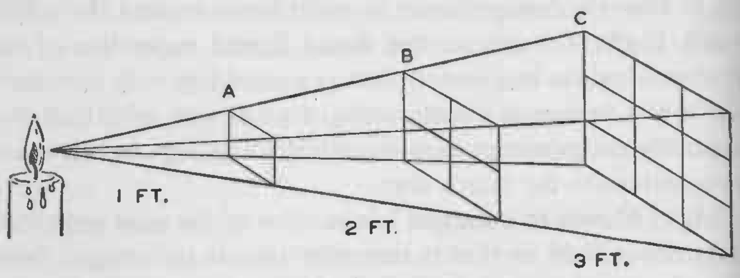

FIG. 159. — This diagram illustrates the law of intensity of illumination. The light from the candle spreads so that the light which falls on the square card one foot away, spreads out and covers a card four times as large two feet away and nine times as large three feet away.

The Intensity of Strength of a Light is measured by the amount of illumination which it will produce on a given amount of surface at a certain distance and is measured in "candle power" by comparing it to the light of an old-fashioned candle made of sperm and of the size which used to be known as "sixes."

A forty-candle-power electric lamp is therefore one which will throw forty times as much light on any given surface as a sperm candle the same distance away.

Light is Produced by what we call a *luminous* body. Or we might turn this statement around and say that

A Luminous Body is one which emits light. The sun, a burning match, a lighted lamp, and fire of any sort are familiar examples of luminous bodies. When the light originates in the luminous body, the latter is said to be *self-luminous*. The sun and a lighted candle are self-luminous but the moon and the objects which we see by the light of the candle are said to be *illuminated*.

When the light from the sun, from a lamp, or from any other source strikes an object, part of the light is thrown back again or *reflected*. Every boy who has flashed a mirror in the sun has seen the beam of light which the mirror throws back or *reflects*.

White objects, or those which are polished, reflect light much better than dark or rough surfaces. Black does not reflect well at all and we can almost say that practically no light is thrown back by a black surface.

All objects absorb light to some extent as well as reflect it. Light passes through almost every substance to some extent even though it cannot be detected with the eye. When an object absorbs so much light that none can be seen to have passed through, it is said to be *opaque*.

Opaque Bodies allow light to pass through quite readily when in thin layers. The sun may be seen through a thin layer of gold leaf, although a less brilliant light would be invisible.

Some substances absorb very little light and objects can be seen through them distinctly. They are said to be

Transparent. Glass, water, and air are transparent.

A Translucent Body allows some light to pass through but objects cannot be seen through it. Smoked glass, heavy mist, and muddy water are examples of translucence.

There is really no such thing as a perfectly transparent substance. The truth of this is quite plain because we can always see little reflections from the surface of the most perfect pane of glass or the clearest water.

These reflections mean that light has been reflected to our eyes and therefore that all of it has not passed through the substance and it is not perfectly transparent.

If we look at a lighted candle, we see the candle flame by means of the light which comes directly to our eyes or by what is known as *transmitted* light. If we read a book by the light of a candle, the light passes from the candle flame to the page of the book from which it is reflected and we see the printing by *reflected* light.

It has already been stated that white objects reflect light much better than dark objects. Just why this is we do not know. We can however learn two other interesting facts about the reflection of light.

One is that a red surface only reflects red light, a green surface only reflects green light, a yellow surface only reflects yellow light and a blue or violet surface only reflects blue or violet light.

The other fact might be termed the law of reflection. Every boy who has ever played billiards or pool already knows something about the law of reflection even though he may not realize it.

Any one who has ever thrown a rubber ball against a wall knows that if you throw the ball straight against the wall, it comes back *straight*. If you throw it sideways, it rebounds or is reflected sideways to the same extent to which it was thrown sideways. Likewise if you roll a ball against the cushion on a pool table at an angle, it will come away from the cushion again at the same angle. The angle at which the ball is rolled against the cushion is called the angle of *incidence* and the angle at which it rebounds the angle of *reflection*. The angle of incidence and the angle of reflection are always equal whether we are dealing with billiard balls or with light.

Why it is difficult to see through a Fog. Since both air and water are usually transparent and fog is nothing but small particles of water in the air, you may have wondered why it is difficult to see in a fog. It is because the little particles of water in the air furnish a countless number of little surfaces, each one of which reflects light. Each little particle of water is sending out reflected beams of light and these countless little beams travel in every conceivable direction instead of only towards our eyes. They are said to diffuse the light.

You can show the effect of

Diffused Reflection by a simple experiment. Fill a glass fruit-jar with smoke. Cover the mouth of the jar with a piece of cardboard, through the centre of which is a hole about three-eighths of an inch in diameter. Then with a small mirror,

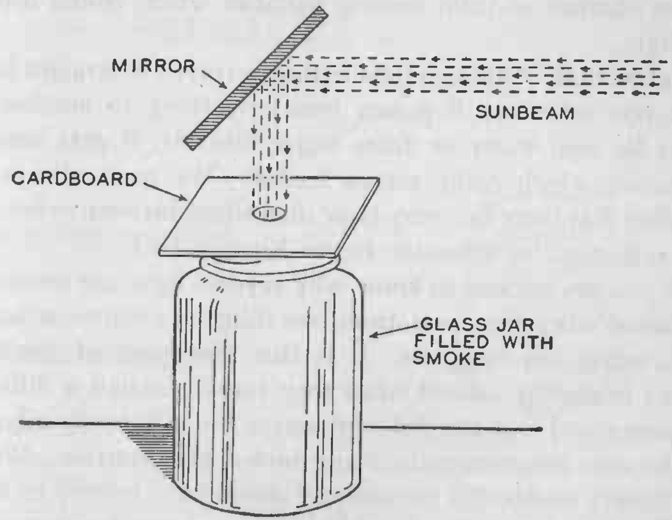

Fig. 160. — A simple method of showing how light is reflected and diffused by the millions of little particles in a jar of smoke.

reflect a beam of sunlight into the jar through the hole in the cover. The whole interior of the jar will be illuminated. The small particles of smoke floating in the jar furnish a great many surfaces and the light is reflected from them in as many different directions and the light becomes scattered or diffused.

The Benefits of Diffused Reflection. Fog and smoke cause almost complete diffusion. Everything which we see diffuses light to a certain extent. A perfect reflector would be invisible and it is therefore only by a diffused reflection that objects become visible to us. The earth, the trees, houses, plants, particles floating in the air and all other objects, reflect in every direction the light of the sun and thus fill the space about us with light.

Aeronauts who have ascended to very high altitudes claim that the sky becomes black when far above the earth, owing to the absence of little floating particles which would diffuse the light.

Refraction. Although light naturally travels in straight lines, as a rule whenever it passes from one thing to another, as from air into water or from water into air, it gets bent or *refracted,* which really means *broken.* We must always remember that there is a very clear distinction between *refraction* and *reflection* for reflection means *bending back.*

If you are curious to know why rays of light are broken or refracted when they pass from one thing to another, a partial explanation can be given. It is that the speed of the light waves is slightly altered when they travel through a different substance and that the different waves are differently affected.

Our eyes are continually being fooled by refraction. We do not always realize this because our senses have learned to make a correction unconsciously. How many of you knew that we never see the stars exactly where they are? But it is true.

When the light traveling from the stars through the empty space above our world reaches our air it is very slightly retarded and bent. As a result we do not see any heavenly body where it really is but at some spot a little distance away. And what may seem more strange to you still is the fact that we can actually sometimes see the sun when it is below the horizon because the rays are refracted as they pass through the air.

You may not wish to believe this at first but I am going to give you some other examples of refraction and some ex-

periments which you can try for yourself and see how easy it is for your eyes to be fooled.

Take a straight stick or a pencil in your hand and look at it. You are able to see the stick, as you see everything else by the rays of light which come from it. These rays of light, if they possibly can, travel in straight lines. Since the stick or pencil is straight when we see all parts of it through the

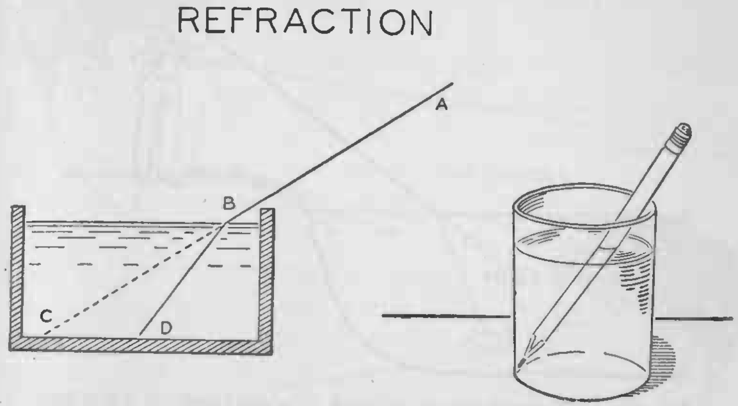

FIG. 161.—The diagram at the left represents a beam of light (AB) striking the surface of a tank of water. Since light tends to travel in a straight line it should continue in the direction shown by the dotted line BC. It is however really bent or refracted by the water and actually travels from B to D.

If you place a pencil in a tumbler full of water, the pencil will appear bent at the point where it enters the water.

air, it appears straight. But we shall not see it straight if we put half of it in water. You can try this for yourself by putting a stick in a pond or a pencil in a tumbler of water. You will notice that the stick or pencil appears bent at the surface of the water. You will see it best if you look at it sideways. The light rays from the lower part of the stick or pencil pass through water and then through air before they reach our eye and are *refracted* making the stick appear bent.

Those of you who have ever tried to spear a fish in a pond may remember that you had very poor luck in your first attempts. The light rays coming from the fish and by means of which you were able to see it were bent as they passed from the water into the air and made the fish appear to be in a spot where he really was not. If you want to have any luck in catching a fish in that manner you will have to thrust

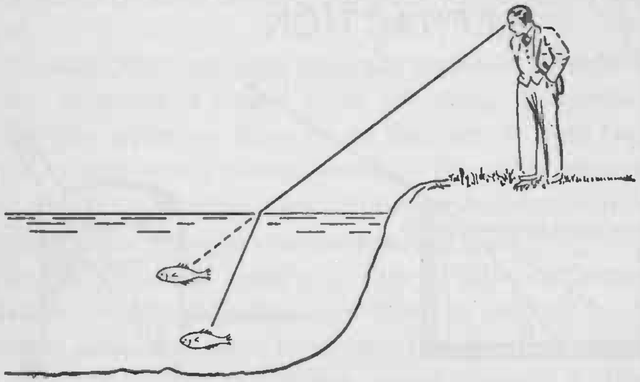

Fig. 162. — If you stand on the bank of a pond and see a fish in the water, the fish is not where it appears to be. The fish appears to be in the position of the fish at the end of the dotted line in the sketch. It is actually in the position of the fish shown at the end of the solid line.

your spear at a point a little nearer you, because that is where he really is.

The accompanying illustration will explain this.

Now that you understand why the stars are not really where they appear to be, perhaps you would like to try an experiment showing how it is possible to see the sun when it is below the horizon.

Sometimes we can see around a corner. Put a saucer on a table and place a penny in the middle of it. Look at the penny and stoop down low until the penny is just hidden by

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the rim of the saucer. Maintain your position and without moving the level of your eyes in the slightest, pour some water in the saucer until it is full. The penny will come into sight. The penny has not moved but the water has refracted the light so that you are seeing around the edge of the saucer.

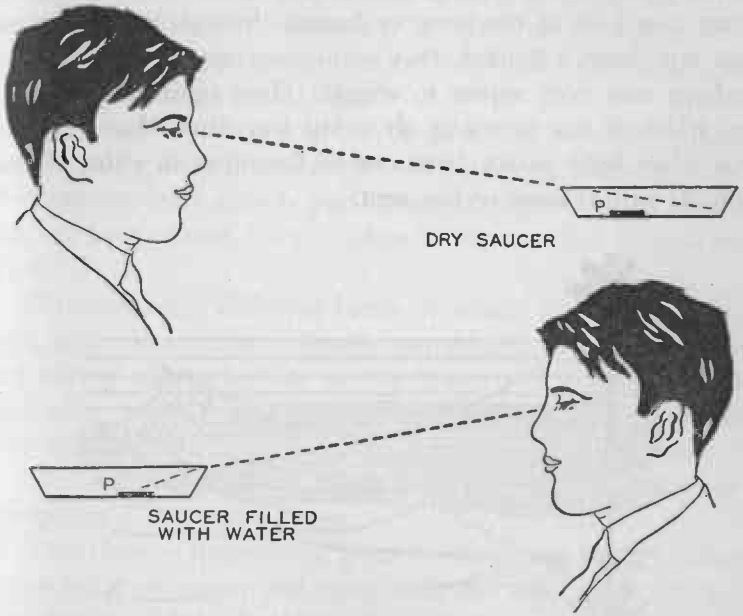

Fig. 163. — Place a saucer or a shallow pan on a table on the level with your eyes so that a penny (P) lying on the bottom is just hidden by the edge. If then, the dish or pan is filled with water you can see the penny when it is really behind the edge because refraction bends the light waves.

Why the Stars Twinkle. The twinkling of the stars which we have all noticed at night is one of the phenomena due to refraction. There are layers of air moving around above the earth. Some of these layers are cool and some are warm. The cool layers are more dense than the warmer layers and

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when the light from the stars passes from the dense layers into the thinner layers, or vice versa, it is refracted and bent back and forth causing the "twinkle."

Why Objects sometimes seem crooked when we look at them above a Fire. Another phenomena due to refraction which some of my young readers may have noticed is that when you look at the trees or houses through the hot gases that rise from a bonfire, they sometimes appear crooked and perhaps may even appear to wiggle. Here again is a happening which is due to warm air being less dense than cold, so that when light passes from one to the other in either direction, its path is more or less bent.

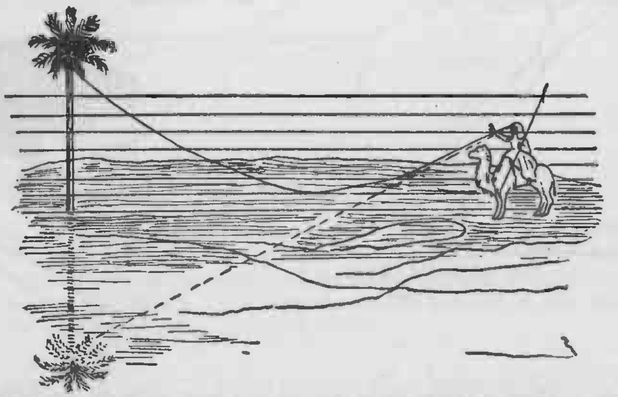


FIG. 164.—A mirage. The straight lines represent layers of air of different temperatures and density which refract and bend the light waves. The palm tree appears up-side-down to the Arab on the camel in the sketch.

What Causes a Mirage? Travelers over the sandy plains of a hot desert and sailors at sea sometimes see an optical illusion of trees and lakes or ships or distant objects which are still below the horizon. This is called a *mirage* and is also due to a warm layer of air bounded by a cold layer. When the mirage takes place on a desert the warm layer of air is usually on the bottom next to the earth, and when it takes place at sea, the cold layer is next to the water. The light rays are bent by these layers of air and the result is an illusive image.

Something about Lenses and why a Magnifying Glass Magnifies. Now that you understand a few things about reflection and also how a light ray is refracted or bent when it passes from one medium to another you will be able to see how a lens can change a ray of light.

The most common form of lens is that usually called a magnifying glass and known to some boys as a "burning glass." Perhaps you have already performed the experiment of causing the sun's rays to set fire to a piece of paper with a magnifying glass.

There are many different forms of lenses. The most familiar type is that known as a *double convex* because both surfaces are curved outward. The convex lenses will magnify an object when you look at it through one of them while a *concave* lens will diminish or reduce the appearance of the object.

You can buy a small magnifying or reading glass very cheaply at a stationery store.

If you hold a magnifying glass in the strong sunlight above a few scraps of paper and move the glass back and forth until you find the point where the image of the sun which the glass casts on the papers is the smallest, the papers will commence to smoke and soon catch on fire.

Light rays passing through a lens are bent. The sun's rays passing through the reading or magnifying glass are bent in towards each other and concentrated. All of the light and heat is concentrated in such a small spot that it is very intense at that point and sets fire to the paper.

When you look at an object such as a playing card, through the magnifying glass, the rays of light thrown off by the card pass through the glass and are bent by the curved surface—just as the stick which you put in the water appeared to be bent. When the rays of light reach the eye, the eye imagines that they have come in a straight line. The eye throws them out again in straight sloping lines at the end of which an image of the card is seen which is much larger than the real card. What you therefore see is not the real card, but the rays of light

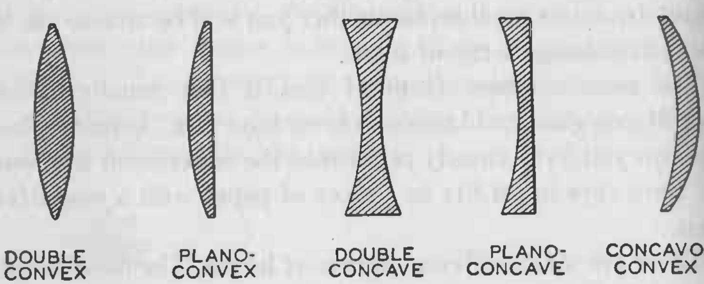


Fig. 165.—Cross-sections of the most common forms of lenses.

thrown off by the card, first bent by the glass and then straightened out so as to appear to cover a much bigger space.

A strange thing happens, however, if the rays of light are allowed to pass beyond the eye without being focussed by the eye, the image will turn upside down. You can try this experiment with the aid of a looking-glass as shown in Figure 221.

Magnifying lenses are made use of in telescopes, microscopes, etc. The instruments are composed of a number of lenses arranged so that the magnified image from one is further magnified by the others. When seen through a telescope or a microscope, an object seems many times as large as when seen with the unaided eye.

You will get a great deal of instruction and spend many interesting hours if you invest a small sum in a little pocket microscope.

Half the wonders of the world right about us are never seen by human beings, and a new realm will be opened up before your eyes and you will be surprised to see how changed things seem when they are magnified. An apparently smooth

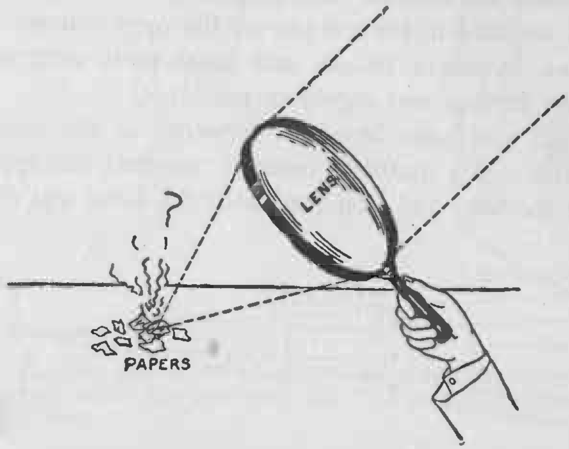


Fig. 166.—If a magnifying glass is held in the strong sunlight at the proper distance above a few scraps of paper, the paper will commence to smolder and soon catch fire. The lens bend the suns rays and concentrate them at a point called the focus.

piece of thread will appear like a huge rough rope, the point of a needle will look blunt, plants will be found covered with fine hair, bugs will look like demons, and you will make many other interesting discoveries.

Newton's Discovery

There is still to be seen, in a lovely vale of Lincolnshire, England, a small, stone, peak-roofed manor house in which on Christmas day, 1642, one of the world's greatest scientists, Sir Isaac Newton was born.

The sun-dial made by him when he was a boy is still legible on the side of the house where he placed it over two-hundred and fifty years ago. The bookshelves made by him out of some packing-cases are also preserved in the room where he used to study his lessons. The playthings of this young man, who was destined to become one of the most famous of men, were saws, hammers, chisels, and other tools with which he built many curious and ingenious machines.

Many of you have heard of Newton, as the young man who seated in his mother's orchard, watched the apples falling from the trees and wondered what the force was that drew

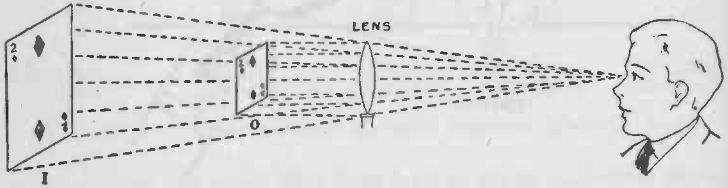


Fig. 167. — This diagram shows how a magnifying glass makes an object appear larger than it really is. The card I is the magnified image. O is the actual card.

them to the ground. What is the force that holds the moon and the planets in their spheres? Why does not the moon fly off into space? And those apples, dropping slowly from the trees and falling at a visibly increasing speed led him to discover the great law of the *attraction of gravitation,* considered by scientists to be the most brilliant and valuable discovery ever made by human mind.

But the solution of this mystery was not by any means the only great discovery made by Sir Isaac Newton. He spent a great many years experimenting in the realm of physics, chemistry, and Nature.

One of the most famous of all Newton's experiments in

physics, like most famous experiments of all ages, was exceedingly simple to perform and cost scarcely anything to

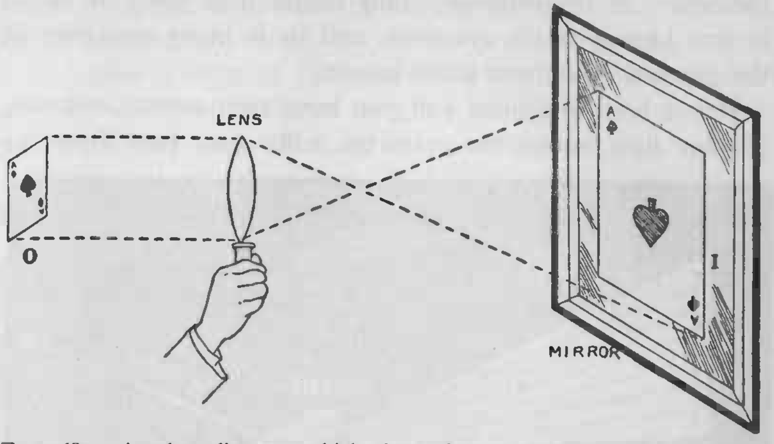


Fig. 168. — Another diagram which shows how a magnifying glass makes objects appear larger than they really are. The dotted lines show the path of the light rays.

make. It required, however, the mind of a genius to attempt it in the first place.

All that Newton did was to close the shutters in a room,

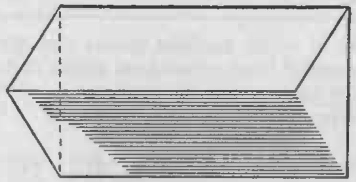


Fig. 169. — A prism. It is by means of a prism that the spectrum is most easily revealed.

make a small slit in one to let a ray of light through into the darkened room and then take a prism, which is simply a three-sided piece of glass and see what happened when the ray of light passed through it.

He found that the *white* sunlight coming through the hole in the shutter was broken up into a band of colors, which were the colors of the rainbow. This simple little band of colors is now known as the *spectrum,* and by it many mysteries of the universe have been made known.

It has been explained and you have seen several instances of how light waves are refracted when they pass from air

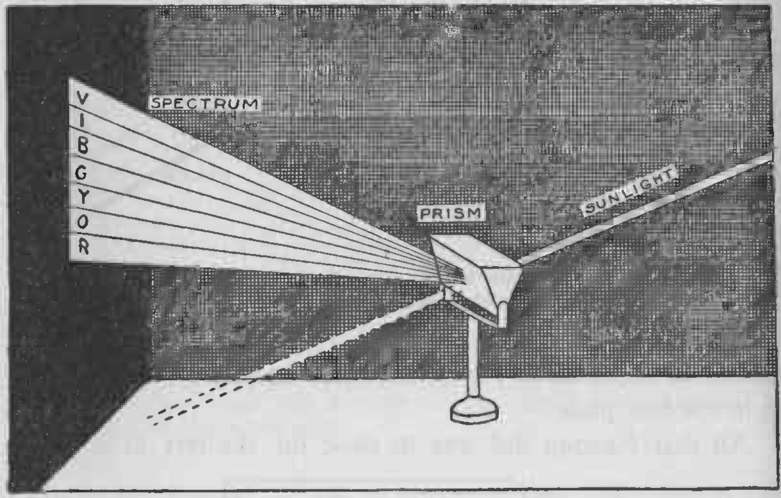


FIG. 170. — If a beam of white sunlight passes through a prism it becomes broken up into a beautiful band of rainbow colors called the spectrum. The dotted line shows the path which the sunbeam would follow if it were not refracted by the prism.

into glass or from glass into air, etc. As long as nothing bends the light rays they travel in absolutely straight lines, but when they pass from water into air or from air into water, or from air into glass, or from glass into air, they are bent.

The light rays coming through the hole in the shutter would have kept in their course in a straight line, if the prism had not been there and only made a bright spot on the floor or opposite wall.

But the prism refracted or bent them and turned the rays from their natural course. And since white light is not a single thing but a mixture of all the colors of the rainbow, something else happened.

The rays of light of different wave length which make the different colors all different from each other is the extent to which they are bent. The red rays are the least bent and the violet rays are the most bent. Red is therefore found at one end of the spectrum. Orange, yellow, green, blue, indigo, and

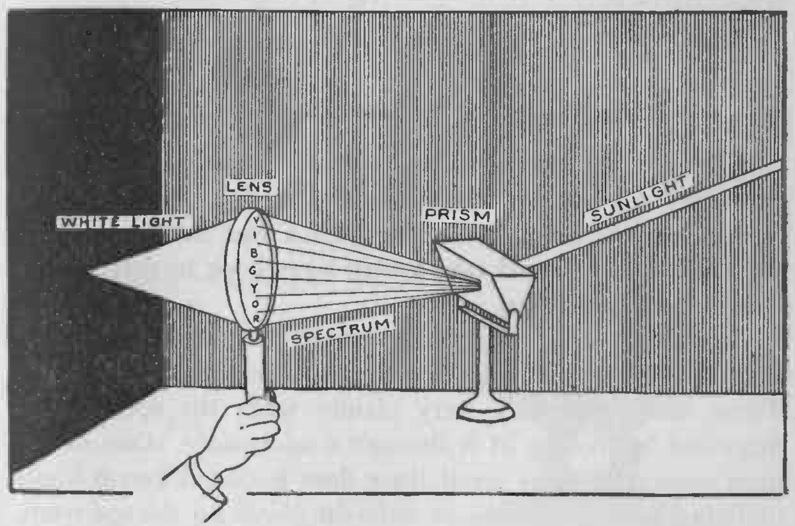


FIG. 171. — The beautiful band of rainbow colors may be changed back into white light with the aid of a magnifying glass.

violet succeed, each imperceptibly merging into that which follows.

If you can secure a glass prism you can repeat Newton's experiment for yourself and show that white light is made up of the seven colors of the spectrum. A glass prism of the sort used on fancy chandeliers will serve the purpose.

You can also prove that these seven colors when mixed together again will produce white light. Arrange your glass prism in a sunbeam so as to form a spectrum. Let the light of the spectrum pass through a large reading-glass and on to a screen and the image will be white.

These experiments will now enable you to understand how a rainbow is formed. The rainbow itself is made out of white sunlight shining on raindrops in the air. The countless little raindrops act just as Newton's prism acted and refract the white sunlight so that it is broken up into the colors of the spectrum.

The Wonders of the Little Band of Color

This great discovery that white light is a mixture of colored lights is the basis of the wonderful branch of science called *spectrum analysis* and has led to such a vast number of consequences that it would take a very large book to describe the merest outlines of them.

One thing which missed the notice of Newton is the fact that there are certain dark lines in every part of the spectrum. These dark lines show very plainly when the spectrum is magnified by looking at it through a microscope. One of the most wonderful facts about these lines is that different kinds of light produce the lines in different places on the spectrum. The light coming from a piece of red-hot iron produces certain lines. The light coming from a burning candle produces other lines. If we put any sort of a chemical substance in a fire and then examine the spectrúm produced by the light from the fire we shall find that every different chemical element produces its own lines which are different from those of every other element.

We can therefore tell what kinds of elements are giving

forth light in the sun by examining the dark lines in the spectrum produced by sunlight.

By examining the light from the stars we can in this manner tell that there is iron, oxygen, or copper in the star.

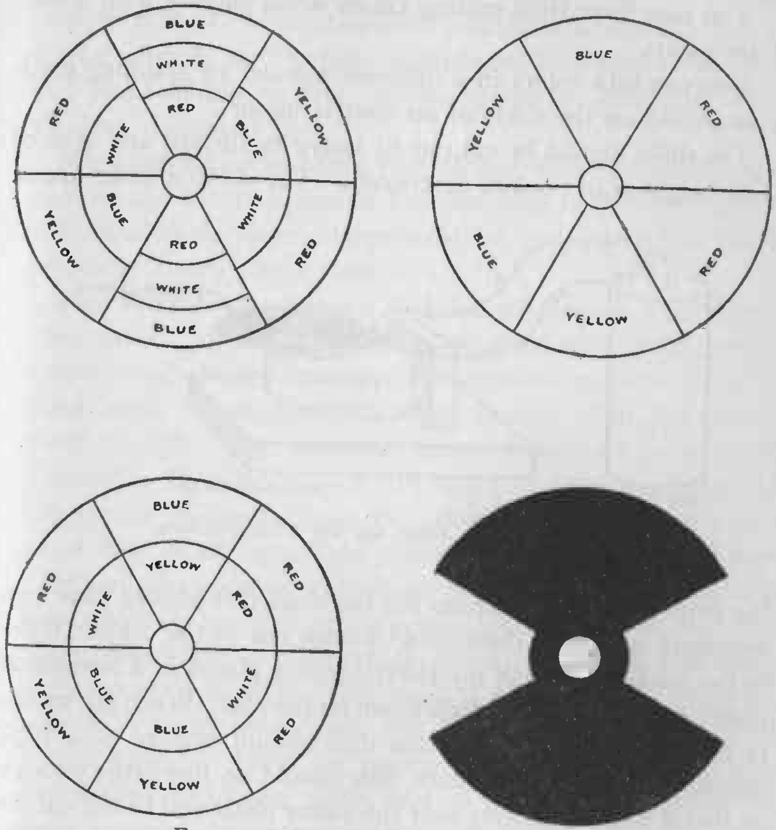


FIG. 172. — The disks for the color top.

All the colors of the spectrum, when mixed, produce as we have seen, white. If the red light is left out, the result is a bluish green. In the same manner, if we mix any two or three of the colors together we produce other colors.

A mixture of no two colors will produce, *red, yellow,* or *blue.* These are therefore called *primary* colors, while the others are called *secondary,* as they all can be obtained by mixing the primary colors.

You may have tried mixing colors when playing with water-color paints.

You can mix colors in a different manner by spinning cardboard disks on the shaft of an electric motor.

The disks should be cut out of heavy cardboard and colored with bright water colors or crayons. The colored disks are in

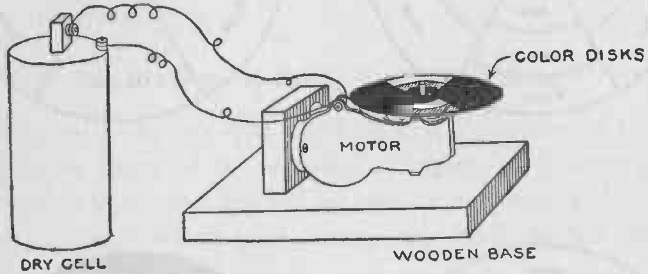


FIG. 173. — The color top for mixing colors.

the form of complete circles but the black disk should have two segments cut out as illustrated. Fasten one of the colored disks to the shaft of a small toy electric motor placed in a horizontal position so that you can look down on the disk. When the motor is connected to a dry cell the disk should revolve at a high speed. The hole in the black disk should be just large enough so that it will slip loosely over the motor shaft and lie flat on the colored disk. When the motor is running, the colors on the disk will be blended together and as the black disk slips slightly and changes its position so as to expose different colors from time to time, an ever changing colored design will be produced.

Photography

Light Affects Chemicals. We are all familiar with the wonderful colors of plants and vegetation. The same magic sunlight affects certain chemicals which can be spread on paper or glass and so used to form a *photograph. Photo* means light and *graph* means writing. A photograph is something which has been written by light.

Many of you may think that photographs cannot be made without the aid of a camera but that idea is quite wrong, for it is possible to make many beautiful and instructive photographs in a very simple manner.

Fun With Photography. All that you need is a package of "blue-print" paper which can be obtained at a photographic-supply store. Blue-print paper is coated on one side or "sensitized" with certain chemicals which change when they are exposed to light. The sensitized paper should not be carelessly exposed to light before you are ready to make a photograph, but should be handled in a very dim light and all the unused paper kept in the light-tight package where it is dry and dark.

When you open your package of paper you will find that it is white on one side and a greenish-blue color on the other. The colored side is the surface which is covered with chemicals sensitive to light. Cut a little piece off one sheet and take it outdoors where you can expose the sensitive surface to the sunlight. Hold the paper by one corner so that your thumb and forefinger cover part of the surface. After you have exposed the paper to the sunlight for a few moments take the paper back in the house and wash it in cold running water. You can watch it changing color. You will find that the little piece that your fingers covered so that the light could not reach the chemicals turns white and the rest of the paper where the light struck turns dark blue.

When you have done this, you will understand how a photograph is made and realize that you have a wonderful paper which changes color when it is exposed to light, those parts which are shaded becoming white while the rest of the paper becomes dark blue.

Just why the light affects certain chemicals, we do not know but the explanation of what happens when the paper is washed in water is this. The greenish-colored chemical with which the paper is coated before it is exposed to the sunlight, will dissolve in water and if you wash the paper before it is

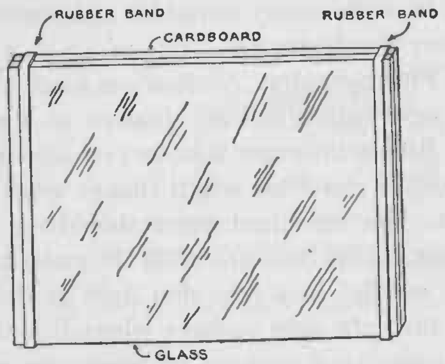


FIG. 175.—A simple printing frame for making photographs.

exposed to the light, the color will all come off. When light strikes this chemical, however, it changes into a chemical of a different sort and color. This new chemical is *insoluble,* that is, it will not dissolve in water. When you exposed the paper, that portion of the chemical which was under your fingers was not struck by the light and therefore being unchanged, it washed off and left the paper white at that point. The chemical on the rest of the paper affected by the light became insoluble and would not wash off.

Now you can see how easy it is to make photographs.

Figure 174 shows several photographs of leaves which were made by laying a leaf on some blue-print paper and exposing it to the sun. The paper was then washed.

The leaves are not apt to lie flat on the paper unless you press them down closely by putting a sheet of clean glass over them, or else you place them together with the paper in a printing frame. You can make a printing frame from a sheet of glass five inches long and four inches wide, together with a piece of heavy cardboard of the same size.

Then in order to photograph a leaf, lay it first on the glass. Put a piece of the photographic paper against the leaf with the coated side towards the glass and place the cardboard over the paper. Two strong rubber bands slipped over the glass and cardboard at the end will hold them together tightly and prevent the leaf and paper from moving.

Now you are ready to make the photograph and it is only necessary to take the printing frame out into the light and leave it in the sun until the exposed portion of the paper seen through the glass has turned dark.

Then take it indoors, slip off the rubber bands and wash the paper thoroughly. You will have a wonderful picture of the leaf with all the delicate tracings of the veins showing quite clearly.

You will find it quite easy and interesting to make photographs of all sorts of leaves, seaweed, flowers, etc., in this manner. You can reproduce drawings, pictures cut from magazines, etc. All your friends in the "funny paper" can thus have their photographs taken. Choose a picture which has nothing printed on the back because the printing on the back will show in the photograph as well as that which is on the front. It will be necessary to make the picture which you are hoping to reproduce, somewhat transparent so that the light will pass through easily, and you can accomplish this by rubbing on a little machine oil or olive oil. It should then be pressed between two pieces of blotting paper so as to remove the extra oil before putting in the printing frame.

The *time* required to expose the paper to the sunlight and *print* the picture depends upon the brightness of the sun and transparency of the *negative*. The negative is the leaf or the picture which you are making a photograph of. It is well to time the exposure with a watch, and after you have noted how long it takes to make the best pictures you will soon be able to judge the sunlight and your negative.

It is best to let the finished photographs or *prints* remain in the water a short time so that all of the unchanged chemicals are surely washed off. Otherwise the picture may fade.

A Camera Without a Lens. You have now seen how easy it is to make photographs when you have a negative to print

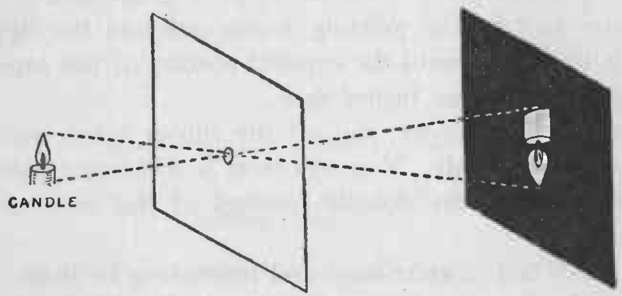


FIG. 176.—The image of a candle flame may be produced on a screen by letting light rays pass through a small hole in a piece of cardboard.

from. It is also a very simple matter to make a photographic negative of any object which you may desire. This is accomplished by means of a camera. A camera consists of a dark chamber (the word camera by the way means *chamber* in Italian), a lens in front and a sensitive plate or film at the

back. The plate or film is covered with chemicals which change when they are exposed to light.

You may have often heard that taking a good picture "is all in the lens," but as a matter of fact it is not all in the lens, and you can take a very good picture with a camera which has no lens at all.

The first thing required in order to make a photograph of an object is an image of the object on the sensitized paper or plate. It is easy to form an image of a leaf by placing the leaf against the paper and letting the light shine through it, but you could not do that if you wanted to make a photograph of a house or of a friend. Another method is necessary and it is a very simple one.

It is only necessary to take advantage of that which we have already learned, that is, that light rays travel in straight lines.

When rays of light pass into a dark chamber through a small opening and are received upon a screen, they form an image of the external object which the rays come from.

You can try this experiment for yourself. Take two sheets of cardboard about the same size and make a small round hole about one-sixteenth of an inch in diameter in the centre of one. The hole should be round and the edges sharp and clean. Prop the piece of cardboard with a hole in the centre in a vertical position and place a lighted candle in front of it, a few inches away. Hold the other piece of cardboard in back of the piece with the hole in it and a few inches away. If you perform this experiment in a dark room you will see an image of the candle and the candle flame in an inverted position on the second piece of cardboard.

This is very easy to understand if you will refer to the illustration. Consider a ray of light traveling from the top of the candle flame to the hole in the cardboard. When it reaches the cardboard, it keeps right on going in the same straight line and hits the screen. A ray of light from the bottom of the candle does the same thing and inasmuch as the rays must travel in a straight line, they cross each other at the hole in the cardboard and form an inverted image.

In this simple experiment you have illustrated the principle of the camera and of the human eye.

The eye is nothing but a dark chamber having a small opening in front closed by a transparent lens. The light rays

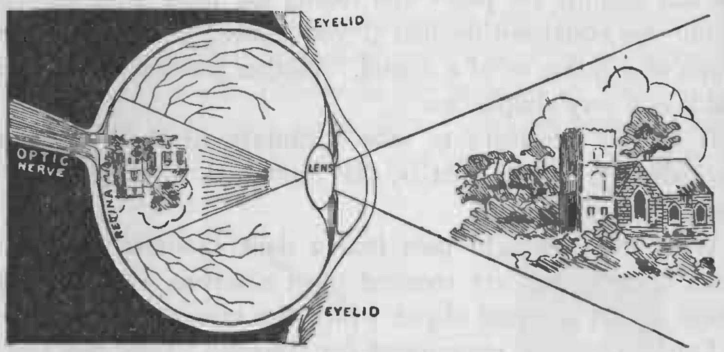


FIG. 177. — A diagram of the eye showing how rays of light pass from an object, pass through the lens in the eye and form an inverted image on the retina or screen at the back of the eye.

from any object which we look at travel to the eye in a straight line crossing at the opening and forming an inverted image on the screen or *retina* at the back of the eye. The rays of light stamp themselves upon the retina of the eye and the optical nerve carries them to the brain. *The image in the eye is upside down.* What happens in the brain, no one knows, but the brain receives the image with the right side up.

A camera is merely sort of a mechanical eye and you can take a very good picture with nothing but a box, a photographic plate, and a *pinhole.*

A photographic plate covered with chemicals which are sensitive to light like those on the blue-print paper is placed in the back of a box. A small hole in the front of the box allows the light rays to enter and form an inverted image on the plate of an object which is in front of the opening. A white object like the face or collar sends a strong white light into the plate and changes the chemicals which it finds there. Dark objects, such as the shoes, do not send such strong rays and therefore

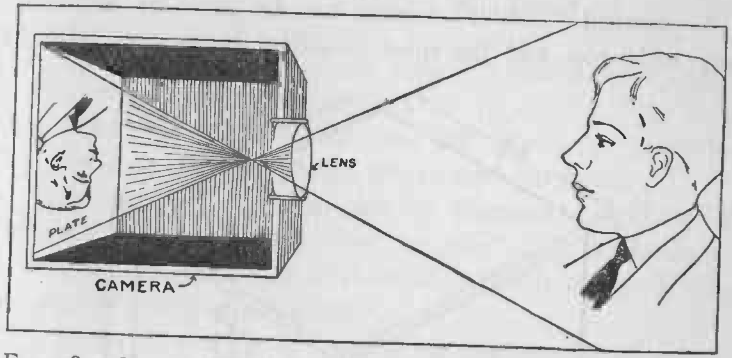


FIG. 178. — The principle of the camera is very similar to that of the eye.

the chemicals on the plate struck by those rays are not so greatly affected.

After the plate has been exposed, it is merely necessary to take it out and place it in a chemical solution which will dissolve the chemicals on those portions which have not been strongly affected by the light. This is called *developing* the negative. After the negative has been developed it is placed in a *fixing* bath which prevents the light from ever again having any effect on the plate. The plate is called a negative because those parts which were white in the object are black on the plate and those which are dark on the object are white on the negative.

The finished negative is laid on a piece of sensitive photographic paper and printed in the sunlight in just the same manner as you made the prints of the leaves. The dark spots on the negative come out white on the print and the white places dark so that the finished photograph looks just like the original object from which it was made.

How to take a Picture with nothing but a Box, a Plate, and a Pinhole.

A practical "pinhole" camera can be made by any one at very little cost and the most beautiful pictures of still life,

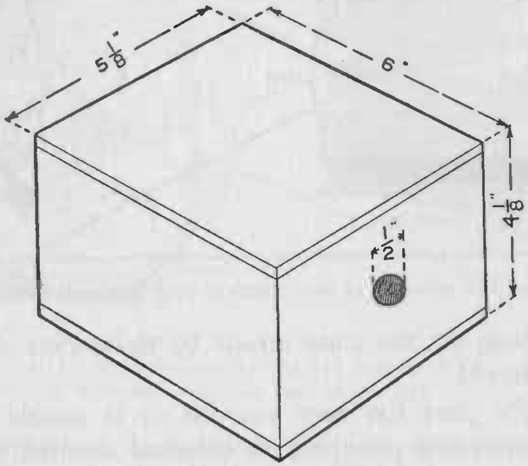


FIG. 179. — The box of the pinhole camera viewed from the front. The copper disk bearing the pinhole is placed over the hole in the front of the box.

landscapes, etc., rivaling the work of the greatest artists, made with very little trouble.

All the fine details produced by a camera provided with an expensive lens do not appear but the pictures are more like the brush work or etchings of an artist who would not think of drawing all the endless small things.

All that is necessary is a perfectly light-tight box which will exclude all the light rays except those which come through a small hole provided in the front.

The box may be built of cigar-box wood and should measure five and one-eighth by four and one-eighth by six inches inside. Glue four strips of cigar-box wood around the inside and one-quarter of an inch from the edge of the opening at the back. These strips are for the photographic plate to rest against. The back of the camera is made of two pieces of cigar-box wood, one being of the same size as the outside dimensions of the box and the other five and one-eighth by four and one-eighth so that it will fit snugly into the box.

The whole box, both inside and out should be painted a dull black with some lampblack mixed with turpentine.

A hole about one-half an inch in diameter should be cut in the centre of the front. The "pinhole" is to be cemented over this hole on the inside of the box so that it will be directly opposite the centre of the plate.

The secret of success in making the camera lies in making the box light-tight and in the perfection of the pinhole. The pinhole is really a "needle hole" because it is made with a No. 10 needle in the centre of a disk of very thin sheet brass or copper about one inch in diameter.

The hole must be as nearly perfectly round and as smooth as it is possible to make it. The burrs can be removed with a piece of very fine emery paper. Blacken both sides of the disk with the lampblack and turpentine before cementing it in place.

A little cardboard disk should be arranged so that it can be swung down over the pinhole to act as a simple shutter to exclude the light before and after exposure.

Purchase some 4 by 5 film pack, i.e. cut film, and load your camera in a dark room with the aid of a ruby lamp.

You will find that one surface of each piece of film is glossier than the opposite side. The duller side is coated with light-sensitive chemicals. Place a piece of film in your camera with the sensitized or dull side toward the pinhole opening. Put the back of the camera in place and secure it with two rubber bands. Then seal the back of the camera all the way around with gummed tape so that there is no danger that any light will leak into the camera from the back and "fog" the film.

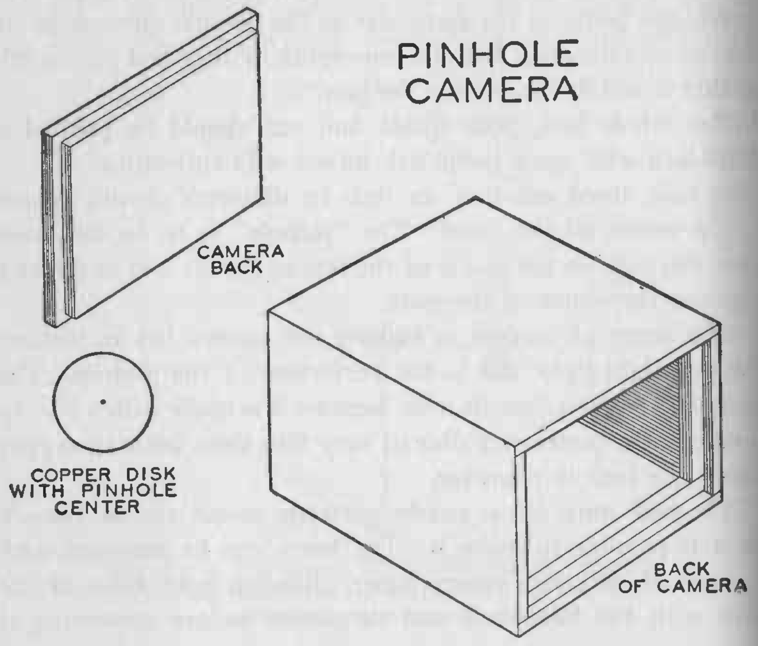


FIG. 180. — Details of the pinhole camera.

When taking a picture, the sun should be at the back of the camera so that it shines on the objects to be photographed. The camera must be placed on a solid and level foundation so that it will not move during the exposure.

Open the shutter and expose the film for about one minute, providing the sun is shining brightly. When the minute is up close the shutter. You can then take the camera back to your dark room and place the exposed film in a light-tight box and load your camera with fresh film. It will be well to make a test three different times, taking a photograph of the same object with the camera in the same position each time. Expose the first film about one minute, the second a minute and one-half, and the third for two minutes. These trials will give you a working basis for the proper time to expose film in the future.

You can have the films developed by a photographer or do the work yourself. The directions which come with the film tell the proper chemicals to use. The method of developing is so well known and so ably treated in many little booklets which you can obtain at a photographic store that it is not necessary to give it here.

If you will not let a few possible poor results upon your first attempts discourage you, the charming photographs which you will soon be able to obtain with your "camera without a lens" will well repay your time and trouble.

If you desire to be able to tell beforehand the extent of the view which will be included in your picture you can accomplish this by drawing a line from a point directly over the pinhole on the top and side of the box to each edge of the plate. By sighting along these lines, the angle of the view can be determined at a glance.

OPTICAL ILLUSIONS

Can We Always Believe Our Eyes?

The human eye is far from being perfect. Some people cannot see objects which are close to their eyes as well as they can see those objects which are farther away. Others see objects which are close to their eyes the best. The first kind of an eye is said to be "long-sighted" and the other "short-sighted." These defects are due to the eye being too long or too short along its axis so that the image is formed in front or behind the retina. Using "glasses" which are nothing more than properly shaped lenses to suit each particular eye, remedies

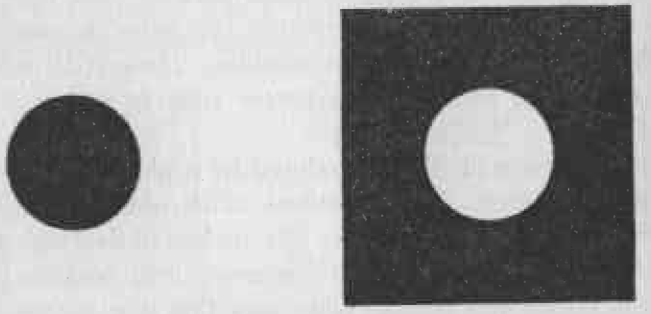


Fig. 182. — If the white circle in the center of the black square appears larger to your eyes than the black circle in the center of the white space, measure and see if there is any difference.

this trouble by helping the eye to form the image in the proper place on the retina.

Other people who have perfectly normal eyes in every other respect are unable to distinguish certain colors and are said to be *color blind.*

There are a host of other defects of vision and that is why so many people nowadays wear glasses. Aside from these cases where there is actually something wrong with the muscles, nerves, or size and shape of the eye, every normal eye does not see things as they actually are as has already been explained in several instances in the foregoing pages.

Even though you may have to wear glasses, your eyes can be easily fooled by an *optical illusion.* Most optical illusions are due to a strange happening called *irradiation,* which causes

white objects or those of a very bright color to appear larger than they really are when seen on a dark background. Thus a white ball or a white square on a black background seems much larger than an exactly equal ball or square on a white background.

Thus when white and black have an equal chance, the white subdues the black because the white is *light* and black is *absence of light.*

When we see a light object against a dark background, it

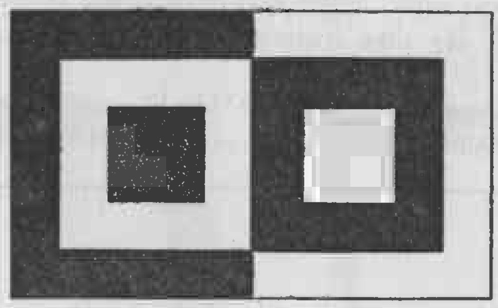


Fig. 183. — Here is another trick which the phenomenon called irradiation plays on our eyes. No matter how they appear, the corresponding white and black squares are the same size.

is really only the light that we see. A dark thing is seen only by contrast with the light around it.

When the retina of the eye is excited by light, the effect of the light spreads a little all around the edge of the image. It is as if the light at the edge radiated sideways a little bit.

When we look at the white circle in the centre of the black background or the white paper surrounding the black ball in Figure 182, a little of the effect of the white light is felt on the retina of the eye, on the part where there is really no image and so the white appears larger than it really is.

Irradiation is therefore due to the fact that the impression produced on the retina by a white object extends beyond the outline of the image.

For that reason a luminous body looks larger than a dark one of the same size and shape. A red-hot wire or the white-hot filament of an electric lamp appear much larger than when cold.

One of the most common instances on which our eyes are fooled by irradiation is when we look at the stars, for they actually appear much larger than they would if we could see them in the day time without a black background, of the dark sky.

Did you know that there is a "blind" spot in both of your eyes at the point where the optic nerve enters the retina? You

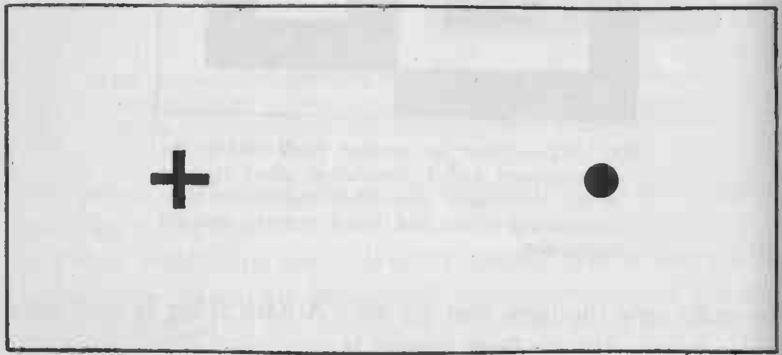


Fig. 184. — Close your left eye and look at the cross. Look only at the cross and bring the page of this book closer to the eye. You will find that the black dot disappears.

can prove this by closing your left eye and looking at the cross in Figure 184. You will probably see both the cross and the dot but if you try to look only at the cross and bring the page closer to the eye, at a certain point the dot will disappear. Bringing the page still nearer to you will draw the spot into

view again. If you reverse this experiment and look at the dot, with the right eye closed you will find there is a certain point at which the cross will disappear.

The illustrations in Figures 182 to 191 are optical illusions showing some of the comparatively simple ways in which the eyes are fooled.

The Persistence of Vision

Why Spinning Lights Make Rings. When a lighted lantern or the burning end of a stick is whirled rapidly around in

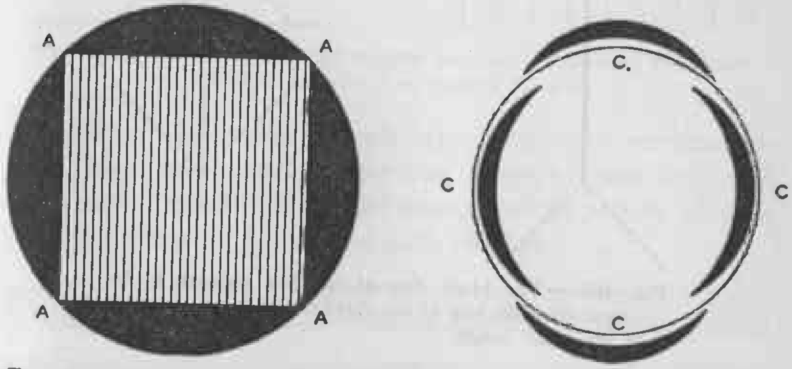


Fig. 185 — The circles AAAA, and CCCC are perfectly round but the left-hand circle appears flat at the points AAAA and the right-hand circle appears egg-shaped.

the dark we cannot distinguish the lantern or the end of the stick but see a continuous circle of fire. This is due to the fact that when an image is produced on the retina of the eye, the impression remains there for about one-twentieth of a second. We therefore see things for a short time after they have moved from before our eyes or we have ceased to look at them. If, after having looked at a brightly illuminated window for a few seconds, the eyes are suddenly closed, the image will remain for a short time and you can still see the window. Try it. This phenomenon of the eye is called

The Persistence of Vision and is another example of how our eyes easily deceive us. That which appeared to be a circle of fire is really only a lantern or spark being whirled around. The reason that we see the circle and not the lantern is because

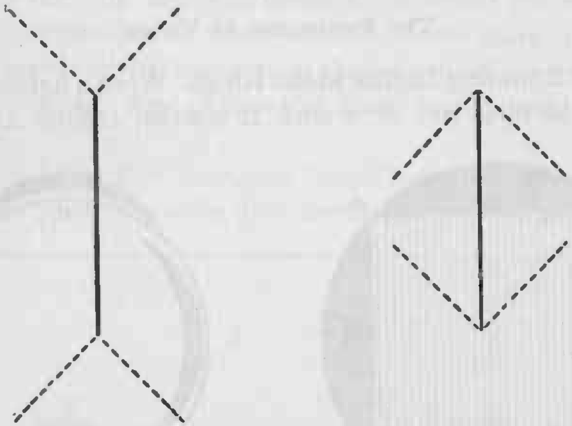


FIG. 186. — The black line at the left appears to be longer than the line at the right but they are actually of the same length.

it is moving so rapidly that the image of it in each separate position as it moves around in the circle does not have time to fade away in our eye and all the separate images are blurred together in a circle.

We can often learn much from our senses when they deceive us, and if our eyes did not make us believe that we see things for a tiny fraction of a second after they are gone we should not be able to enjoy moving pictures.

Moving pictures are made with a camera which takes separate pictures on a long film at the rate of twenty to forty a second. If the object which is being photographed is moving, each pic-

ture shows a slightly different position or view. After the pictures have been developed and printed they are run through a sort of stereopticon which projects them on the screen in rapid

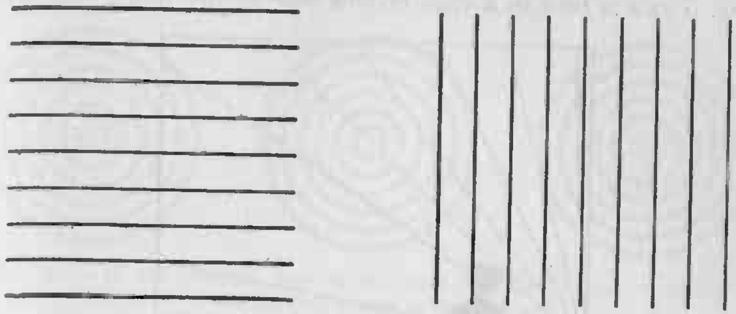


FIG. 187. — The two groups of straight lines appear to form rectangles but they actually form perfect squares.

succession. The image of each separate picture remains impressed just long enough for the next picture to come along, and so they are blended together and appear like one picture which is moving, instead of a lot of separate pictures.

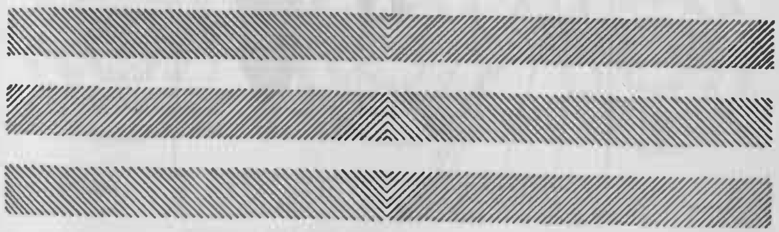


FIG. 188. — The groups of lines appear to be closer together at the ends than in the center. Lay a straight-edge along them and see if your eyes are deceiving you.

Figure 192 illustrates an interesting experiment based on the ability of the eye to retain an image. A black star is drawn on a blank card glued in a slot in one end of a round stick. When the card is rapidly spun by rolling the stick between the palms of the hands, the star will change into two circles, one gray and one black.

Another form of this same experiment is shown in Figure 193. Draw a bird in a cage on one side of the white card and

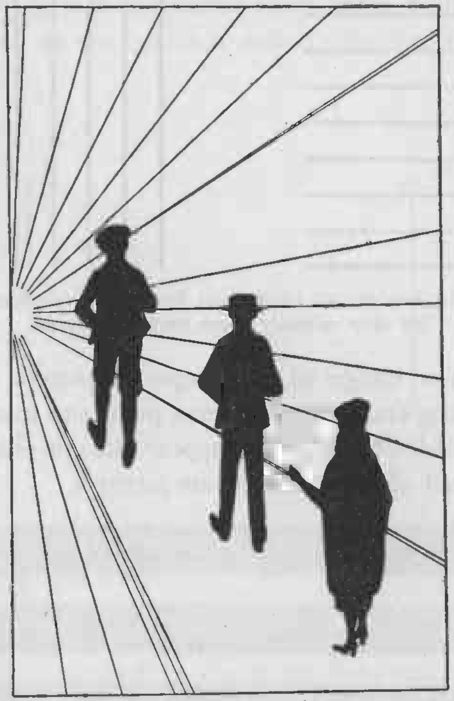


FIG. 189. — All three figures in the sketch above are the same size but the converging lines produce an illusion in which the figure in the distance appears to be taller than the others.

set in one end of a round stick. Draw another bird on the backside of the card. Spin the card rapidly by rolling the stick between the palms of the hands and two birds will be seen in the cage.

You can illuminate the principle of moving pictures by means of the magic wheel shown in Figure 194. Figures in different poses of arrested action are pasted or drawn around the edge of a cardboard disk.

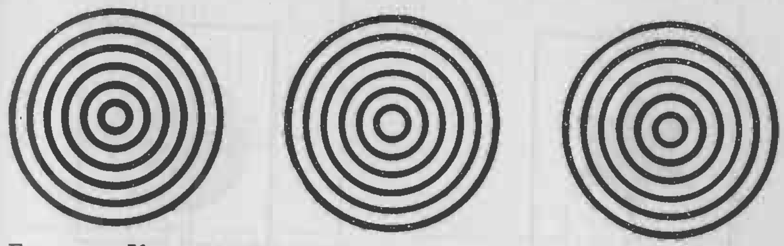


FIG. 190. — If you give the page of this book a slight circular motion, the circles will appear to revolve.

Under each figure is an oblong opening or slot. A pin is stuck through the centre of a disk into a wooden stick so that the side of the disk can be revolved in front of a mirror. If you hold the side of the disk on which the figures are drawn towards

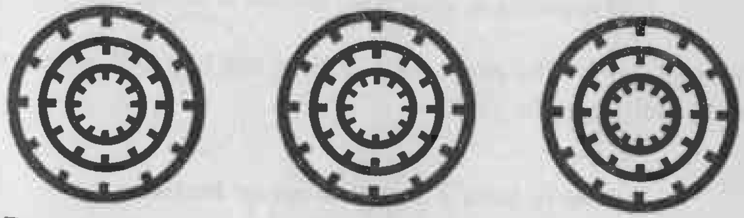


FIG. 191. — Give the book a slight circular motion and the cox-wheels will revolve slowly.

the mirror and then look through the slots, the figures will appear in sections, like moving pictures.

Figure 196 shows twelve different positions of a boy jumping rope. If you trace these with a pen and ink upon tracing paper, you can cut them out and paste them on a cardboard disk about six inches in diameter and make your own magic wheel. The figures should be set at equal distances around the disk and at the same distance from the centre. Cut the slots directly underneath each picture. Fasten the disk to a stick by means of a pin passing through the centre on which it can freely turn. When you spin the disk before a mirror and look

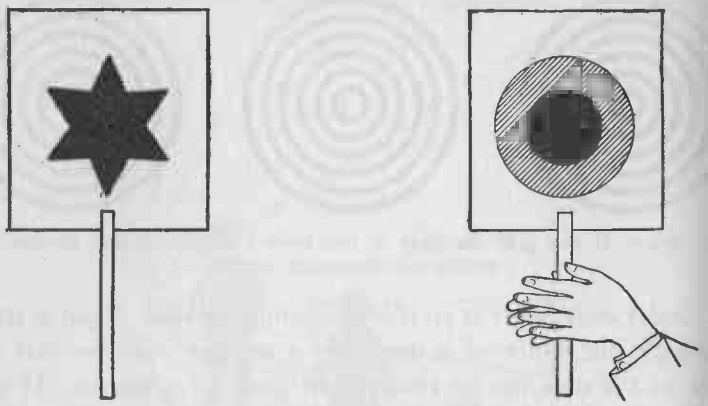
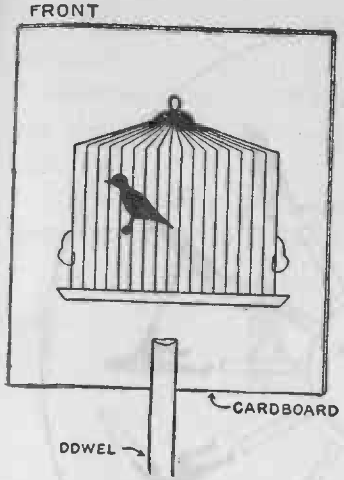


FIG. 192 — The black star on the card at the left appears like a black-and-gray circle when the card is twirled.

through one of the slots, the figure of the boy will appear to move and jump the rope.

How to build a Reflectoscope or Projector

We can put the knowledge which we have now gained about reflection and action of a lens to good advantage in making a "reflectoscope" with which it is possible to magnify the pictures cut from magazines or on post-cards and project them on the wall or a white screen like stereopticon pictures. Unlike the stereopticon or "magic lantern" you will not have to use prepared slides for your reflectoscope but the post-cards and photos which your friends have sent you or which you may have collected on your vacation can be thus



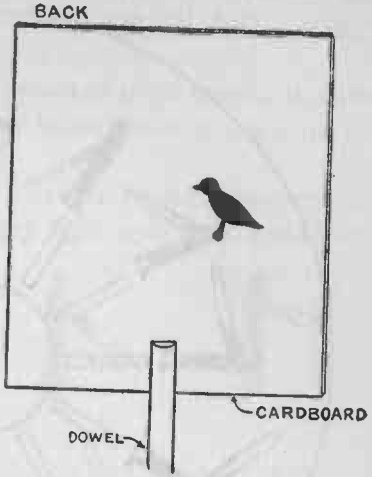


FIG. 193. — The persistence of vision will cause two birds to appear in the cage when the card is twirled.

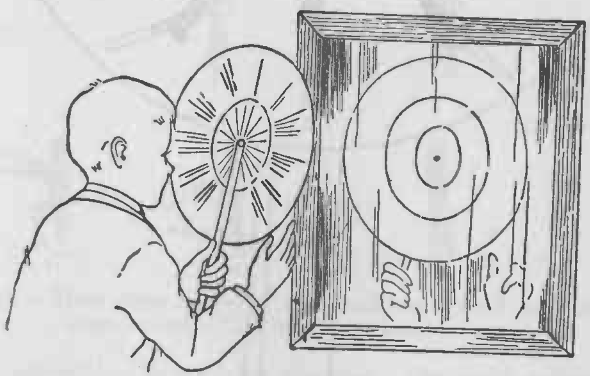


FIG. 194. — Use the magic wheel in front of a mirror. Look through the slots at the reflection in the mirror.

magnified to three or four feet in diameter and shown in all their natural colors.

You will not tire of this sort of a lantern because you can always easily get new pictures for it. Any pictures or object

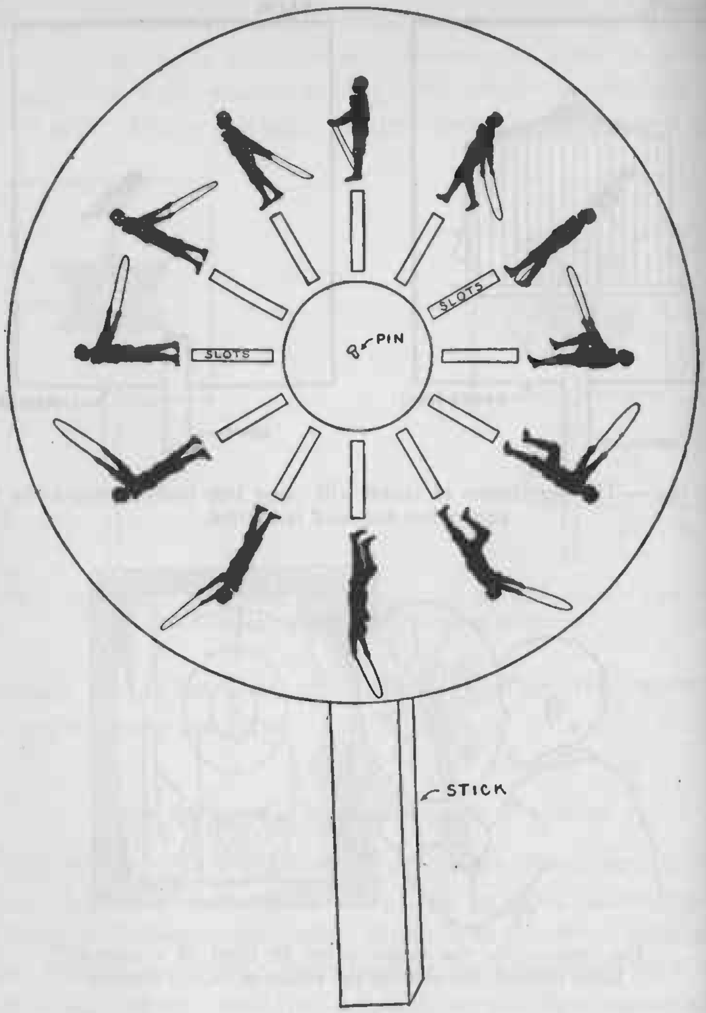


FIG. 195. — The magic wheel.

such as your watch, bugs, butterflies, flowers, etc., placed in the back of the lantern will appear on the screen greatly magnified. You will be surprised to see how huge a fly will appear

if you put one inside and he walks across the back of your lantern.

The completed Reflectoscope consists of a rectangular wooden box about ten inches long, seven inches wide and six inches high.

The principle is quite simple. The box contains two electric lamps arranged to throw a strong light upon any picture or

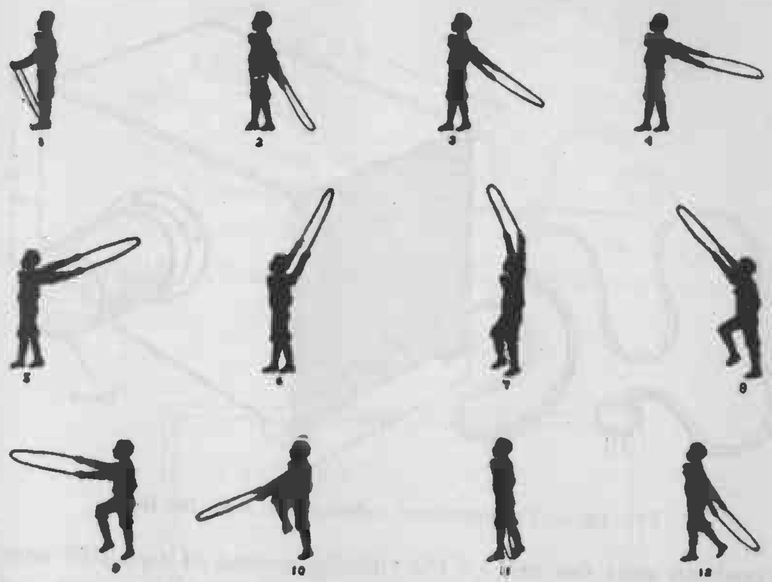


FIG. 196. — Trace these figures or make new ones of the same sort for the magic wheel. Place one figure beneath each slot.

object placed in the back of the box. The light reflected from the picture or the object then passes through a lens and the light rays are projected on the screen greatly magnified.

The methods of making a wooden box are too simple to need explanation. Care should, however, be taken to make the box light-tight so that no light can escape through any cracks when the lamps are placed inside.

You may be able to obtain a lens for the reflectoscope from an old bicycle lantern. A lens which is polished on both sides, of the double convex type and about two and one-half inches in diameter will serve the purpose the best.

Make a tube by rolling up a piece of sheet tin and soldering the edges together. The tube should be of just the right size so that the lens will slip in tightly. The lens should be held in

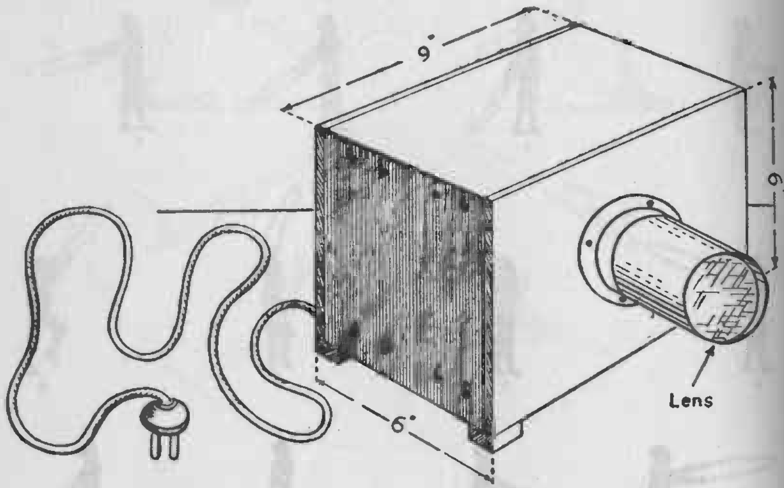


FIG. 197. — The completed reflectoscope from the front.

position near one end of the tube by means of two stiff wire rings which are springy and tend to open against the sides of the tube. It is a good plan to solder one of the rings inside of the tube so that it cannot move and then put in the lens. The other ring can then be pushed down against the lens and should hold it firmly.

Make a second tube out of tin, about three inches long and of such diameter that it will just slip over the first.

The back of the box is provided with a rectangular opening about six inches long and four inches high. The opening is

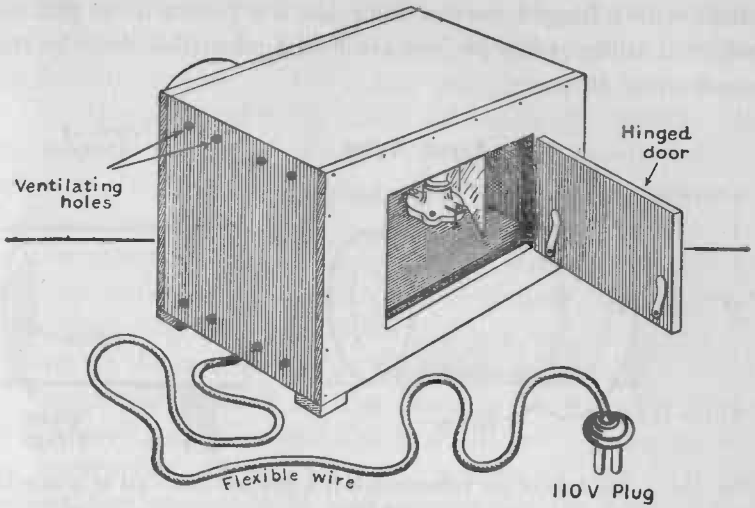
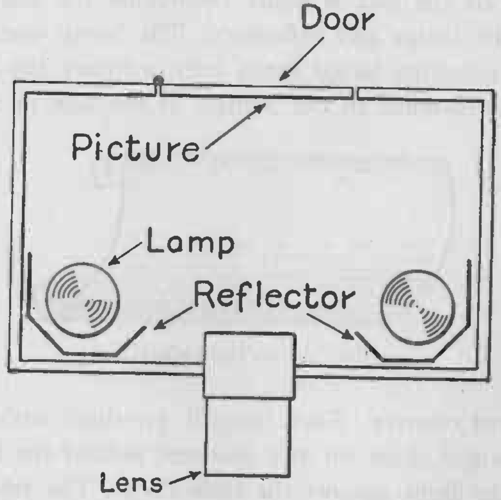


FIG. 198. — Back view of the reflectoscope with the door open.



FIR. 199. — Top view of the reflectoscope with the cover removed to show the interior arrangement of the lamps and reflectors.

fitted with a hinged wooden door and the postcards or pictures which it is desired to project are held against this door by two small metal strips.

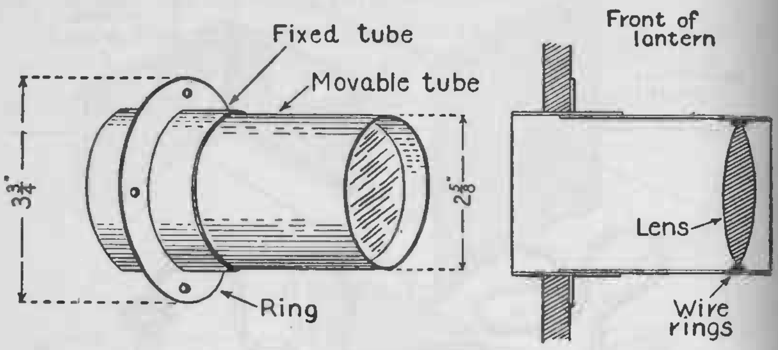


FIG. 200. — The lens of the reflectoscope is a double-convex set in a movable tin tube.

The top of the box is made removable for convenience in fitting in the lamps and reflectors. The lamps consist of two sixty-watt tungsten lamps fitted into ordinary flat-case porcelain sockets fastened to the bottom of the box in each of the

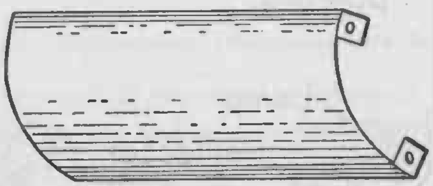


FIG. 201. — The reflector.

two forward corners. Each lamp is provided with a reflector made of bright sheet tin and fastened behind the lamps so as to throw the light against the little door. The reflectors may be held in place by screws passing through small tabs at the bottom.

The interior of the box, with the exception of the surfaces of the reflectors next to the lamps should be painted a dull black with a mixture of lamp black and turpentine.

The current is led to the lamps by means of a flexible wire passing through the bottom of the box and provided at the other end with a plug which can be screwed into an electric light socket.

The reflectoscope must be operated in a dark room and the pictures projected on a white wall or a sheet. The movable tube containing the lens must be slid back and forth until the picture on the screen becomes clear and distinct.

The proper distance for the reflectoscope from the screen will depend upon your lens and you will have to discover this by experiment. If you place the lantern too far from the screen, the image will be much larger but the light will be faint and the edges will be blurred.

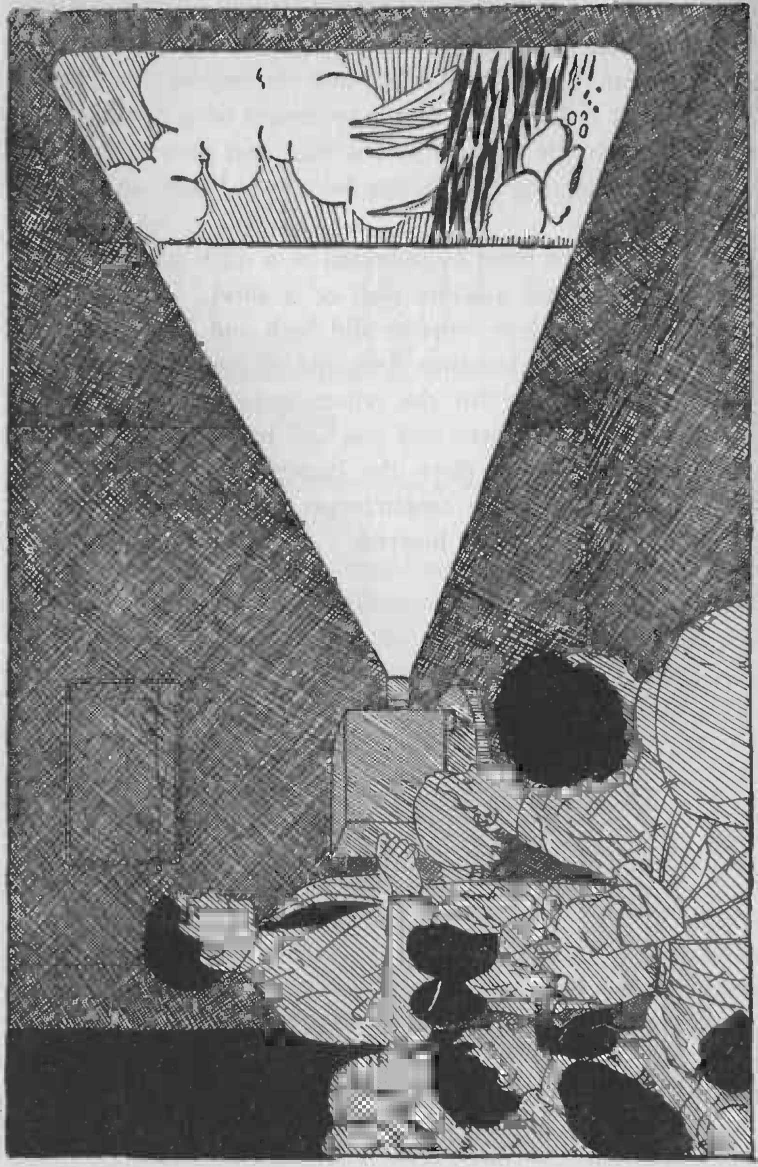


FIG. 202. — The reflectoscope in use.

CHAPTER VIII

ELECTRICITY

ELECTRICITY is perhaps the most powerful and the most mysterious force in the world.

What is electricity?

That is quite naturally the first question which you will wish to have answered. But I am sorry to say that no one really knows. Many learned scientists have offered explanations but they only have told us what they *thought* electricity might be.

It is almost impossible to define electricity and explain what it is in any manner except that which would only be understood by a trained scientist. Our knowledge of this subject has all been gained in recent years, and we can only secure a somewhat complicated explanation which cannot really be proved.

If you want this explanation, I will give it to you in the simplest possible words.

Electricity is the name given to an invisible agent known only to us by the effects it produces. It appears to be distributed uniformly throughout all space and the modern scientist considers it to be composed of immense numbers of exceedingly minute quantities, each such quantity being called an *electron*.

Perhaps, however, we really do not need to concern ourselves with what electricity is and had better not try to understand, but pass on to some of the wonders of this unknown agent, for much is known about the rules and laws which it obeys.

We can produce it at will and use it so as to make it our servant. It is easy nowadays to push a button or turn a knob and so light up a room. Electricity moves many of our trains and produces many wonderful chemical substances. By its means, we can talk to one another when three thousand miles apart or even to the pilot of an aeroplane far away in the sky. Electricity has multiplied the strength of man a billion times. The tasks of Hercules would now be but chores which could be accomplished by the closing of a switch. Mighty rivers go roaring through intake and turbine to drive the dynamos which in turn drive the wheels of the industries of a distant city and turn the night into day. A list of the feats of this wondrous power would be almost endless.

The name *electricity* is also given to that branch of science which deals with the phenomena of electricity and the laws and theories concerning it.

For a long time, it was thought that there might be different kinds of electricity because it acted differently at various times. Later discoveries, however, showed that electricity sometimes moves and sometimes stands still and that the properties of electricity when moving are very different from those of electricity when it is at rest. Furthermore, not only does electricity sometimes move but it moves in different manners. It may be classified according to its motion, as:

1. **Static Electricity,** or electricity at rest.
2. **Magnetism,** or electricity which is rotating.
3. **Current Electricity,** or electricity which is in steady motion.
4. **Electric Waves,** or electricity which is vibrating.

These four branches of electricity are very closely connected. The object of this chapter is to give the young experimenter a little knowledge of the main facts of these, and an explanation of their simpler relations to one another.

Static Electricity

Static Electricity, was the first known to man and was probably discovered many thousands of years ago when it was observed that a piece of amber which has been rubbed possesses the power of attracting to itself such light bodies as dust, chaff, etc. A Greek philosopher named Thales, mentioned this in his writings, 2500 years ago. The Greek word for amber is *elektron,* and from this is derived our word electricity.

The electricity which appears on amber when it is rubbed is produced by *friction.* How or why friction produces electricity is hard to explain but nevertheless a great many substances do generate *static* electricity when subjected to friction under the proper circumstances.

For a long time only amber and jet were known to have this power but about the year 1600, an English professor by the name of Gilbert, discovered that a very large number of substances, such as diamond, glass, sulphur, sealing-wax, resin, etc., would produce static electricity when rubbed and so he called these substances *electrics.*

Some of the methods which various scientists used in uncovering the secrets of electricity were far from complicated and any boy can try them for himself. It was by means of some such simple pieces of apparatus as are described below that great scientists and inventors came to understand the mysterious powers that now make possible the telephone, telegraph, dynamo, electric railway, etc.

All experiments with static electricity result better in the winter time when the air is cold and dry than during damp weather or in the summer. Cold air is much drier than warm air. Summer air contains considerable moisture and water vapor. Water vapor is a partial conductor of electricity and damp air conducts static electricity away from your apparatus as fast as it can easily be produced.

A simple method of generating static electricity is by shuffling or sliding your feet over a wool carpet. The friction generates and charges the body so that if the tip of a

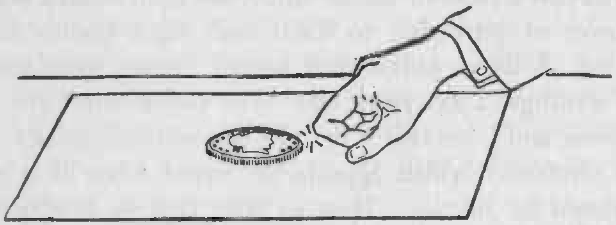


FIG. 203. — An experiment which produces static electricity.

finger or the knuckles are brought near to another person or to some metallic object such as a gas fixture or a radiator, a snapping little electric spark will jump across. This experiment will only be successful in the winter time. A pair of slippers with thin leather soles are better than shoes on the feet for this purpose.

There are many other ways of producing electricity by friction. Have you ever noticed a crackling and snapping sound when combing your hair with a black rubber comb? If you had looked in the mirror at the same time, you would have noticed that your hair was trying to stand up all over your head instead of lying down flat. Here is the explanation. The ebonite comb is rubbed by the hair and becomes electrified by friction. The comb rubbing against the hair also electrifies the hair. Later, we shall learn the reason why the hair stood

up instead of lying down. The little crackles you heard were the sounds of electric sparks which jumped between the comb and the hairs.

Now, let us try some other experiments. If the day is cool and dry so that everything outside is frozen hard, take a large sheet of ordinary writing paper and warm it for a few minutes near a fire. Then lay it on a flat table and try to lift it up by one corner. You can probably lift it easily and it will slide along the table if you give it a little push. But smooth it out flat on the table again and rub it briskly with the hand or with

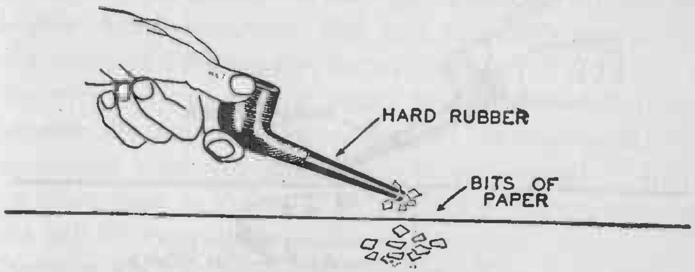


FIG. 204. — Rubbing a hard rubber pipe-stem with a piece of flannel will electrify the rubber so that it will attract small bits of paper.

a warm, dry clothes-brush. Try to lift the paper. It acts differently. It will stick to the table and will not slide along easily as it did at first. If you raise one corner and try to lift the paper off the table it will tend to cling to the hands and the clothing. If held close to the face it will produce a tickling sensation. If you place it against the wall it will cling fast. Why is this? Rubbing the paper electrified it.

It is even possible to secure sparks from an electrified paper. Warm a large sheet of stiff paper until it is thoroughly dry, lay it flat on a wooden table, and then rub it very briskly with a piece of warm flannel or woolen material so as to electrify it. Then place a piece of metal, a bunch of keys, or a silver dollar in the centre and lift the paper off the table by two opposite corners. If some one else quickly puts his fingers to the metal a bright spark will jump out to meet it.

There are other substances which will electrify more easily than paper. A glass rod, a stick of sealing-wax, or a piece of hard rubber is a better *exciter* of electricity. Fountain pens and most black hair combs are made of hard rubber and will easily become electrified.

Rub a piece of glass rod, sealing-wax, or a fountain pen,

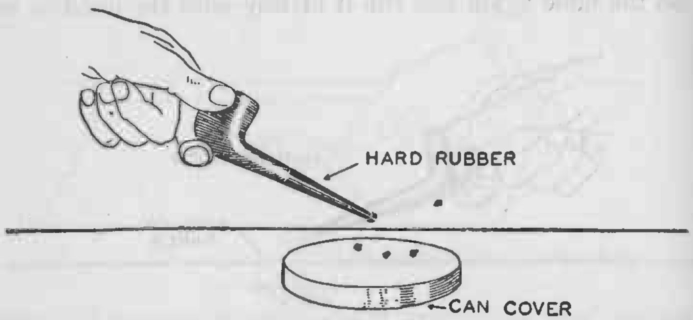


FIG. 205.— The apparatus used in the experiment illustrated above comprises an electrified pipe-stem, can cover, and some fragments of charcoal from a burnt match. The experiment shows the repulsion which takes place between two objects charged with the same kind of electricity.

whichever is the most convenient, briskly with a piece of warm flannel. Then hold it near some tiny scraps of paper and it will pick them up. You will sometimes find that after the pieces of paper have been picked up by the attractive power of the electricity they will suddenly fly off and cannot immediately be picked up again.

This is because the little pieces of paper have received a charge of electricity from the rod, and when *two electrified bodies are charged with the same sort of electricity, they repel one another.*

You have now had several opportunities to observe the **Electrical Attraction** between an electrified body and one which is *neutral,* that is, does not bear a charge of electricity, such as the bits of paper before they touched the rod. If you have been observant you may have noticed the

Electrical Repulsion between two objects charged with the same kind of electricity, as the rod and the bits of paper after the papers have touched the rod, shown in the last experiment.

You can illustrate this electrical repulsion in a little better manner in the following way. Burn an ordinary match stick until it is charred all the way through. Break up the remaining substance, which is carbon, into very small bits and lay them on the cover of a baking-powder can.

Electrify the rod with a warm flannel cloth and bring it down over the bits of carbon on the can. As soon as the rod is close enough they will jump up to it but instead of sticking for a short time as did most of the bits of paper, the carbon pieces will fly away again as fast as they can.

Positive and Negative Electricity. There are two kinds of static electricity, just as you will learn later there are two kinds of poles to a magnet. They are called *positive* and *negative* electricity. If two bodies are charged with these opposite kinds of electricity, one being negative and the other positive, they will attract one another just as the two different poles of magnets attract each other.

A glass rod rubbed with *silk* produces *positive* electricity and sealing-wax or hard rubber rubbed with *flannel* gives negative electricity.

An Electroscope is a device for indicating the presence of static electricity and will enable us to see that there are two kinds of static electricity. You can construct an electroscope by making a tiny ball out of the pith in the centre of an elder-berry stick. This pith is very light when dry, and easy to form into a small ball about as large as a pea. If you cannot obtain any elderberry pith, a very small feather or even a tiny piece of cork may be used although they are not so good. Fasten the ball to a piece of silk thread and hang the thread from the end of a wire stuck into the cork in the neck of a bottle as in Figure 206.

Then if you excite a piece of glass rod by rubbing it with a warm silk cloth and hold it near the pith ball, the latter will

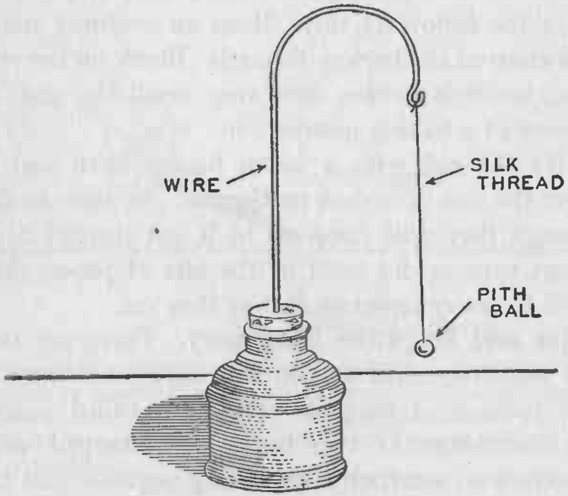


Fig. 206.—An electroscope is a device for indicating the presence of static electricity. A pith ball electroscope consists of a tiny ball of dry pith (you can also use cork) suspended from a silk thread.

be attracted by the rod, but after once touching it, it will fly away and will keep away as long as any electricity remains on the rod. But, if you excite a stick of sealing-wax or a hard-rubber fountain pen by rubbing it with a warm flannel cloth and bring it near the pith ball, the ball will be attracted.

Rubbing the glass rod with the silk charged the rod with

positive electricity. When the pith ball touched the rod it also became charged with positive electricity. Since the ball and the rod were then both positive, the rod repelled the ball. Rubbing the sealing-wax or the fountain pen with the flannel produced *negative* electricity. The negatively charged wax or pen then attracted the positive electricity on the ball.

You can amuse yourself with another form of this same experiment by making a small paper clown as shown in

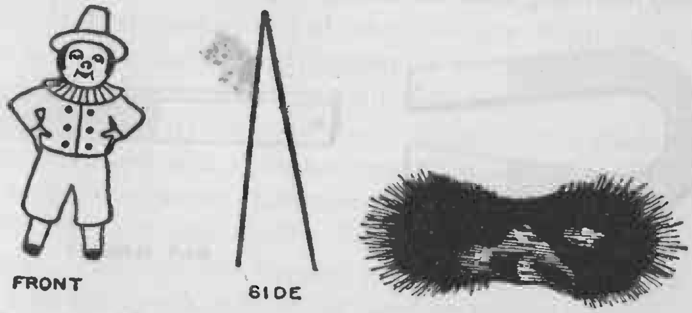


Fig. 207.—The electrical clown is made out of thin paper and should be about the same size as the clown shown above. If a bit of lodestone is dipped into iron filings, the filings will cling to the stone in two tufts which show the location of the lodestone's poles.

Figure 207. Take a piece of paper about three inches long and half an inch wide and fold it across the centre so as to bring the two ends together. Draw a man or a clown on the paper as shown in the illustration and cut it out to shape. Do not cut it at the top but leave it so that the figure is double and will stand up as illustrated.

If you hold a glass rod charged with positive electricity near the clown he will roll over towards it. If you then hold a stick of sealing-wax or a fountain pen charged with negative electricity at the other side he will tumble back that way, and so you can make him roll and slide all around the table.

Magnetism

Scattered over various parts of the earth is found a wonderful ore which has the marvelous power of attracting pieces of iron. Such *magic* power, as this was then deemed, made the ore famous and fabulous stories of huge mountains which would pull the iron nails out of ships, and of large masses of ore which caused strange and terrifying happenings, existed until long after the Middle Ages.

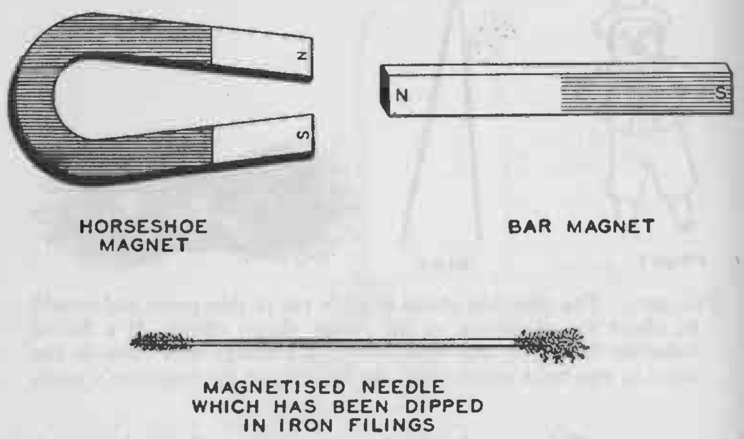


Fig. 208. — A common type of horseshoe magnet and a bar magnet. Iron filings will cling to the poles of a magnetised needle.

This ore is found in quantities in Sweden, Spain, Arkansas and the Island of Elba, also in *Magnesia* in Asia Minor, where it is said that it was originally discovered.

No one knows who first noticed its attractive power. The Greek poet, Nicander who probably lived about two hundred years before Christ tells us that a shepherd named *Magnes* guarding his flocks on the side of a mountain in far-away Asia Minor, one day found small stones adhering to the iron-shod end of his staff. Upon looking farther around about him, he found many other pieces of this peculiar hard black mineral, the smaller bits of which tended to cling to the nails and studs in the soles of his sandals.

The name *Magnet* was thereupon given to these stones, but for many hundreds of years the mineral was of little use to mankind save as a curiosity. Its strange power was a mystery to the superstitious ancients who hardly dared think about it for fear of incurring the anger of the gods.

If a magnet stone is dipped into some iron filings or a pile of small tacks, the iron will gather in two tufts on opposite ends of the stone as shown in the illustration.

When a piece of hardened steel such as a knife-blade or a needle is rubbed with a magnet stone, it will be found to have acquired the properties characteristic of the stone.

The steel will pick up iron filings or tacks and small bits of iron. The steel has become an *artificial* magnet, as it is called to distinguish it from the stone or natural magnet.

Artificial Magnets are those made from steel by the application of a magnetizing force. The principle forms are the Bar and the Horseshoe, so called from their shape. The bar magnet is a straight magnet. The horseshoe magnet is a bar magnet bent into a "U" shape. See Figure 208.

Artificial magnets are very much handier to use and far more powerful than the lodestone. They are an essential part of most magnetos, voltmeters, ammeters, telephones, and countless other electrical instruments.

Small horseshoe and bar magnets can be purchased at toy stores at small cost and can be used to perform a number of very interesting and instructive experiments.

A bar magnet can be made from any hardened piece of steel such as a large darning-needle, file or knife-blade by stroking it with one end of a horseshoe magnet or another bar magnet.

The process of making a magnet in this manner is called *magnetization.*

Try the experiment of making a magnet by stroking a large darning-needle from end to end, always in the same direction, with one end of a bar or horseshoe magnet. Then dip the needle in some iron filings and it will be found that the iron filings cling to the ends of the needle, few if any fastening themselves anywheres near the middle. This experiment thus shows that

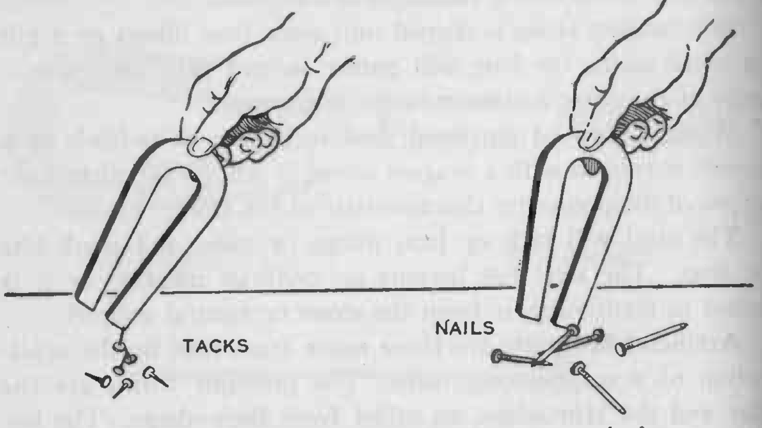


FIG. 209. — An experiment which illustrates magnetic force.

the attractive power of a magnet exists at two opposite places. These are called the *poles.* The poles of the bar and horseshoe magnets shown in Figure 208 are marked *N* and *S*.

Magnetic Force. Place some small tacks on the table and hold the poles of a horseshoe magnet above them. Gradually lower the magnet until the tacks jump up to meet it. Then try some large nails in place of the tacks. The nails are heavier than the tacks and it will require a greater force to lift them. The magnet will have to be brought much closer to the nails than to the tacks before they are lifted, showing that the greatest power of a magnet lies nearest to it.

Magnetic Substances are those which are attracted by a magnet. If you experiment with a number of different materials such as wood, coal, paper, brass, iron, silver, glass, steel, china, etc., and try to lift them with a magnet it will be found that iron and steel are the only ones which are attracted.

Iron and steel are the only substances which are capable of being attracted by your magnet, but if you could experiment with a very powerful magnet you would also find that cobalt and nickel are slightly attracted. Those substances which are not attracted are called *nonmagnetic.*

Magnetic Attraction through Bodies takes place in most cases just as if nothing intervened. You will find that you

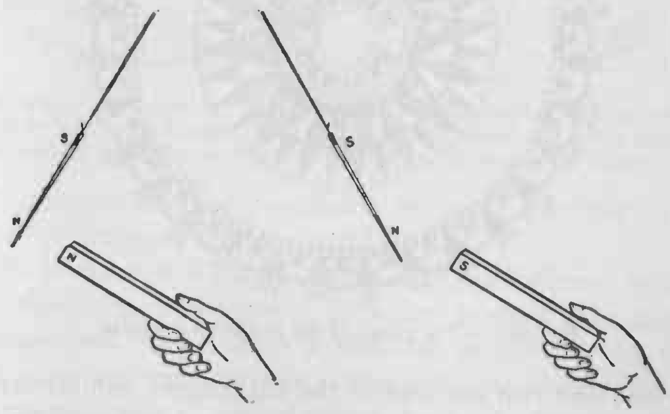


FIG. 210. — An experiment demonstrating that like poles repel and unlike poles attract.

can attract or lift a tack up with your magnet when there is a thin sheet of paper, glass, brass, wood or any non-magnetic substance between the magnet and the tack. Through an iron or steel plate, however, the attraction is greatly reduced or entirely checked because the iron takes up the magnetic effect itself and prevents the force from passing through and reaching the nail.

Magnetize a sewing-needle and hang it from a thread. Bring one end of a bar magnet near the lower end of the magnetized needle. Then turn the bar magnet around so that the opposite end is presented to the lower end of the needle.

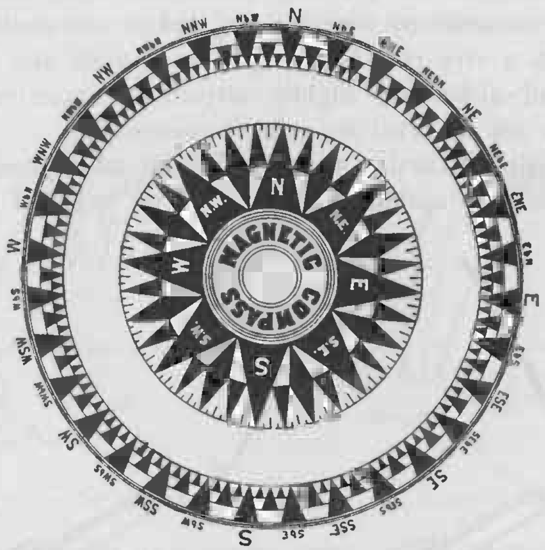


Fig. 211. — The points of the mariner's compass.

You will find that one end of the bar magnet will *attract* the lower end of the needle while *the other end will repel it.* Apparently the two poles of the magnet are *different.*

This fact gives rise to the general law of magnetism which is; *like poles repel each other and unlike poles attract each other* and is the principle of

The Magnetic Compass. You can make a simple compass if you magnetize a needle and lay it on a flat cork floating in a glass vessel filled with water. Remove all other magnets

and iron objects from the immediate neighborhood and the cork will move around until the needle comes to rest lying nearly in a North and South line, with the same end always towards the North.

The pole of the needle magnet which turns towards the north is called the *north-seeking pole* and the opposite end is called the *south-seeking pole.* These names are usually abbreviated to simply the north and south poles. The north pole

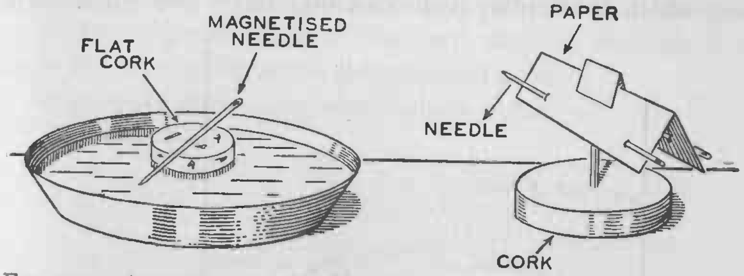


Fig. 212. — A magnetised needle lying on a cork floating in a saucer of water will come to rest in a north and south position. Another method of making a simple compass is illustrated in the right-hand sketch.

of a magnet is usually indicated by a straight line or the letter *"N"* stamped into the metal.

The sketches in Figure 212 and 213 show different methods of making simple compasses. The first method is to suspend a magnetized needle from a fine silk fibre which has been split from a piece of thread. The adjoining sketch shows a bar magnet lying in a small stirrup bent out of wire and suspended from a thread so that it is free to swing. The third method illustrates a very simple compass made from two magnetized needles passing through the opposite sides of a paper support. The north poles of both needles should be at the same end. The paper support rests on a pin stuck into a cork. The details of the arrangement can be seen in the illustration.

The Modern Mariner's Compass is quite an elaborate affair when compared to the simple arrangements just described but its principle of operation is just the same.

It consists of three parts, the *bowl*, the *card*, and the *needle*. The bowl, which contains the card and the needle, is a hollow brass hemisphere, supported in a pair of brass rings called gimbals, in such a manner that the bowl will remain horizontal no matter how violently the ship may pitch and roll. The card, which is circular, is divided into thirty-two equal parts,

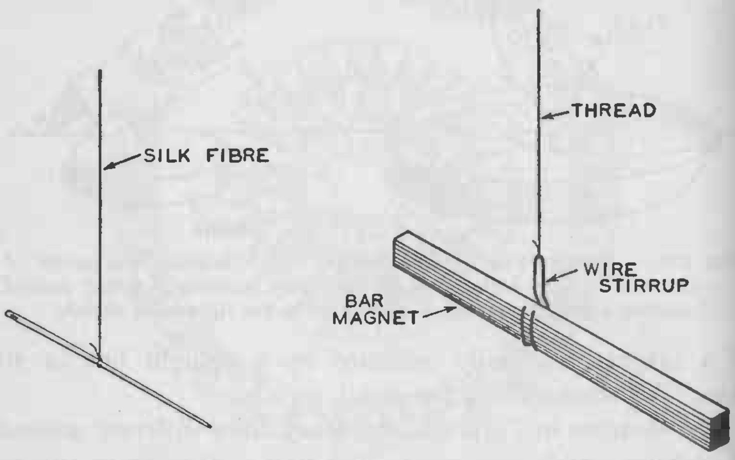


FIG. 213. — Two methods of making simple compasses by suspending bar magnets from threads. The bar magnet at the left is a magnetised sewing-needle.

called the points of the compass. The needles, of which there are usually several, are attached to the bottom of the card. In the centre of the card is a conical socket, delicately poised on an upright pin fixed in the bottom of the bowl, so that the card may freely turn.

You may wonder what it is that causes the compass needle to turn and always assume the same position, that is, pointing North and South. This is because

The Earth is a Great Magnet and its action on the compass needle is exactly like that of the bar magnet upon the magnetized needle hanging from the thread. The northern end of the earth is one pole of the earth magnet and attracts the north-seeking pole of the compass needle. The opposite end of the earth attracts the south-seeking pole of the needle.

The direction assumed by the compass needle is called the *magnetic meridian* of the earth. The compass needle does not generally point exactly towards the true North. This is because the magnetic poles of the earth are not situated in exactly the same place as the geographical poles.

Magnetism flows along certain lines called

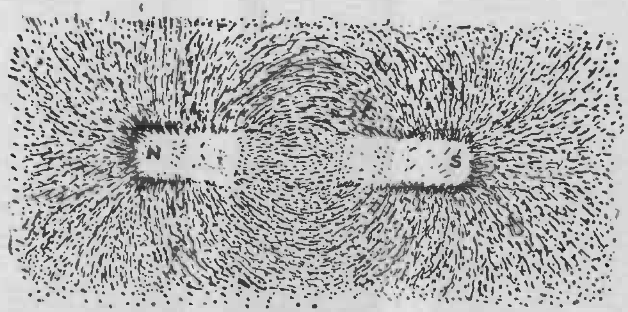


FIG. 214. — The "phantom" of a bar magnet.

Lines of Magnetic Force. These lines always form closed paths or circuits. The region in the neighborhood of a magnet, through which these lines are passing is called the *field of force* and the path through which they flow is called the

Magnetic Circuit. The paths of the lines of force may be easily shown by means of a magnetic "phantom." A phantom is made by placing a piece of paper over a magnet and then sprinkling iron filings over the paper, which should be jarred slightly in order that the filings may be drawn into the magnetic paths.

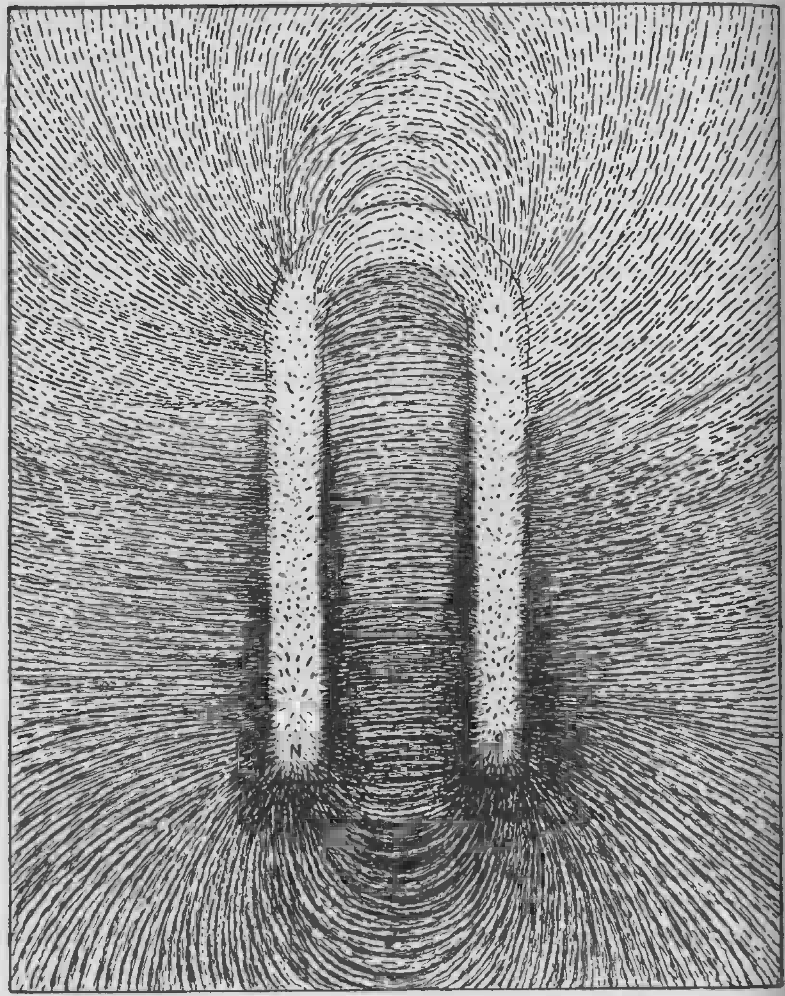


FIG. 215. — The phantom of a horseshoe magnet. The method of making a magnetic phantom is explained in the text.

The filings will arrange themselves in curved lines, diverging from one pole of the magnet and curving around until they meet the opposite pole.

Figure 214 is a phantom of a bar magnet and Figure 215 that of a horseshoe magnet. Notice how the lines of force try to pass across the poles of the horseshoe magnet.

Current Electricity

Static Electricity is exceedingly interesting from an experimental standpoint but it is not of any practical use in our every

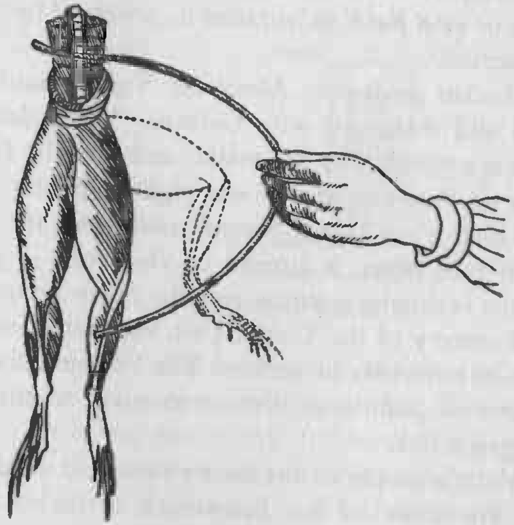


FIG. 216. — Nearly one hundred and fifty years ago, an Italian professor of anatomy, named Galvani, made a startling discovery concerning the legs of a frog which resulted in the creation of the first electric batteries.

day life and it was not until the means of producing an *electric current* was discovered that electricity could be made a real servant. The story of this discovery is very interesting.

A little over one hundred years ago, an Italian professor of Anatomy, named Galvani, noticed that the hind legs of a dead frog would kick and move if the nerves along the back bone were connected to the leg muscles with a piece of metal. After much experimenting, he further discovered that if one end of a strip of *zinc* is inserted in the back bone and the end of a strip of copper touches one of the muscles of the thighs or legs, the dead frog's legs would kick still more violently whenever the two strips of metal were brought together.

Galvani thought that this strange action was due to some sort of electricity or *vital fluid,* as he called it, produced by the frog's muscles or nerves.

Another Italian professor, Alexander Volta, heard of these experiments and disagreed with Galvani. Volta claimed that electricity was generated by the metals and that the frog's legs were merely an *electroscope.* He was right, and later succeeded in proving that when two different substances are placed in contact with each other, a current of electricity is generated, one substance becoming *positive* and the other *negative.* This led to the discovery of the Voltaic Cell, the first means of producing current electricity in motion. The Voltaic cell made possible all sorts of additional discoveries such as the dynamo, motor, telegraph, etc.

One of Volta's proofs of his theory consisted of the apparatus known (in honor of the discoverer) as the

Voltaic Pile. You can easily make one by cutting a number of disks, about the size of a quarter-dollar, out of sheet zinc and an equal number out of sheet copper.

Place a pair of disks of zinc and copper in contact with one another with the copper uppermost. Then lay a piece of blotting-paper of the same size as the metal disks, which has been moistened with strong salt water, on top of the copper disks. Then place another pair of metal disks, one of zinc and one of

copper, on top and so on, each pair of disks in the pile being separated by wet blotting-paper. Such a pile, if composed of twenty-five or thirty pairs of disks will produce enough electricity to give quite a perceptible shock if the top and bottom disks are touched at the same time with moist fingers. If you connect a telephone receiver to the top and bottom disks by means of two wires, the current will make a loud click in the receiver every time the wires are touched to the disks.

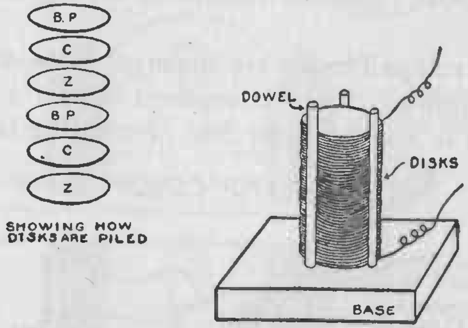


Fig. 217. — A simple Voltaic pile.

After devising the Voltaic pile, Volta soon realized that it was not a practical source of electric current. He was "on the right track," however, and it only remained for him to substitute a glass jar filled with dilute sulfuric acid for the blotting-paper moistened with salt water and to immerse the zinc and copper plates in the acid solution.

This arrangement of Volta's is called a simple Voltaic cell and may be used to generate sufficient electric current to operate small lights, motors, telegraphs, telephones, and other electrical apparatus.

A Simple Voltaic Cell is easily made by placing some water mixed with a little sulfuric acid in a glass tumbler and immersing therein two clean metal strips, one of zinc and the other of copper. The zinc and copper strips are called the *elements* of the cell and the acid solution, the *electrolyte.*

The elements must be kept separated from each other. The sulfuric acid should be diluted by mixing it with about ten times its volume of water. When mixing acid and water, always remember never to pour the water into the acid but to perform the operation in the opposite way and pour the acid into the water.

A copper wire should be soldered to the top of each of the strips.

When the zinc and copper are immersed in the dilute acid, no electric or chemical change is apparent beyond a few bubbles which begin to rise from the *zinc.* But if the two wires at-

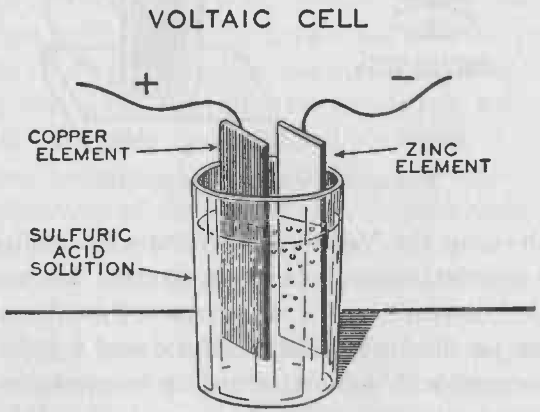


FIG. 218. — A simple Voltaic cell.

tached to the copper and the zinc are connected together, a chemical action starts and large quantities of bubbles arise from the *copper. A current of electricity is also passing through the wire.*

The chemical action of the cell is not easy to understand and is not of any great consequence to you in your experimental

work and so we will pass it by, remembering only that the solution of sulfuric acid attacks the zinc and not the copper and causes a current of electricity to flow through the wire from the copper to the zinc and back through the electrolyte from the zinc to the copper.

When you connect several cells together in series, be certain to arrange them so that the current can flow through a copper,

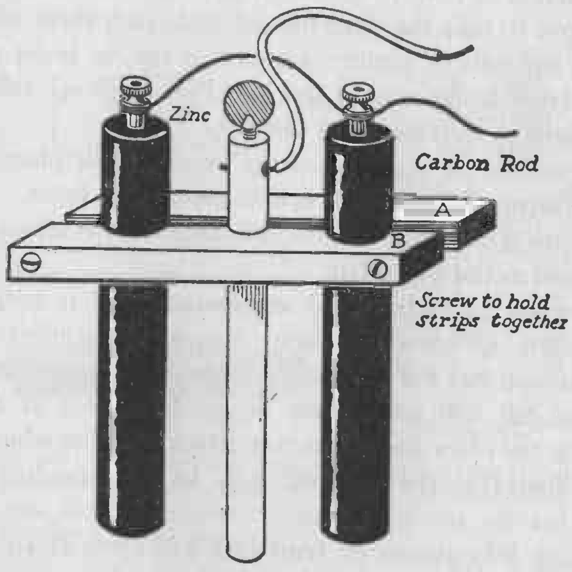


FIG. 219. — The elements of a homemade Voltaic cell, consisting of two carbon rods and a zinc rod may be clamped between two wooden strips. The strips should be painted with paraffin.

a zinc to a copper, and so on. If you hitched a pair of horses at opposite ends of a wagon and they pulled in opposite directions, the wagon would not move. If however both horses were hitched so that they could pull in the same direction the wagon would move. It is the same with a number of electric cells. If you connect them so that they all pull in the same direction a current of electricity will move.

When speaking of cells and batteries do not make the common mistake of referring to a single cell as a "battery" but call it a "cell." A "battery" is a group of two or more cells.

Volta's cell has the disadvantage that the sulfuric acid solution slowly eats the zinc away whether the cell is delivering electric current or not. It would not be very convenient or practical to have to take the elements out and wash them off every time that the cells or battery was not in use, in order to save the zinc from being wasted and so other types of cells were soon devised to overcome the difficulty.

A carbon rod or plate is usually employed in place of the copper element of the Voltaic cell in these other types.

There are a number of different chemical solutions which may be used as the electrolyte.

Ammonium chloride or sal ammoniac, as it is more commonly called, dissolved in water, makes an excellent battery electrolyte and has the advantage of being inexpensive. A sal ammoniac cell will not deliver as much current as an acid cell but on the other hand does not attack the zinc when not in use and therefore the elements may be left standing in the solution.

Ordinary jelly-glasses or fruit jars will serve nicely as containers for the solution. The jar which is to be used should be filled nearly full of water and sal ammoniac added until no more will dissolve. The zinc and carbon elements may then be placed in the solution.

Carbon elements for homemade cells are most easily and cheaply obtained from old dry cells. Carbons used in dry cells are in the shape of rods. About the only way that a dry cell can be broken open is with a cold-chisel and a hammer. Care must be taken, however, in order not to break the carbon.

The elements should be mounted on a wooden support which has been dipped in some hot paraffin wax so that it will not be affected by the chemical solution. Round carbon and zinc rods may be clamped between two wooden strips.

Using two carbons so as to increase the surface of the carbon element improves a cell. The two carbons should be connected.

Sal ammoniac cells of this type are known as "open circuit"

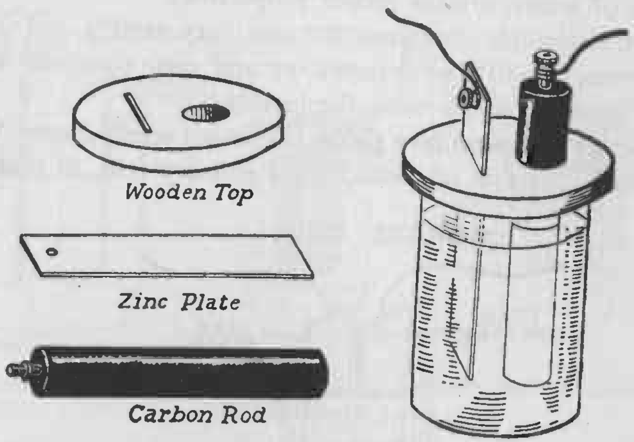


FIG. 220. — A homemade open-circuit cell using sal ammoniac solution as electrolyte is easily assembled from a strip of zinc, a carbon rod from an old dry cell and a paraffined wooden cover.

cells. They should only be used intermittently so that they stand idle a much longer time than they are in use. Miniature lamps, telegraph instruments, bells, medical coils, and all apparatus requiring only a very small amount of current may be operated satisfactorily by sal ammoniac cells of the type described above.

If you attempt to operate motors, spark coils, or any other apparatus requiring any considerable amount of current, by means of sal ammoniac cells, you will not secure satisfactory results because the cells will become exhausted very quickly.

It will be necessary to substitute cells having an electrolyte made of a solution of sulphuric acid and *dichromate of potash.* Your battery will then give a more powerful current for a longer time.

Four ounces of dichromate of potash, added to a solution composed of four ounces of sulphuric acid, mixed with sixteen ounces of water, are the proper proportions.

This electrolyte consumes the zinc very rapidly and it will be necessary to lift the elements out and wash them off, whenever you are through using the battery.

Storage or Secondary Cells, also called accumulators, differ from cells like that of Volta, called *primary* cells, in that they

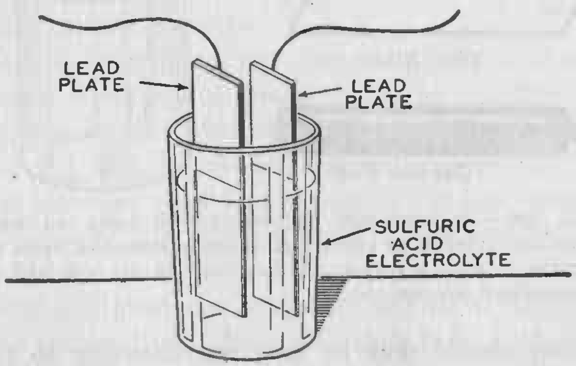


FIG. 221.— An experimental storage cell consisting of two strips of sheet lead immersed in a solution of sulfuric acid in water.

will not give forth an electric current until they have been *charged* by first passing an electric current through them.

The storage cell is therefore a very convenient means of storing up electric current for future use. From this however, it must not be considered that *electricity* is actually *stored* in

such a battery. The energy of the electric charging current is really changed into *chemcial energy* and this energy produces electricity when the cell is again discharged.

Storage cells consist of lead plates immersed in an electrolyte of dilute sulfuric acid.

An Experimental Storage Cell may be quickly constructed by cutting two strips of lead about an inch wide and five inches

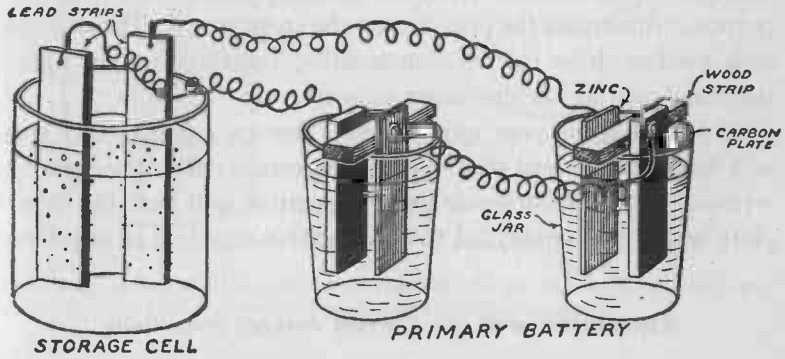


FIG. 222.— Charging the experimental storage cell with the current from two homemade cells.

long. Any thickness will serve. Attach a wire to each of the lead strips and immerse them in a jar full of an electrolyte composed of

10 parts of water
1 part sulfuric acid

Connect the wires leading from the plates to the terminals of your Galvanoscope (for description of the galvanoscope see page 344) and you will see that the needle does not move, showing that the storage cell is not generating any current.

Disconnect the galvanoscope and connect the storage cell to two dichromate of potash cells in series. Bubbles of gas will immediately rise from the lead plates. Let the cells remain connected for about five or ten minutes and then disconnect them. Now if you connect the lead plates to your galvanoscope, the needle will swing to one side very quickly, showing that the lead plates are producing a strong current.

You will find that your storage cell, for the two lead plates in the solution are now a storage cell, will ring a bell or run a small motor for a few seconds. The two lead plates were charged by the current from the primary cells. This little experiment illustrates the principle of the storage cell. The storage cells used to drive electric automobiles, for starting and lighting, etc., operate on this same principle.

If you examine your experimental storage cell carefully you will find that the lead plate which was connected to the positive terminal of the dichromate cells is positive and that the other plate which was connected to the negative terminal is negative.

Experiments with the Current derived from Cells

Electricity was not of any great value for a long time, even after the discovery of the Voltaic cell, because no useful apparatus which could be operated by the electric current thus secured had yet been devised. The telegraph, electric motor, electric light, etc., were unheard of and undreamed of. Before these wonderful devices could be invented, it was necessary to discover something about the properties of an electric current flowing through a wire.

About 1802, a scientist named Romagnosi observed that a Voltaic pile sometimes seemed to influence a compass needle.

Seventeen years later, the reason for this was learned and *electromagnetism* discovered by Hans Christian Oersted. You may easily repeat his experiments yourself.

Electromagnetism. Connect two copper wires to a cell or battery and bring a portion of the wire near a compass needle,

holding it parallel to the needle and as close as possible without touching. Then bring the free ends of the wires together so as to complete the circuit and notice that the needle moves. After swinging back and forth a few times it will come to rest at an angle with the wire instead of parallel to it as before when no

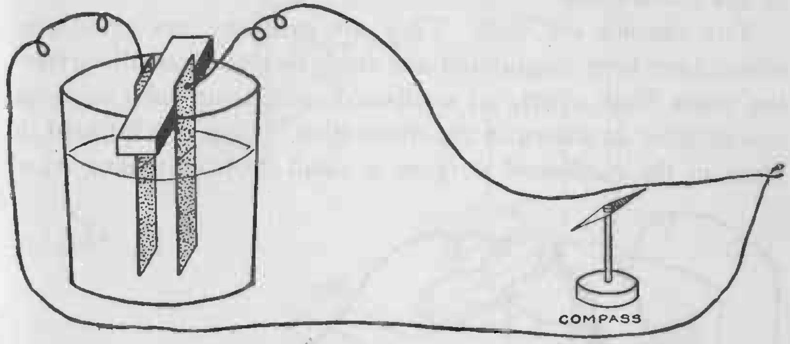


FIG. 223. — Oersted's famous experiment by means of which he discovered that an electric current will produce magnetism.

current was flowing in the wire. Next form a loop of wire and place the needle within as in Figure 281.

This experiment, first performed by Oersted in 1819 shows that the region around the wire has magnetic properties during the flow of electricity.

A compass needle employed in this manner becomes a simple form of

Galvanoscope. *A galvanoscope* is an instrument for detecting electric currents. You will find an instrument of this sort very valuable for performing a number of interesting electrical experiments.

A simple galvanoscope may be made by winding about fifty turns of No. 30 to 36 B.S. gauge single-silk or cotton-insulated magnet wire into a coil about two and one-half inches in diameter. Shape the coil into an ellipse and fasten it to a wooden base with some hot sealing wax as in Figure 225. Bind the coil with some silk thread in two or three places so that the wires are held together except at the top where they should be separated into two groups.

Make a standard composed of two strips of wood as shown in the illustration.

Two needles are used. They are ordinary sewing-needles which have been magnetized and stuck through a small carrier-bar made from a strip of cardboard, with their poles opposite one another as shown in the illustration. They may be held in place in the cardboard strip by a small drop of sealing-wax.

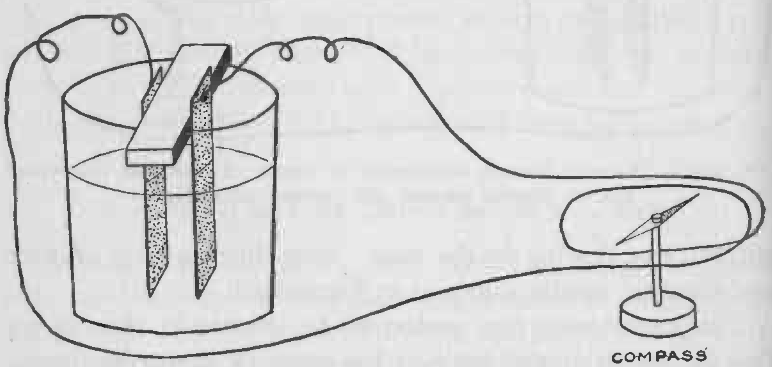


FIG. 224. — Forming a wire which is carrying an electric current into a coil makes the magnetic effect much greater.

A small hole is punched in the top of the carrier, through which is passed the end of a silk thread. The upper end of the thread is fastened to the standard and adjusted so that the needle hangs in the centre of the coil. The carrier-bar passes through the space where the coil is split at the top and should swing perfectly free. The terminals of the coil are connected to two binding-posts mounted on the base-block. The knurled thumb-nuts from an old dry cell together with the two nuts and screws of the right size will make excellent posts.

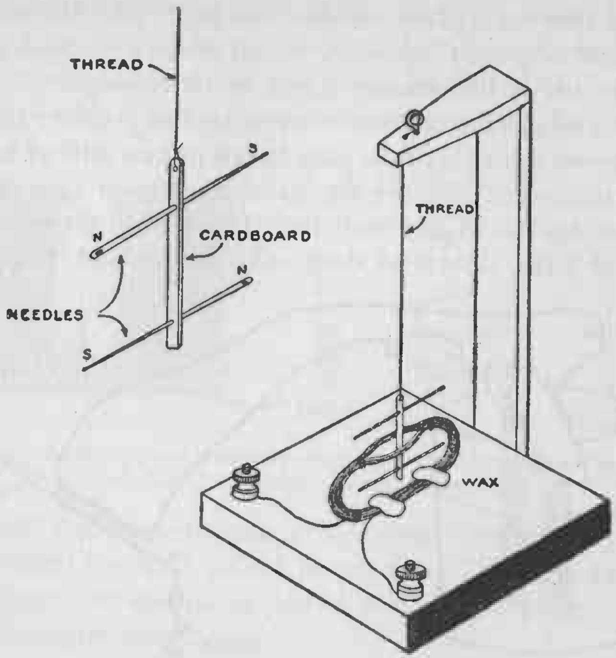


FIG. 225. — A simple form of Astatic galvanoscope which a boy can build.

Electromagnets. After it had been learned that a wire carrying an electric current created magnetism, it was a comparatively simple matter to discover that forming the wire into a coil greatly increased the strength of the magnetic field.

Roll up a small paper tube about one-half an inch in diameter and three inches long. Wind three or four layers of magnet wire on the tube. Test the magnetic properties of this winding by connecting it to two or three cells of battery and bringing it near to a compass needle. It will be found that the coil possesses very marked magnetic properties and will readily cause the needle to swing about, even though it is held quite a distance away.

If an iron rod is placed inside of the paper tube, the magnetic effect will be greatly increased. A coil of wire wrapped around an iron core in this manner forms an *electromagnet.*

If you wrap some insulated wire around an ordinary iron nail and connect the ends of the wire to one or two cells of battery, the arrangement will become an electromagnet and the nail will pick up bits of iron and steel. If you hold the nail above a pile of tacks, several of them will jump up and cling to the

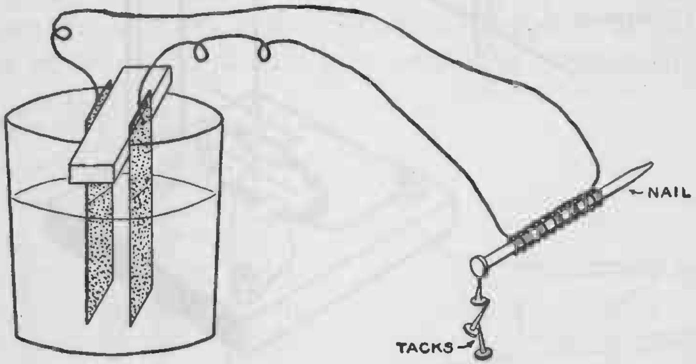


FIG. 226. — If some insulated wire is wound around an iron nail and the terminals of the coil connected to a battery, the nail will become an electromagnet.

nail while the current is flowing through the coil. As soon as the circuit is opened, the magnetism disappears and the tacks will drop.

Electromagnets play an important part in almost all electrical machinery. They form an essential part of the modern dynamo, motor, telephone, telegraph, etc.

The size and shape given to an electromagnet depends upon the use to which it is to be put. The horseshoe type is the most common. This consists of two electromagnets mounted on an iron strap called a *yoke* and connected so that the two free poles are north and south poles.

A home-made horseshoe electromagnet is illustrated in Figure 228. It consists of two small bolts, about one-quarter of an inch in diameter, and two inches long clamped to an iron yoke by means of a nut on each side of the yoke. Each bolt is

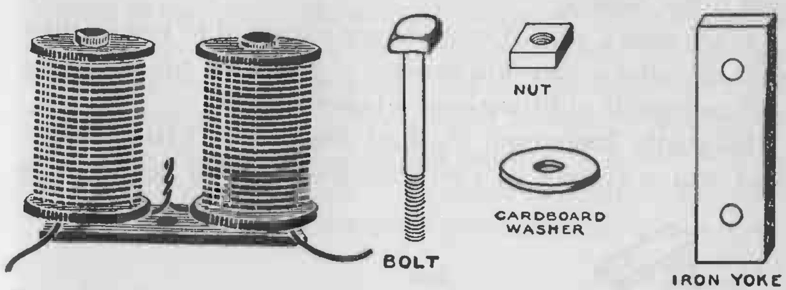


FIG. 227. — At the left is a horseshoe electromagnet. The parts for making a horseshoe electromagnet are also illustrated.

fitted with two washers made of thin sheet fibre or heavy cardboard which has been soaked in paraffin. The space between the washers is wound full of No. 18 or 20 B. & S. gauge cotton-covered magnet wire.

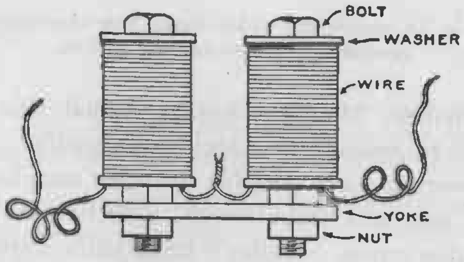


FIG. 228. — An electromagnet made with the parts shown in Figure 227.

The body of each bolt should be insulated with two or three layers of shellacked paper so that the wire cannot come into contact with the metal at any point.

The ends of the wires may be led out from the coils through two small holes in the washers at the bottom of the bolts. Both coils should be wound in the same direction. The inside terminal of one coil should be connected to the inside terminal of the next so that the two outside terminals are left free to connect to the battery.

When such a pair of magnets are connected to two or three cells of battery, they will produce a great deal of magnetism and are capable of lifting quite a heavy weight.

Magnetic Induction. A short time after Oersted discovered that a current of electricity flowing in a coil of wire

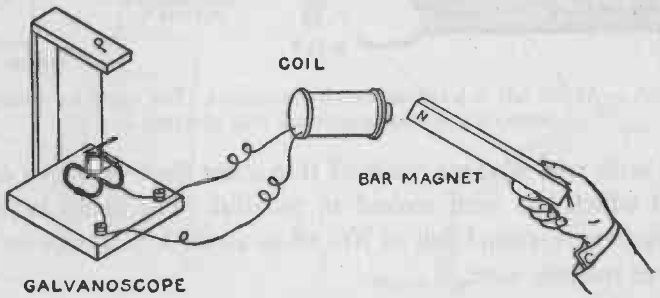


FIG. 229. — An experiment which shows how electricity can be generated by magnetism and motion.

creates magnetism, Michael Faraday found that magnetism could be made to *produce a current of electricity.*

This discovery made it possible for other men later to devise the dynamo, magneto, transformer, induction coil, etc.

You can also repeat Faraday's remarkable experiment with very simple apparatus.

Connect the terminals of an electromagnet to your galvanoscope. An electromagnet containing a very large number of turns of wire will serve best for this experiment. The wires leading from the electromagnet should be at least two feet long so that the coil and the galvanoscope are not close together.

Move a strong bar magnet quickly up to the end of the electromagnet and watch the needle of the galvanoscope very closely. If you swing the bar magnet close to the end of the electromagnet quickly, you will notice a slight deflection of the needle. As long as the magnet lies motionless near the coil, your needle will show no signs of current. If however, you pull the bar magnet rapidly away, the needle will be deflected in the opposite direction. As long as the magnet remains motionless, it induces no current in the coil, but when it is moved back or forth, it sets up the currents. The source of electrical energy is the mechanical work done in moving the magnet. The currents

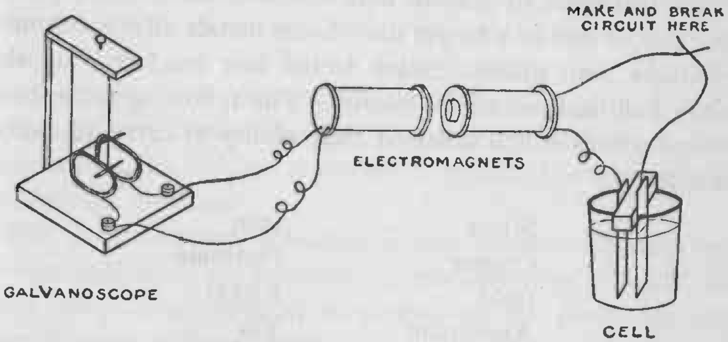


FIG. 230. — With this apparatus you can demonstrate the important principle of electromagnetic induction and also show that electricity can be produced by electromagnetism and motion.

generated in this manner are produced by magnetic induction and are called *induced* currents.

Electro-magnetic Induction. Place a second electromagnet with its pole against that of the one connected to the galvanoscope. Connect this second electromagnet to one or two cells of battery and make and break the circuit by touching the wires together.

Every time the circuit is made or broken, a current is induced in the galvanoscope circuit. You will be able to notice that the *induced* currents which are generated in the coil connected to the galvanoscope flow in one direction when the circuit is made and in the opposite direction when the circuit is broken.

Currents that are produced in this manner are said to be generated by *electromagnetic induction* and are also called induced currents.

Electricity Generates Heat. Whenever a current of electricity flows through a wire or a conductor it meets with a certain amount of *resistance* which tends to impede or interfere with the current flow just as the sides of a pipe cause friction with a stream of water and retard its progress.

The resistance of a small wire or conductor is much greater than that of one of a larger size. Some metals offer much more resistance than others. Silver is the best conductor of electricity and lead one of the poorest. The following table shows several metals in the order of their ability to carry an electric current.

Silver	Iron
Copper	Platinum
Gold	Nickel
Aluminum	Tin
Zinc	Lead

One of the most interesting facts about resistance is that whenever an electric current passes through a wire or conductor the resistance in its path *causes the current to generate heat.*

If you take a piece of fine magnet wire (No. 30 to 36 B. & S. gauge) about a foot long, and connect it to the terminals of a battery it will become very warm and may even melt. If you wrap the wire in a small coil, you may easily detect the heat with your fingers.

This property of an electric current is made use of in a number of ways.

There is always danger that too much current may possibly flow in a circuit and damage the apparatus or mechanism. Small strips of metal which melt easily and possess considerable resistance, called *fuses* are therefore included in the circuit. If too much current flows, the resistance of the fuses will cause a great deal of heat at that particular point and they will melt, thus interrupting the circuit and stopping the current before it can do any damage.

You can try this experiment by cutting a narrow strip of tinfoil about one-thirty-second of an inch wide with a pair of scissors. The strip should be about an inch long. If you connect it to the terminals of a strong battery the tinfoil will melt.

Certain alloys of metals offer a very great resistance to an electric current and also have a high melting point. These alloys are drawn into wire and formed into coils and used in the construction of electric flatirons, toasters, soldering irons, furnaces, stoves, etc. When a current is passed through the coils they become very hot.

The Incandescent Electric Lamp is probably the best known application of electricity to our everyday life and depends upon the property of an electric current producing heat when it meets with resistance.

The filament of the lamp is a fine wire, usually made of carbon or tungsten and possesses considerable resistance. It is heated white-hot by the passage of the electric current. The filament is enclosed in a glass bulb from which the air is pumped so that no oxygen can reach the filament. Otherwise it would quickly burn up. You can easily feel some of the heat generated by the electric current passing through the filament by touching an electric light with your hand.

Figure 231 shows a scheme for making a simple and handy form of electric lamp which utilizes the current from a home-made sal ammoniac cell.

It consists of a glass fruit jar, filled with a tight wooden top having the battery elements mounted on the under side. A miniature porcelain socket and a 1.5 volt miniature tungsten lamp are mounted on top. A lamp and a socket may be purchased at almost any electrical store. You will also find these parts on the electrical counter in a dime store.

The wooden top should be dipped in hot paraffin wax so that it will not absorb any of the battery solution. The positive

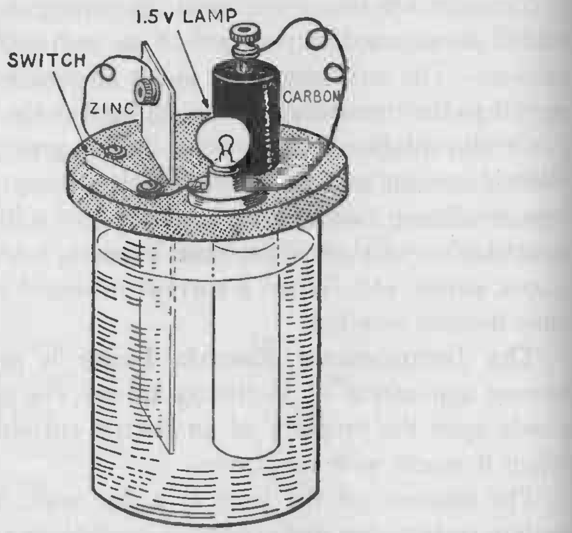


FIG. 231. — A simple homemade electric lamp.

element is a carbon rod from an old dry cell and the negative is zinc. The lamp is connected to the carbon and zinc but has a little switch, composed of a strip of sheet brass and two round-headed brass screws in the circuit so that the lamp may be turned on or off at will.

Fill the jar nearly full of sal ammoniac solution and the lamp is ready to use. It will prove very useful as a night lamp.

The Dynamo and Electric Motor

One of the first practical applications of the knowledge of electricity which was gained during the early part of the nineteenth century was the devising of **The Electric Motor,** which is perhaps excepting the electric lamp, the most practical and useful electrical device we have to-day. It has done more to

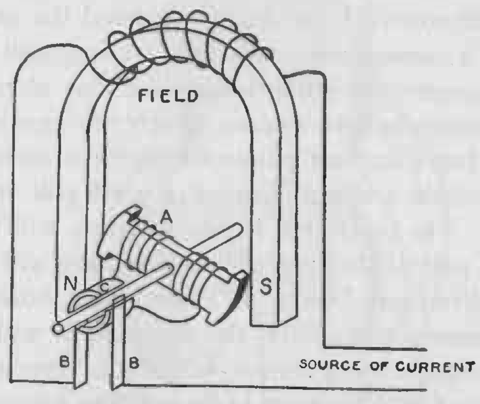


FIG. 232. — The principle of the electric motor is illustrated by this diagram. A is the armature, C is the commutator and BB the two brushes.

lighten the labor of men and increase the production of articles made by machinery than any other invention except perhaps that of the steam engine.

Millions of electric motors are in use all over the world. The various uses to which motors are put is practically unlimited. They vary in size from that of the little affair used to mix drinks on the soda fountain to the huge machine for driving a powerful battleship. Electric motors move elevators, automobiles, cars, trains, ships, unload and load vessels and drive practically every conceivable type of machinery. Their use is endless.

An electric motor is a machine in which the motive power is derived from an electric current by means of the magnetic effect of a current flowing through a coil of wire.

The principle of the modern electric motor is shown in simple form in Figure 232. An iron "armature" having a coil of wire wound around it so as to form an electromagnet is mounted on a shaft free to rotate between the poles of a magnet called the *field*. The terminals of the winding around the armature are connected to a *commutator* consisting of a ring split in two sections. The armature winding is supplied with electricity from an outside source by two *brushes* which rub against the commutator. When a current passes through the armature winding, one end of the armature becomes a north pole and the other a south pole. The north pole of the armature will be attracted by the south pole of the field and the armature will start to rotate in that direction. Due to the commutator, however, whenever the armature turns over, the direction in which the current flows through the armature winding is reversed. Reversing the direction of the current in the winding reverses the magnetic poles. The commutator is placed on the shaft of the motor in such a position that the poles of the armature are reversed just as the north pole of the armature reaches the south pole of the field.

The north pole of the armature which has now become a south pole is therefore attracted by the north pole of the field and the armature continues to revolve in the same direction. This process is repeated and consequently the motor keeps on revolving as long as current is supplied.

Although the diagram in Figure 232 is of the utmost simplicity it illustrates the fundamental principle which is employed in the modern electric motor, the only difference being that the up-to-date motors utilize a field having several poles produced by powerful electromagnets and an armature con-

taining many coils of wire with a corresponding larger number of sections in the commutator.

The first American patentee and builder of a practical electric motor was a young blacksmith by the name of Thomas Davenport, who lived in the town of Brandon, Vermont.

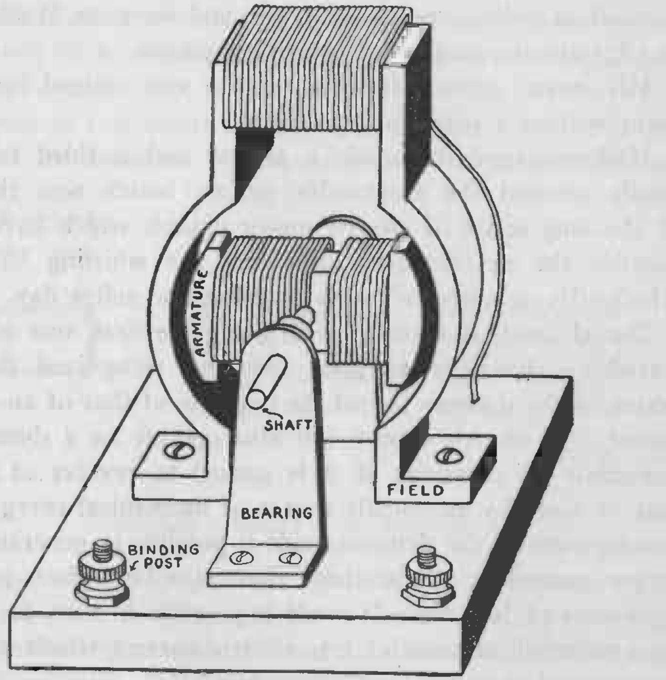


FIG. 233. — A small electric motor which you can build.

At the time that Joseph Henry succeeded in utilizing Oersted's discovery in building some powerful electromagnets, Davenport heard of Henry's wonderful "galvanic magnet" which was said to be strong enough to lift a blacksmith's anvil, and immediately set to work experimenting with batteries and magnets.

Insulated wire was not yet manufactured in those days and Davenport had to make his own wire for his experiments. He was a poor man, often unable to buy some of the materials which he needed but continuing his experiments in spite of almost insurmountable difficulties and making many sacrifices which were shared equally by his family, he was finally enabled to build a practical motor and went to Washington in 1835 for the purpose of securing a patent.

His errand proved fruitless and he was obliged to return home without a patent and penniless.

Undiscouraged, he made a second and a third trip and finally secured the memorable patent, which was the first of the long series of electric motor patents which have made possible the electric locomotive and the whirling little fan which stirs up a breeze for us on a hot and sultry day.

Daniel Davis is credited with being the first man who put Faraday's discovery to good use and recognized that the action of the *dynamo* is just the opposite of that of an electric motor. An electric motor will also operate as a dynamo or generator of electricity if it is caused to revolve at a high rate of speed by an outside source of mechanical energy. The development of the dynamo made it possible to generate much larger quantities of electricity than was heretofore practical by means of batteries. It made it possible to turn the power in a waterfall or cataract into electric current which could be transmitted to nearby towns and cities.

A small dynamo is not easy to construct without proper facilities but a toy electric motor can be made without great difficulty. The usual home-made motor is not very efficient and will not deliver an appreciable amount of power but will revolve at high speed when supplied with current from a battery and form an instructive working model which illustrates the principle of the larger machines.

A Home-made Electric Toy Motor

The little motor shown in the illustration is very similar to the one shown in diagram in Figure 232 with the exception that the field is formed by an electromagnet in place of a permanent magnet.

The Armature is cut out of a strip of sheet iron one-eighth of an inch thick and filed to the shape and dimensions shown in Figure 234.

A brass or iron shaft should be forced into the hole in the centre of the armature. If the shaft does not fit into the hole

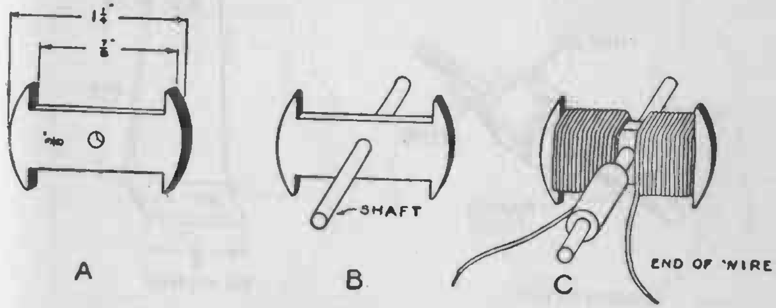


FIG. 234. — Details of the armature.

tightly, solder it firmly in position. Wind the armature full of No. 25 B. & S. gauge double cotton-covered magnet wire as shown in Figure 292. It is a good plan to insulate with paper those parts of the armature where the wire is liable to touch the iron so that there is no possibility of the wire short-circuiting through the sharp edges of the iron cutting through the insulation on the wire. The terminals of the wire should be fastened with a heavy thread so that the coil cannot unwind. The free ends of the wire are scraped bare of insulation and bent into shape to form the commutator sections. The sketch in Figure 235 shows how this is done. The wires are bent so that they fit closely to a paper core formed by winding a strip of paper three-eighths of an inch wide around the shaft close to the armature until it is one-quarter of an inch in diameter. The paper should be given a coat of shellac on one side and allowed to get sticky before it is wrapped about the shaft. Bind the wires tightly to the core with silk thread. The wires should be at opposite sides and in the position shown in the illustration.

The Field is made by first cutting out a strip of heavy sheet iron three-eighths of an inch wide and bending it into the shape

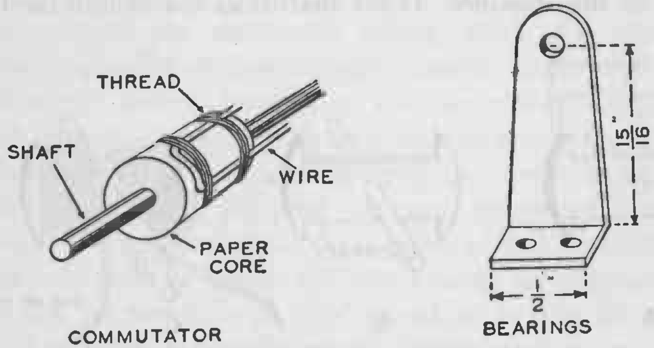


FIG. 235. — The commutator is formed by bending the ends of the armature wires and binding them in position on the paper core. The bearings are made according to the shape and dimensions shown above.

and according to the dimensions shown in Figure 236. Two small holes are drilled in the feet of the field frame to receive small round-headed wood screws which fasten it to the base.

Wind four or five layers of No. 25 B. & S. gauge double cotton-covered magnet wire around the upper part of the field frame, leaving about six inches free at each end for leads.

The Bearings are shown in detail in Figure 235. They are easily cut out of sheet metal and then drilled and bent as indicated.

The motor should be assembled and mounted on a small block of wood as in Figure 233.

The brushes are made by slightly flattening two pieces of No. 20 B. & S. gauge bare copper wire by a few light hammer blows. They are each fastened under a small clamp, made of a strip of tin held to the base by two small wood screws. The brushes should be adjusted so that they bear firmly but

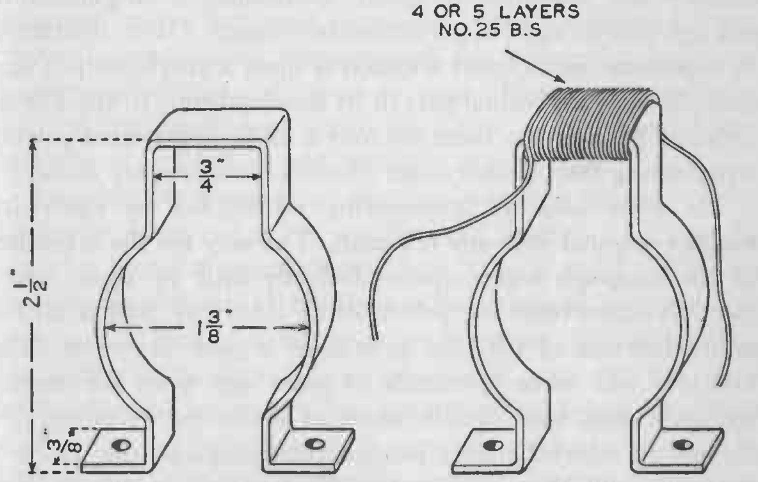


FIG. 236. — The field and the field winding.

lightly against the wires forming the commutator segments when the shaft is turned.

One end of the field winding should be connected to one of the brushes. The other terminal and the other brush should be connected to two binding-posts.

The armature must revolve freely and pass close to the field poles, but without actually touching them.

If the motor has been properly constructed it will run as soon as connected to one or two cells of battery and the shaft is given a twist to start it spinning in the right direction.

The Story of the Telegraph

No one knows who really made the first telegraph instrument, because so many men were concerned in its development that complete credit can hardly be given to any one of them. There is no instance on record, I believe, of a great invention having been completed by the efforts of one man. Usually any invention of great importance is originated in one age, and brought to perfection in another. Often thousands of ingenious minds exert themselves upon a single subject and each plays his individual part in its development. In the Patent Office at Washington there are over a *million* registered patents representing the ingenuity and efforts of one country alone.

The mere idea of transmitting intelligence by electricity was not original with any one man. The way for the invention of the telegraph was prepared little by little by those clever men who discovered the principles of electricity, and is an excellent instance of the slow growth of a great invention. The first step was made thousands of years ago when the ancient Syrian women used distaffs made of amber for spinning. As the spindle whirled around it often rubbed against the spinner's garments and thus became electrified as amber always does when it is rubbed. Then on nearing the ground it drew to itself the dust or bits of chaff or leaves lying there or perhaps attracted the fringe of the clothing.

If a piece of amber is rubbed against cloth, it will also sometimes emit a spark. We have already learned that in Greek, the word *electron* means amber.

The second step toward the telegraph was not made until the middle of the eighteenth century when a Dutch professor invented the familiar Leyden jar, by means of which electricity can be accumulated. From that time on, electricity attracted the universal attention and became, in all civilized countries, the

favorite branch of science. Benjamin Franklin proved that the lightning discharges taking place in the heavens are electrical and Volta devised the first electric battery which has already been described. Nearly all the scientists of this period did something to help by their discoveries, perhaps not deliberately or intentionally, but by placing their knowledge at the disposal of others whose thoughts were bent towards the subject of telegraphy. Finally, after the electromagnet had been invented, little remained except for some ingenious person to devise the mechanical apparatus of the telegraph. A wonderful force had been placed at the command of men. Means had been discovered for creating as much electricity as they needed and methods of controlling and confining it developed.

Probably the inventor of the first telegraph making use of electricity in its operation was Francis Ronalds. He was the son of a London merchant and was born in 1788. When he grew up, he devoted all his time to the study of electricity and succeeded in making a telegraph having wires eight miles long. He built the arrangement in his garden and ran the wires around the garden many times until the total length was about eight miles. A machine which generated static electricity by friction was used to furnish the energy. At each end of the wire, he arranged a dial, which when acted upon by the electricity, caused a letter to appear before an opening in the dial. After having perfected the machine, Ronald offered it to the English government which at that time had only wooden signals worked by hand like railroad semaphores for communicating from place to place.

But governments are always stupid and slow in encouraging inventions and in this case they would not even consider an electric telegraph. After many fruitless efforts to interest the English government, Ronald gave up his experiments in disappointment and the field was left to others. He was perhaps the first man to devise a telegraph system operated by electricity. He lived long enough to have the satisfaction of seeing a successful electric telegraph system in operation all over England, but it did not operate in the same manner as the one which he had devised.

The successful system was developed by William Cooke and Charles Wheatstone. Cooke was an English army doctor and Wheatstone was a professor at King's College. The two men entered into partnership with excellent results. Together they made the first *practical* telegraph ever used in England. Of course, like all new things, it was not perfect in the beginning. For one thing, it required five lines of wire running between each station. The first system was installed in 1838 along the lines of the London and Blackwall Railway. The following year, the number of wires was reduced to two by improvements and in 1845 only one wire was required.

While these two men were working in England, however, events were transpiring in America which have produced a system far more perfect than the clumsy instruments in use in Europe. The American telegraph systems are to-day the most ingenious and efficient in the world.

The first apparatus which is the basis of our modern system of telegraphy was invented by Morse and the story of its invention is very interesting.

During the voyage of the ship *Sully,* from Havre to New York, in October, 1832, a conversation arose one day in the cabin, about electricity and magnetism. Dr. Charles S. Jackson, of Boston, described some experiments which had been recently performed in Paris by means of which electricity had been transmitted through a very long wire arranged around the walls of a large building.

One of the most interested listeners was another passenger by the name of Samuel F. B. Morse, who was returning to

the United States after a three-years' residence in Europe where he had been studying art. Although a gifted painter and sculptor, he was nevertheless also well versed in science. His father was a noted geographer, and besides having assisted his father in this work he had studied chemistry and natural philosophy at Yale. During the years of his artist life he retained his early love for science and kept well informed of its progress. Hence the interest with which he listened to Dr. Jackson's remarks.

"If that is so," said Morse, when the Doctor had finished, "I see no reason why intelligence might not be transmitted instantly by electricity in a very practical manner."

Ships were very slow and voyages long in those days and before the *Sully* dropped her anchor in New York Harbor, Morse had put his idea on paper in drawings and explanations which showed the principal features of the apparatus which he proposed to build and which proved to be the foundation of the greater number of electric telegraph systems in use in the world to-day. As soon as he reached America, Morse worked long and hard in perfecting the details of his invention, and in 1835 produced what was the first really practical telegraph. Jackson later claimed the invention as partly his and went to law about it but was defeated.

An artist is not usually well supplied with capital and Morse had furthermore spent almost all his money during his three years' residence in Europe. He was therefore forced to seek the aid of outside capital in the further development of his invention.

Scarcely any one would believe, however, that his invention could be made a profitable investment and no one could be found who was willing to risk his money in putting the invention to a practical test.

Having no other resource, Morse went to Washington in

1838 and arranged his apparatus where he could exhibit it to the members of Congress in hopes that he might be able to secure money from the United States Government with which to build an experimental line from Baltimore to the capital.

A committee of Congress reported favorably upon the plan but no action was taken during that session and the inventor was compelled to cross the ocean and seek assistance in Europe. His efforts were again fruitless. Neither France nor England would offer any encouragement. Returning home disappointed, but fully possessed of an inventor's confidence in his idea, which shuts a man's eyes to all obstacles, and not discouraged, he renewed his efforts year after year with Congress at Washington.

Finally, upon March 3rd, 1843, the last day of the session, after having spent all day at the House of Representatives in a final effort, his confidence and hope died as the evening wore away and it looked impossible to accomplish anything. Morse went sadly and heartbroken home to bed.

Imagine, however, the rapture with which he heard on the following morning, that late in the night, Congress had voted him thirty thousand dollars for building an experimental line.

But his troubles were far from being over. Still clinging to his original plan for burying the wires in the earth, nearly a whole year and twenty-three thousand dollars of his appropriation were wasted in learning that such an idea would not work.

At last, with but seven thousand dollars left and almost in despair, he abandoned the underground system and set up the telegraph lines over poles.

On May 1, 1844, the first message "What hath God wrought?" was sent from Washington to Baltimore and the system proved sufficiently successful to establish the Morse electric telegraph as a permanent addition to the possessions of man.

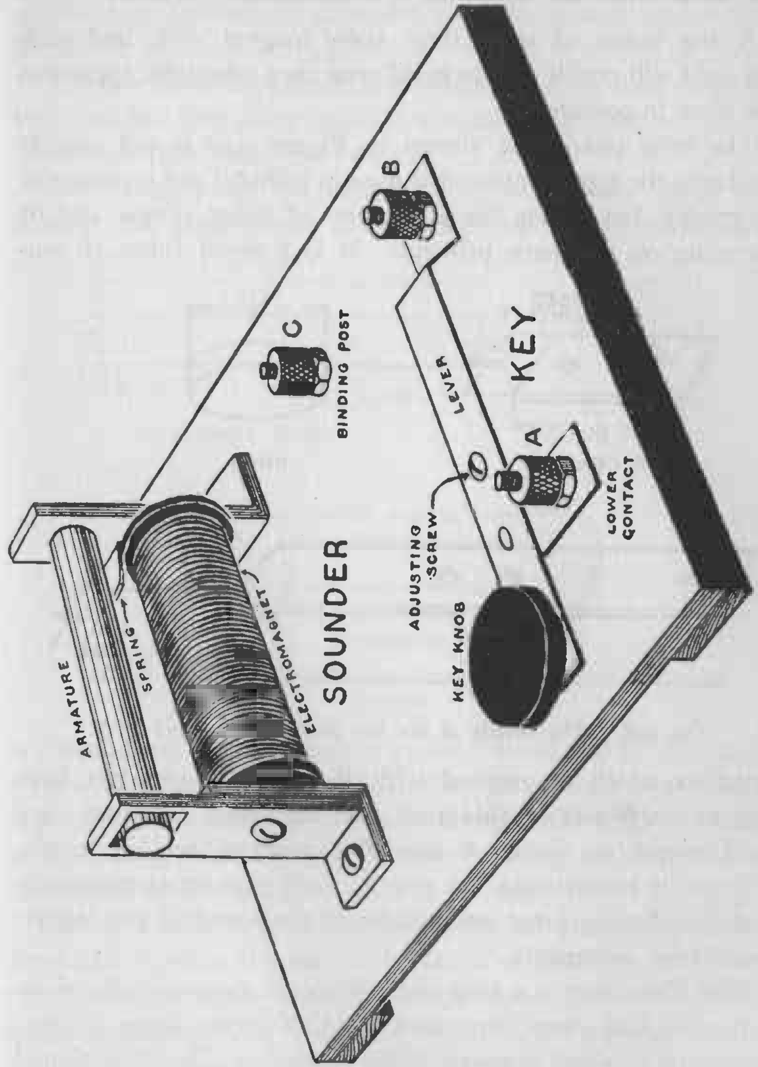


Fig. 237. — A homemade telegraph key and sounder.

The Construction and Operation of a Homemade Telegraph System

A few hours of spare time, some magnet wire, and odds and ends will enable you to build your own telegraph apparatus and learn to operate it.

The little instrument shown in Figure 237 is not exactly similar to the type of apparatus used in railroad and commercial telegraphy, but it has the advantage of being simple and of operating on the same principle. It is a novel form of con-

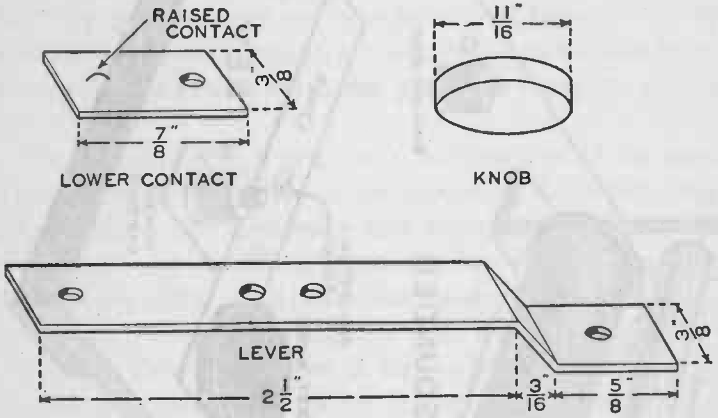


FIG. 238. — The details of the key lever, contact and knob.

struction which is original with the author, who has built a great many sets of this kind, and they have all given very good results on lines not over five hundred feet in length. If properly constructed, the sounder will give an exceptionally loud click having great resemblance to the sound of the regular commercial instrument.

The Key lever is a thin strip of metal, three-eighths of an inch wide and about three and one-half inches long. It may be cut out of sheet brass or heavy sheet tin. The knob should be made of fibre or hard rubber if possible but hard wood can

be made to serve the purpose. The knob should be about three-quarters of an inch in diameter and one-quarter of an inch thick.

The level should be bent up five-eighths of an inch from the back end and then down again at a second point three-sixteenths of an inch nearer the front end.

The contact point is a depression in the key lever made by a small round-nosed punch. Lay the strip upon a piece of lead or

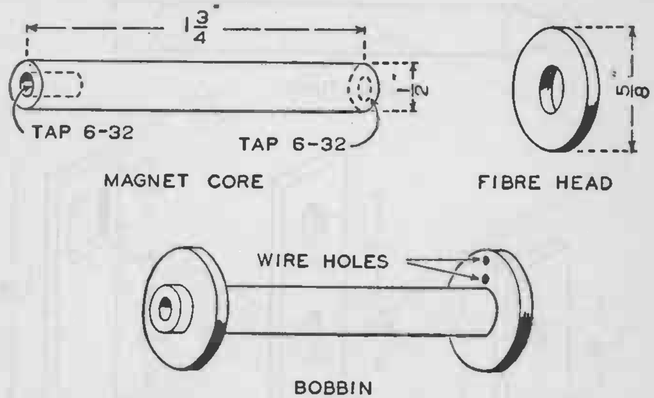


FIG. 239. — The core, magnet head and bobbin for the telegraph sounder.

across the end grain of a piece of hard wood and hit the punch several hard taps with a hammer. The dent should be as deep as is possible without breaking a hole through the strip. A punch can be easily made for this purpose by filing a short piece of one-eighth inch brass rod round at the end.

The dent will form a depression on the under side of the lever and serve as the contact point. The under or lower contact which the lever touches when pressed is directly underneath and consists of a strip of tin or brass having a raised projection formed by means of the punch. The strip is seven-eighths of an inch long and three-eighths of an inch wide. A small hole at the opposite end from the contact enables it to be fastened to the base.

The Sounder is a little more complicated than the key but is easy to construct if a little care is exercised.

The magnet bobbin consists of an iron core fitted with two circular fibre heads fitted on the ends. A hole is bored in the

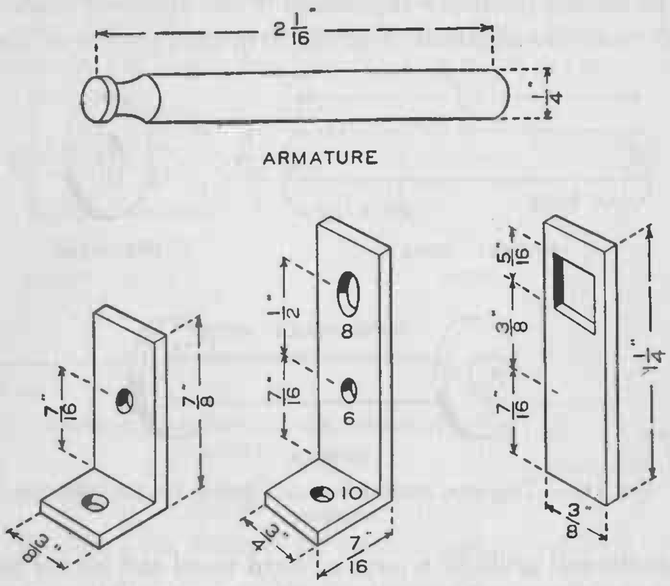


Fig. 240. — The sounder armature and parts of the sounder frame and anvil.

centre of each end of the core and tapped to receive a 6-32 screw. Bore two small holes in one of the fibre magnet heads, near the inside and outside edges respectively to accommodate the terminals of the winding.

The bobbin should be wound full of No. 26 B. & S. gauge magnet wire. Slip the inside end of the winding through the hole in the fibre head nearest to the core and allow about six

inches of the free wire to project through. Wind the wire on in smooth, even layers until the bobbin is full and pass the outside terminal through the other hole in the fibre head.

The completed bobbin is supported in a frame consisting of two L-shaped pieces of soft iron made according to the shape and dimensions shown in Figure 240. The part called the anvil should be made of brass. The holes marked 5, 6 and 7 should be just large enough to slip a 6-32 screw which fits into

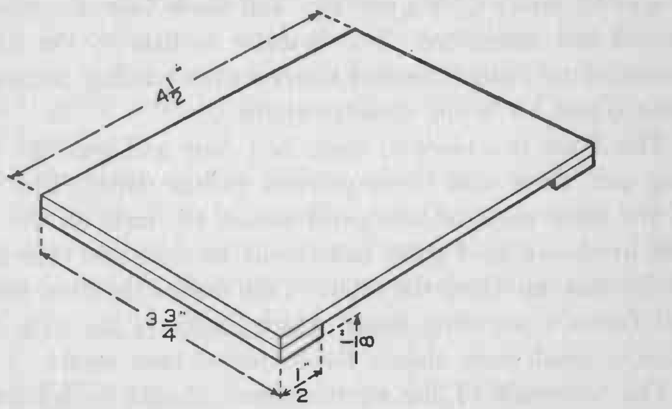


Fig. 241. — The wooden base for the key and sounder.

the threaded holes in the end of the core. The method of assembling the parts will probably be best understood from the sketch in Figure 237.

The armature is made from a piece of one-quarter-inch round iron rod, two and one-sixteenth inches long. One end should be tapered slightly and then notched all the way around as shown in the illustration. The notch should be formed so that when the end of the armature is slipped into the hole, 8, in the sounder frame and pushed up into position by the spring, the upper edge of the hole will rest in the notch. The opposite end of the armature should pass through the square hole in the brass anvil and project about one-sixteenth of an inch beyond.

The spring consists of a thin strip of sheet brass or phosphor-bronze, one end of which is forced between the fibre washer and the sounder frame at the back end of the sounder. The free end is bent so as to push upwards against the bottom of the armature.

The sounder and key are now ready to mount on the base. A careful study of Figure 237 will show how the parts are located and assembled. The sounder is held to the base by means of two round-headed wood screws passing through the holes 9 and 10 in the sounder frame.

The Base is a piece of cigar box four and one-half inches long and three and three-quarters inches wide. Two strips of the same material are glued across the ends on the under side as shown in Figure 241, so as to raise the central part of the base up from the table. This makes the base resonant and forms a sounding board which increases the click of the sounder much more than a flat-bottomed base would.

The terminals of the electromagnet should be led through two small holes in the base and along the under side to the binding-post. One terminal leads to the binding-post, *C*, at the back of the instrument and the other to *A*, mounted on the lower key contact. The third binding-post, *B*, is mounted on the back end of the key lever.

The binding posts may be secured from old dry cells. Having three binding-posts connected in the manner described above, makes it possible to use:

The sounder alone by connecting to posts *A* and *C*

The key alone by connecting to posts *A* and *B*,

or, both the key and sounder by using posts *C* and *B*.

The best adjustment of the key and sounder can probably be determined after a little practice and experience. The

key can be given the right amount of spring by bending the lever. The up-and-down motion is regulated by the adjusting screw.

The tension of the sounder spring will have to be changed according to the number of batteries used. It may also be necessary to adjust the sounder by filing some of the parts until they have the right relation to each other. The bottom of the square hole in the anvil should be just slightly above the top of the sounder frame. The nearer these two parts are to being on a level, the more sensitive will be the sounder, yet if they are so close that the armature touches both when it is pulled down by the magnetism of the coil, it will stick and be slow to act.

The Operation of the Telegraph Instrument. When a single instrument is to be used for practising the code it will only be necessary to lead two wires from a battery to the binding-posts *C* and *B*. Pressing the key will then close the circuit

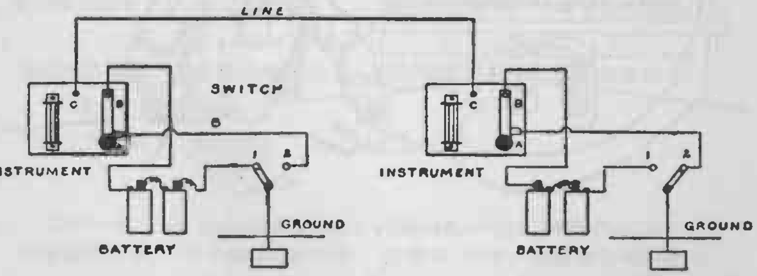


FIG. 242. — The circuit diagram for connecting two telegraph instruments.

so that the electric current flows through the electromagnet on the sounder and causes the armature to be drawn down and make a click against the anvil. When the key is released and the circuit is broken the spring will push the armature up and cause it to click against the upper part of the anvil.

When two instruments are to be used on a line it will be necessary to arrange some method of keeping the line closed so that messages may be sent from either end but without the battery actually in circuit only when required so that it does not become exhausted. This may be accomplished by following the plan shown in Figure 242 which makes use of a two-point switch for the purpose. The diagram indicates one wire leading to a "ground." This scheme may be used to save wire when the two stations are located at a distance from each

FIG. 243. — Amateur telegraph operators.

other. The ground consists of a wire leading to the gas or water pipes. Use care to establish a good electrical connection by first scraping the pipe until it is bright and then twisting the wire firmly in place.

The diagram will explain best how to wire the apparatus. The switch lever should rest on contact one when it is desired to send messages and on contact two when receiving.

The wire used in making the various connections should

be of the same size as that used for the line. No. 18 B. & S. gauge will be large enough for short lines not over one hundred feet in length. No. 14 or No. 16 will be required when the line is longer. The larger sizes of wire do not offer as much

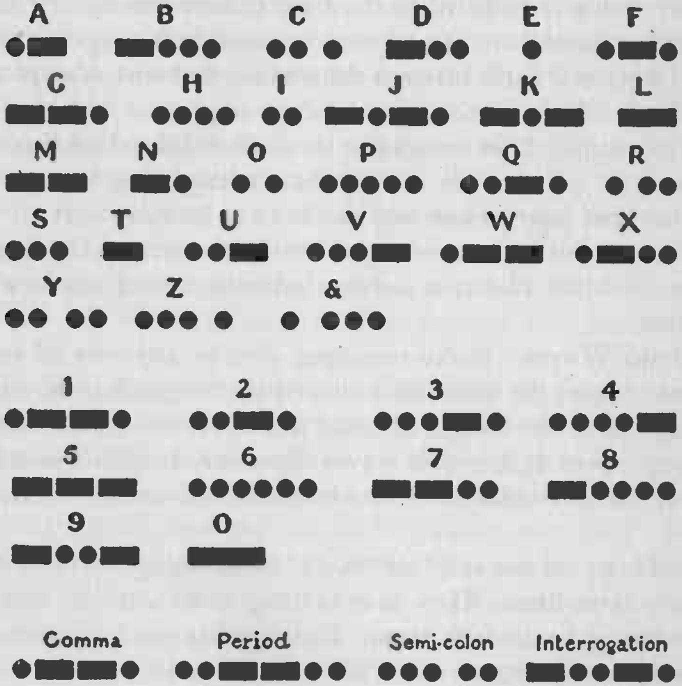


FIG. 244. — The Morse telegraph alphabet.

resistance to the current as a short line and eliminate the necessity of using a large number of cells in the batteries.

Two dry cells at each station should supply sufficient current for lines not over one hundred feet in length. An additional dry cell will be required for each additional one hundred feet increase in the length of the line.

Radio

The science and art popularly named "radio" brought us the magic of radiotelegraphy, radiotelephony, television and radar. Broadcasting is included in the term radiotelephony. At first, radio's greatest feat was to send dot and dash telegraph messages back and forth between ships at sea or between ships and the land. With further development apparatus was devised that so magnified our senses that we are enabled to look through dense fog; we are able to see what is happening beyond the horizon and hear voices and music in a faraway part of the world. All this is the result of scientific discovery which began when Heinrich Hertz, a German scientist, found out how to produce

Radio Waves. Radio messages, that is, any sort of radio signal whether the dots and dashes of the telegraph code, music and speech or the images of radar and television are all carried through space by invisible waves often called radio waves but known in textbooks as electro-magnetic waves and Hertzian waves.

Radio waves are not "air waves" as newspaper writers frequently term them. They have nothing to do with air and air has nothing to do with them. Radio waves can pass through a vacuum and through materials which contain no air.

Radio waves and light waves are similar except in length. Light waves are extremely short in comparison with radio waves. The wave length of dull red light is approximately three-one-hundred-thousandths of an inch. The waves used in radar are a few centimeters long. Broadcasting waves in the U.S.A. range in length from approximately 200 to 600 meters. Radio waves are too long to be seen by human eyes. They must be detected by electrical instruments. The device for detecting radio signals and rendering them visual or audible is called a radio receiver.

Radio waves are produced when a very rapidly alternating current (alternating thousands of times per second) is sent through a circuit under proper conditions. The radio waves which carry the ordinary broadcast programs in the United States are produced by currents which alternate approximately 550,000 to 1,600,000 times per second. The "frequency" or number of times per second the wave-producing current alternates, determines the location on the dial of the receiver where waves of that frequency are tuned in. The Federal Communications Commission assigns each station its own current frequency to be used in producing its waves. The frequencies are spread apart and alloted so that stations in the same area tune in at different places on the receiver dial and do not interfere with each other.

In the half century during which radio developed from a scientific curiosity into a marvelous and universal means of communication, several methods were developed for generating the rapidly alternating currents used to produce radio waves. Electric sparks, arcs and special alternators were used. They have been abandoned in favor of the vacuum tube, a tube quite similar to some of the tubes used in a radio receiver but much larger and capable of handling greater voltages and currents. A tube used as a generator of high-frequency currents is made part of an electrical circuit which includes carefully adjusted condensers, coils and a quartz crystal. When high-voltage direct current is fed into the circuit, part of the energy is converted into high-frequency alternating current. The frequency of the alternations can be altered by changing the condensers, coils and crystal. If one of the coils, called the "tank" coil, is connected to an antenna, high-frequency currents flow into the antenna and radio waves are sent out into space.

The Receiver. When the waves from a radio transmitter travel out through space and strike an antenna, they create in that antenna feeble alternating currents similar to those by which they were produced. In order to make the message carried by the waves perceptible to our senses a process of demodulation or *detection* must take place. First, the circuits of the receiver must be tuned or adjusted so that they will readily accept the desired message and not any other of a different frequency. Then the alternating currents must be converted into direct currents by a *detector*. The modern detector is a vacuum tube. If the signals are very weak, they may be strengthened or amplified by using vacuum tubes as amplifiers.

The Difference Between Radiotelegraphy, Radiotelephony and Television

A radio tube and circuit arranged to generate high-frequency currents is called an oscillator. Every modern radio transmitter, regardless of whether it sends out telegraph signals, speech, music or television scenes, is equipped with an oscillator. So is the transmitting part of a radar station.

An oscillator can be made with a single tube but in order to give the waves plenty of energy, it is customary to use more than one tube.

Modulation. In order to utilize radio waves for carrying signals, it is not sufficient to produce only the waves. The waves are merely a "carrier," in fact, they are termed carrier waves by engineers. The carrier must be given its message to carry. This process is called modulation. Modulation consists of varying the wave in some manner so that the variations correspond to the signals or message. There are two basic methods of modulating a carrier wave. The older method and the one in widest use varies the strength of the waves in accordance

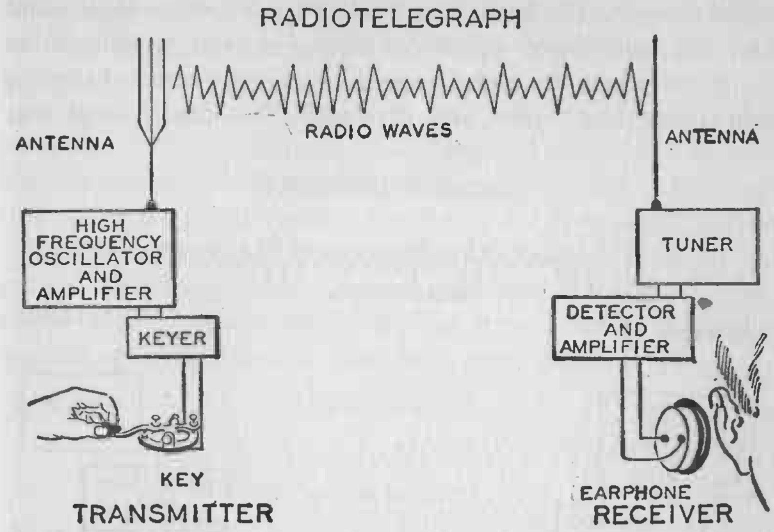


FIG. 245. — The Principle of Radiotelegraphy. By comparing this diagram with Figs. 246 and 247 you will understand that the basic difference between radiotelegraphy, radiotelephony and television lies in the method of modulating or impressing the message on the radio waves.

with the signals. It is called amplitude modulation, commonly abbreviated A.M. The newer method varies the frequency of the carrier wave and is called frequency modulation (abbreviated F.M.).

Perhaps the meaning of modulation can be made clearer by using a telegraph line or a telephone circuit as an example. Manipulating the telegraph key breaks the current on the line or modulates it into dots and dashes which carry a meaning. Speaking into a telephone transmitter varies the strength of the current or modulates it so that it carries sounds.

A radiotelegraph transmitter consists essentially of an oscillator connected to an antenna so as to produce a carrier wave. The waves are modulated or broken up into groups corresponding to the dots and dashes of the telegraph code by a modulator called a keyer. The keyer is controlled by an ordinary telegraph key. The modulated waves are intercepted by the antenna at the receiver and the high-frequency currents generated therein pass through a tuner and detector. The tuner keeps out

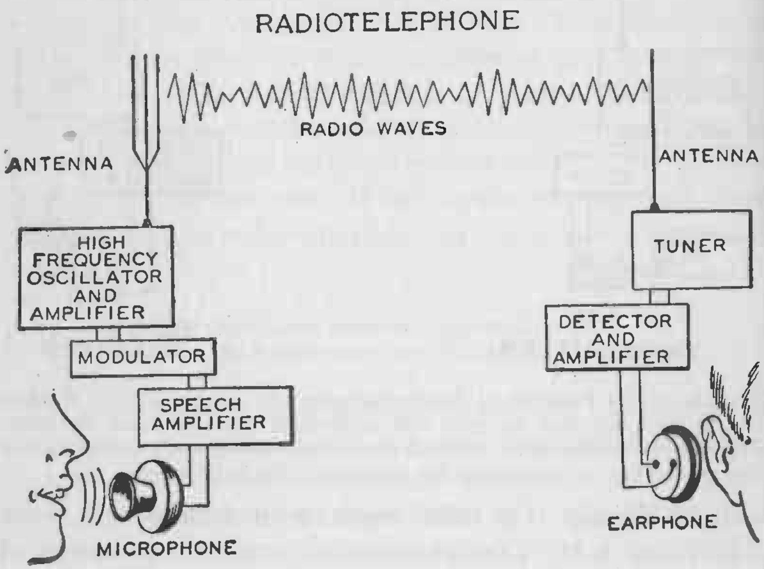


Fig. 246. — The Principle of Radiotelephony.

unwanted interfering messages of different frequency. The direct currents which issue from the detector flow through a telephone receiver or loudspeaker and make the signals audible.

A radiotelephone transmitter employs the same type of oscillator used for radiotelegraphy but has no keyer or key. The carrier wave is given its message by a modulator connected to a microphone into which speech or music is directed. The apparatus used to receive radiotelephone messages is similar to that used to receive radiotelegraph signals. A broad-

casting station is merely a radiotelephone transmitter sending out regular programs for advertising and entertainment purposes.

Radio television is similar to radiotelegraphy and radiotelephony in that it consists of sending and receiving a modulated carrier wave. An oscillator is employed at the transmitter to produce the carrier wave. The waves are given their picture signals by a modulator connected to a television camera. In the camera a moving beam of light examines each part of the scene to be sent and modulates the waves according to the amount of light reflected from each spot scanned.

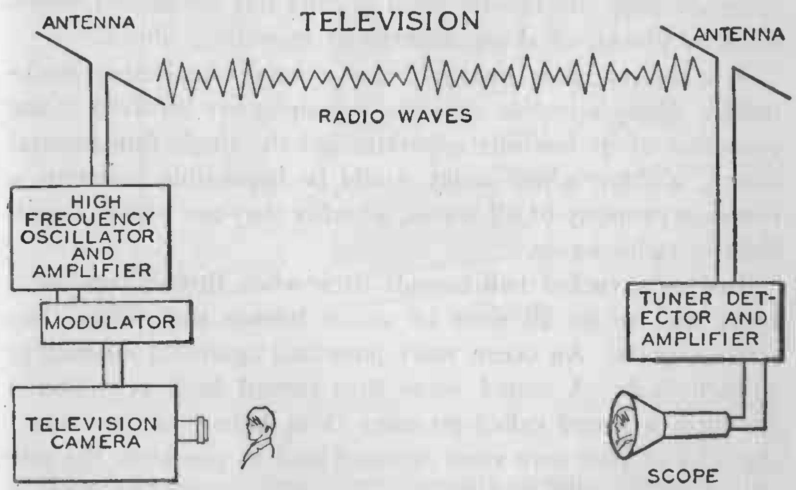


Fig. 247. — The Principle of Television. Notice that a type of antenna different from those shown in Figs. 245 and 246 is shown. The waves used in television are shorter than those commonly used for radio telegraphy and telephony and require a "short-wave antenna."

The carrier wave is intercepted by a receiving antenna and its signals passed to a tuner, detector and amplifier quite similar to those in an ordinary receiver. The amplified currents are then sent into an oscillograph tube. In this a moving beam of light controlled by the incoming signals paints a fluorescent picture on the sensitive chemical screen at the end of the tube.

Radar

Radar is based upon principles long known to scientists and engineers. It was developed to the stage of practical usefulness during World War II and its advent completely revolutionized many phases of warfare. It serves as an instantaneous means of detecting and locating planes and ships when fog, clouds, distance or darkness makes them invisible. It is as useful in peace as in warfare. It gives increased safety to plane or ship. Its unseen beam reaches out ahead and warns of other planes, of ships, icebergs or mountains ahead.

A complete radar installation is a very complicated mechanism. Many scientific laws and principles are involved in the operation of its intricate apparatus but the single fundamental action, without which radar would be impossible, concerns a common property of all waves, whether they are water, sound, light or radio waves.

Just as a rubber ball bounds back when thrown against a brick wall so do all sorts of waves bounce back when they strike objects. An ocean wave pounding against a sea-wall is thrown back. A sound wave thus turned back or reflected produces a sound called an echo. You have doubtless heard the echo of your own voice reflected back to you from the side of a building, cliff or hillside. The rolling sounds of thunder are evidence of sound wave reflection. They are in part the echoes of the original crash reflected from a succession of clouds or hillsides.

The echoes of waves of light are called reflections. A flashlight and a vertical mirror on the wall of a darkened room will enable you to produce reflections which demonstrate the basic principle of radar. If the beam from the flashlight is

directed so that it strikes the mirror at an angle, you see the polished surface change the direction of the light waves and send back a reflected beam. If you stand directly in front of the mirror and direct the beam toward it at eye level, the reflected light waves will travel back to your eyes.

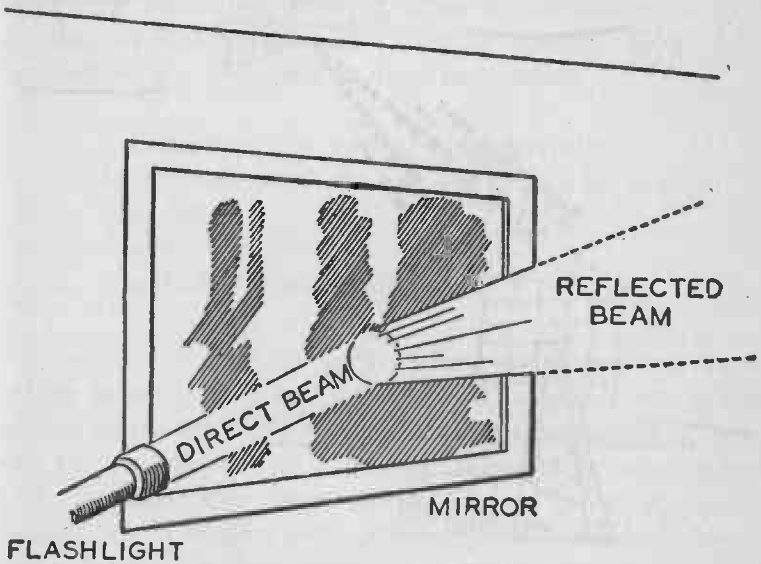


Fig. 248. — Demonstrating a Reflected Wave. The "echo" of a light wave is the reflected light.

Radio waves, being of the same character as light waves, namely electromagnetic waves, are also reflected. A radio wave sent out from the antenna of a short wave transmitter will be reflected back upon striking certain objects. The spelling of the word RADAR is a clue to its underlying principle. It reads the same backwards as forward. A radar station sends out a radio wave in the form of a beam which can be pointed in any direction like the beam of a flashlight. Objects struck by the radio beam reflect it back to the transmitter. The "radio echo" which is reflected back is detected and the time it took to travel out and back indicated by the instruments. The direction of the beam and the tuning of the echo make it possible to calculate

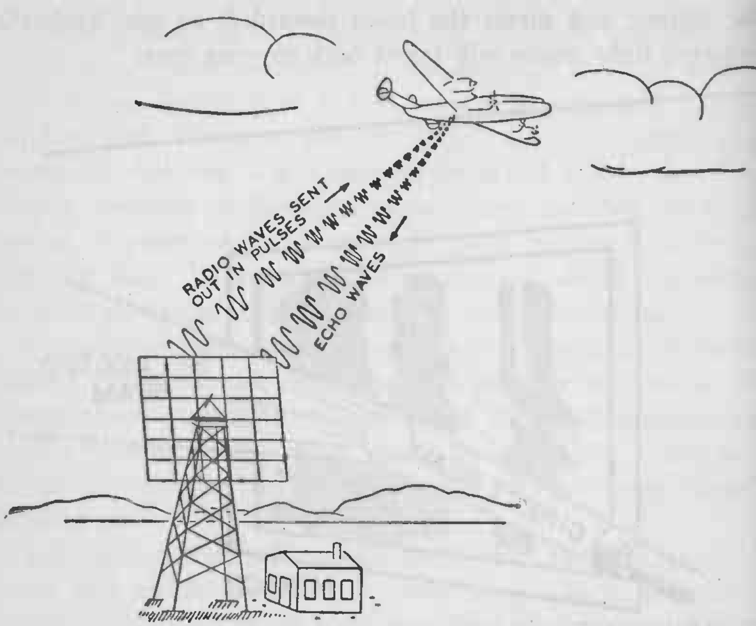


FIG. 249.—The Principle of Radar. Radio waves are sent out in pulses. When they strike an object they are reflected back to the transmitter. Ingenious apparatus locates the reflecting object.

the exact location of any reflecting object even though it is many miles away. With radar, a ship can detect a floating mine in darkness or locate another ship obscured by fog and calculate its direction and speed.

Extremely short radio waves (from a few centimeters to one meter in length) called microwaves obey many of the same laws that govern the behavior of light. They travel in a straight line at the same velocity as light (186,000 miles per second), can be concentrated into a beam which can be aimed in any

desired direction and are easily reflected. Therefore micro waves are used in radar.

A radar installation assumes various forms depending upon its purpose and place of installation. The radar equipment at an airport used to direct planes in making blind landings is necessarily somewhat different from the installation aboard a merchant ship used as an aid to navigation. Most radar installations are composed of four basic units:

1. A transmitter for sending out microwaves
2. An antenna which focuses and directs the microwave beam
3. A sensitive receiver
4. A cathode-ray tube indicator

In what is termed the pulse system, the transmitter sends out its waves in a series of short rapid pulses. Waves which last for only 2 millionths of a second may be produced at intervals of 50 millionths of a second. When these wave pulses strike an object they are reflected back and picked up by the receiver which sends a corresponding pulse to the cathode-ray tube. Across the fluorescent screen of the cathode-ray tube (popularly known as the scope) there is normally a thin straight line of light. When a pulse reaches the tube it produces a hump in the line or a bright spot called a pip. The presence of a pip on the screen of the radar scope indicates an object in the path of the microwave beam which is reflecting back the pulses. The position of the pip gives the exact distance of the object. More than one pip indicates more than one object detected.

The antennas used to send out microwaves do not look at all like the familiar antennas of a broadcasting station. Some of the large radar antennas appear like enormous sets of bed-

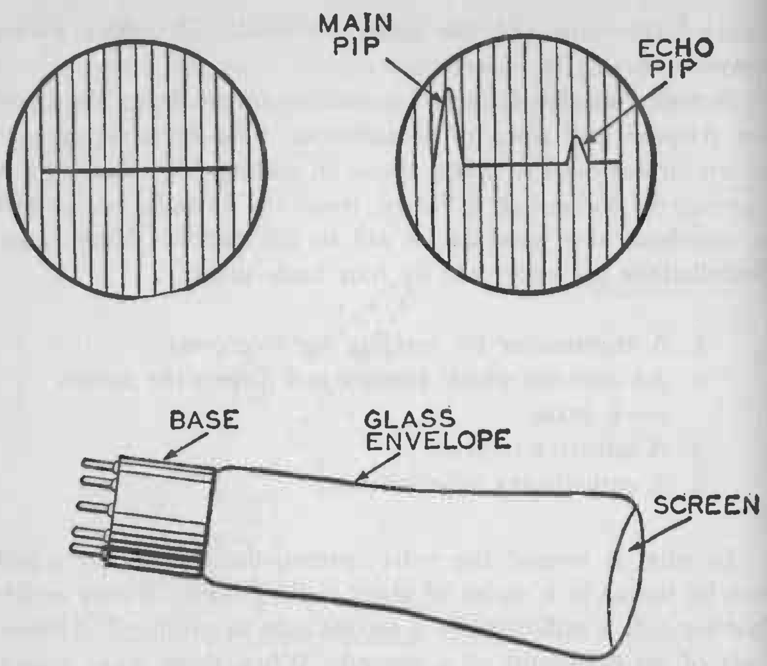


Fig. 250. — A "Scope" and its Screen. A small scope is shown at the bottom of the sketch. The upper left hand sketch shows the scope's screen and the horizontal line which appears on the screen when no signals are "going or coming." The upper right hand sketch shows the "main pip" produced in the horizontal line by a wave pulse from the transmitter and the "echo pip" produced by a reflection of the pulse. The space between the pips indicates the distance of the reflecting object. The position of the transmitting antenna indicates the direction of the reflecting object.

springs. A parabolic reflector, popularly called the "dish" is used in some radar installations.

Note. Those who are interested in constructing simple radio receivers will find plans and instructions in "The Boy Electrician" by Alfred P. Morgan. Published by Lothrop, Lee and Shepard Co., New York City.

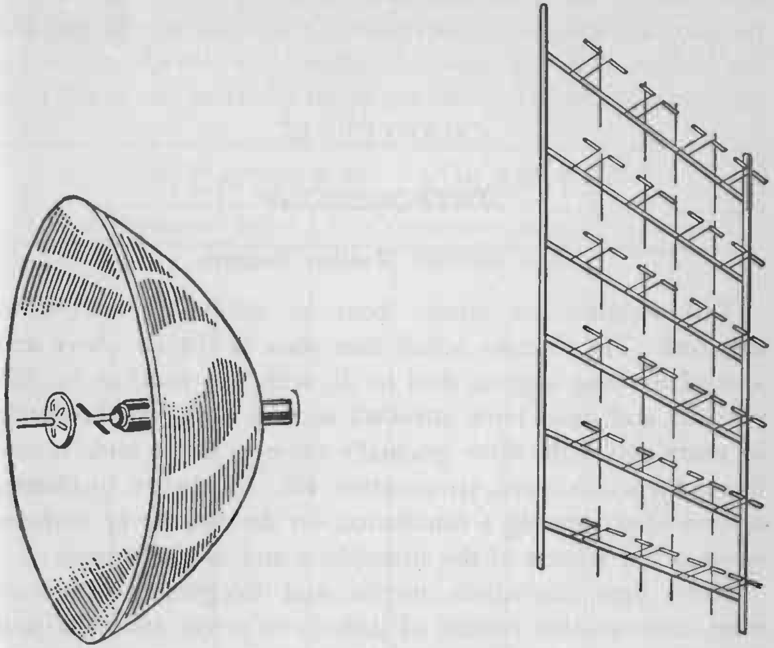


Fig. 251. — Radar Antennas. At the left is the parabolic reflector type and at the right a "bedspring" antenna.

CHAPTER IX

METEOROLOGY

The Amateur Weather Prophet

THE weather has always been an interesting subject to mankind. The changes which take place in the air above and around us have a great deal to do with our comfort or discomfort and must have attracted serious attention thousands of years ago, until there gradually came to be an understanding of the winds, rains, temperature, etc., not always, of course, correct—but forming a foundation for the *Science of Meteorology* or the science of the atmosphere and its phenomena.

Every year, the winds, storms, and droughts cause an almost inconceivable amount of damage to crops, railroads, and shipping. This damage would be even far greater if it were not for the fact that we have learned to explain various phenomena in the atmosphere and are able to predict with more or less certainty what will probably happen in the atmosphere in the immediate future. The "weather prophet" is always more or less of a joke to many people but the real scientific and accurate weather forecaster is a very valuable member of society. The United States Government maintains an elaborate Weather Bureau at Washington which is in constant telegraphic communication with branch offices and observers all over the country. The weather predictions made by this Bureau are therefore accurate and are invaluable to farmers, mariners, and many business men, who, if forewarned of weather changes and storms, can take proper precautions against the possible losses

and damage which might be caused thereby. The farmer who has been forewarned of a coming rainy spell can postpone his planting and avoid the danger of having his seeds washed out by a heavy rain or rotted in the ground on account of too much

WEATHER CHART.

DATE	BAROMETER	WIND	SKY	TEMPERATURE	HUMIDITY	FORECAST

FIG. 261. — The weather chart.

moisture. Likewise, aviator or mariner who is warned of a coming storm can remain in port or set his course so as to avoid a dangerous coast.

Many individuals and corporations whose fortunes are somewhat dependent upon the weather take advantage of the Government's weather forecasts and to some the weather is so important that they employ their own trained observers.

The New York Edison Co., whose large power-houses supply the greater part of the electric current consumed in New York City, keeps a weather man constantly on watch on the top of a tall building in New York. An approaching storm or even a large cloud which would cast a shadow on the city means that countless thousands of electric lamps will be suddenly turned on to replace the sunlight. It would be very costly to keep steam up and huge dynamos running so as always to have a large reserve supply of electricity ready for such emergencies and so when there is no demand, advantage is taken of the opportunity to save coal and money by keeping the weather observer at his post ready to give warning sufficiently in advance so that power will be ready whenever it is actually demanded.

I do not expect every boy to become an expert weather forecaster, but, on the other hand, he can by a little observation become sort of an amateur weather "prophet" and not only will this ability prove a pleasure but the knowledge gained will be useful all the rest of his life.

If you wish really to become proficient in weather forecasting, you will find it necessary to keep a daily record of climatic conditions as they exist at the time.

A proper chart may be made from a sheet of heavy paper or cardboard by ruling it with a pen and ink according to the plan suggested in Figure 261. Make a heading for

THE DATE	BAROMETER
THE WIND	HUMIDITY
APPEARANCE OF SKY	FORECAST
TEMPERATURE	

The space headed "Forecast" should contain the observer's own opinion of the probable weather for the next twenty-four hours. This will enable you to check your prophecies with what actually takes place and so determine the value of your predictions and your ability as a weather man.

Tack the chart up in a convenient place and jot down your observations—making them daily and, as far as possible, at the same hour each day.

You will soon be surprised to find that by regularly keeping this chart, your observation becomes very much more acute in a short time and when you step outdoors into the open, you will unconsciously note the temperature, the telltale clouds and winds, all carrying a forewarning of some sort. And so as your interest increases, so will your sense of perception.

The Wind

A practical weather prophet, upon wishing to know tomorrow's climatic condition looks first to the wind for his knowledge.

When we find the weather vane pointing toward the west, we may usually expect clear weather and when it points towards the east, as a rule, a storm may be expected. When it blows from the north, it hardly ever fails to bring cold days in winter and refreshing coolness in the summer, while a south wind prophesies warmer weather whether summer or winter.

During a storm, the wind usually changes and gradually shifts its direction. This change in the wind will often indicate to the observing weather prophet, how long the storm is going to last. If an east wind brought the storm, but it begins to change its direction, an increase or decrease in the intensity of the storm may be looked for depending upon which way the wind changes. It is different in various parts of the country, but a safe general rule for each particular locality may be easily established by a little observation.

What Winds Are and How They Are Caused

Winds are currents of air moving in the atmosphere in various directions and at different speeds. They are produced by a disturbance in the equilibrium of some part of the atmosphere, due to a difference in temperature between adjacent localities. Thus, if the temperature of a certain place becomes higher, the heated atmosphere rises because air expands when heated and becomes lighter. These upward air currents destroy the equilibrium of the atmosphere at the surface of the earth because the pressure on the colder adjacent parts due to the heavier cold air is greater than on that which has been heated. The warm air moves upward and *outward* from the heated regions while the cooler air from around about moves *inward* along the surface of the earth towards the warmer region.

Winds may be classed according to the more or less constant direction in which they blow as *regular, periodic,* and *variable* winds.

The Regular Winds are those which blow all the year around in practically the same direction. They are also known as *trade* winds and blow from the northeast to the southwest in the Northern Hemisphere and from the southeast to the northwest in the Southern Hemisphere. These winds exist on both sides of the equator as far as about one-third of the way toward the poles and are caused by the hot sun at the equator. The heated air rises as the sun passes around from east to west and its place is supplied by the colder air from the north and south. From this it might at first seem, that the trade winds should blow directly north and south. The reason, however, that they blow from the northeast and southeast is because

the cold air moving along the surface of the earth toward the equator is dragged along by the rotation of the earth on its axis. This movement of the atmosphere along with the earth is, however, at a slightly lower speed than the rotation of the earth itself, so that the trade winds are given somewhat the same direction as the apparent motion of the sun, that is, from east to west.

Periodic Winds blow regularly in the same direction at the same seasons of the year and at the same hours of the day. The *Monsoon,* which blows from the sea towards the continent for

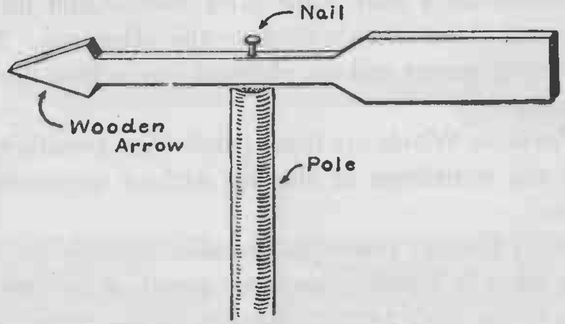


FIG. 262. — A simple wind vane consisting of a wooden arrow pivoted on top of a pole.

six months in the summer around the Red Sea, Arabian Gulf and the Chinese Sea, and in the opposite direction for six months in the winter, is a periodic wind. The *Simoon* is another periodic wind which blows on the hot deserts of Asia and Africa. This hot breeze is known under the name of *Sirocco* in Italy and Algiers and as *Kamsin* in Egypt. When this terrible wind blows, the air becomes darkened and full of fine sand. The skin becomes very dry and a burning thirst is produced. The natives of Africa cover themselves with fat and grease to protect themselves from the effects of the rapid perspiration produced by the *Monsoon.*

The land and sea breezes which blow along the sea-coast, from the sea toward the land during the day and from the land to the sea during the night are the most evident form of periodic winds in the United States. In the daytime, the land becomes more heated than the sea, and hence as the atmosphere over the land becomes more heated than that upon the sea, it ascends and is replaced by a current of cold air flowing from the sea towards the land. During the night after the sun has disappeared, the land cools more rapidly than the sea and therefore winds in the opposite direction are produced. Sea breezes usually commence a short time after sunrise and increase in strength until about three o'clock in the afternoon. They decrease towards sunset and are changed into a land breeze during the evening.

The Variable Winds are those which blow sometimes in one direction and sometimes in another without apparently obeying any law.

In spite of the fact that many winds seemingly do not obey any laws, there is a strong tendency for them to veer around according to the sun's motion,—that is, to pass from the north to the northeast, from the east to southeast, and so on around. They often make a complete circuit, occupying several days in so doing. The wind very rarely or never makes a circuit in the opposite direction. This tendency of the wind is most marked during the winter time.

How to Make a Weather Vane

The Weather Vane is so common that it will scarcely need explanation in order to make its construction understood.

Weather vanes are usually patterned after an arrow, and indeed all that is necessary in order to make a very simple vane is to whittle a little arrow out of wood. Bore a hole for

the pivot and set the arrow over a wire nail driven into the upper end of a pole. The arrow should turn freely, and if so will move back and forth in the breeze and show which way the wind is blowing.

The arrangement shown in Figure 263 is somewhat more elaborate. The vane is also patterned after an arrow but is cut out of a piece of half-inch wood, twenty-four inches long, and three inches wide. The work of cutting out can be easily accomplished with the aid of a pocket-knife and a saw.

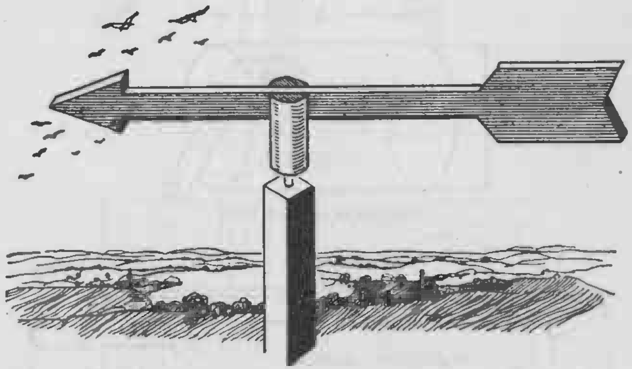


FIG. 263. — A more elaborate weather vane than the one shown in Figure 262.

The vane is set in a slot measuring half an inch wide and three-quarters of an inch deep cut in the top of a wooden cylinder, three inches long and an inch and one-half in diameter. It should be fastened with two or three small nails. The distance from the front end or tip of the arrow-head to the centre of the slot should be ten inches. This make the back part of the arrow fourteen inches long or four inches longer than the forward part. Before the vane is set in the slot, a quarter-inch hole should be bored through the axis of the cylinder to accommodate the rod set in the top of the pole. When the vane is finally set in the slot, place a strip of heavy sheet iron or brass, half an inch wide and an inch and one-half long in the slot in the cylinder under the arrow so that the upper end of the pivot rod will bear against the under side of the metal strip and not against the arrow. The continual swinging of the vane in the wind would soon cause the end of the rod to wear through the arrow if the latter were not protected by the metal.

A piece of one-quarter inch steel rod, six inches long, which is rounded at its upper end is driven in the top of a strong

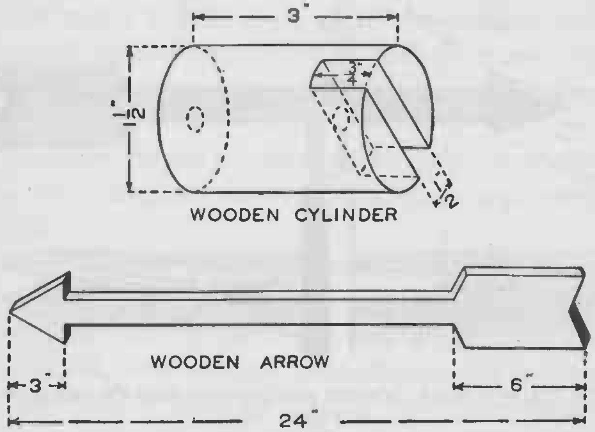


Fig. 264. — Details of the wooden arrow and cylinder for the weather vane.

wooden pole. The pole should be mounted on the roof or in some place in the yard where it is visible from the windows and open to the winds from all directions. A sheltered spot is quite useless for a weather vane.

The vane should swing freely on its pivot without friction. It is a good plan to smear a little grease on the rod before setting the arrow in place. A coating of paint or varnish will protect the vane from the effects of the weather and largely

eliminate any danger of the wood cracking or warping. After this is done, the vane is ready to set up in its final position in the wind.

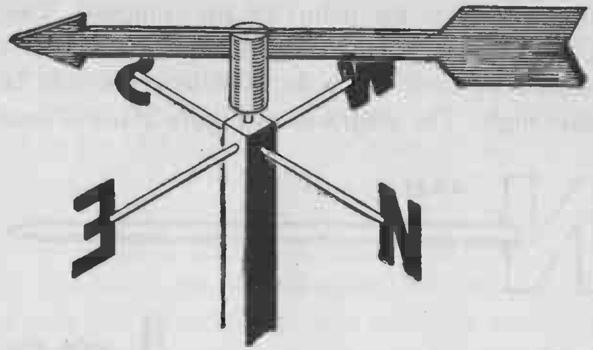


Fig. 265. — A weather vane which shows the points of the compass.

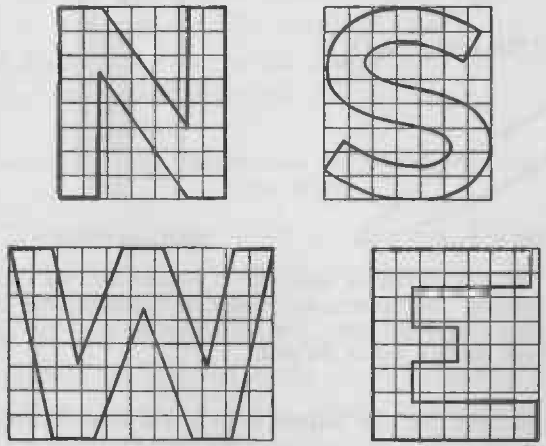


Fig. 266. — A guide for making the letters.

The tip of the arrow will swing around and point towards the direction *from which the wind blows* and you will have to use your general knowledge of which way the points of the compass lie in order to tell whether it is east or west or north or south.

It is quite an easy matter to provide your weather vane with four arms to indicate the points of the compass. The letters N, S, E, and W may be cut out of heavy sheet iron or tin and set in the ends of four iron rods. The letters should be about three inches high. The diagrams in Figure 266 will enable you

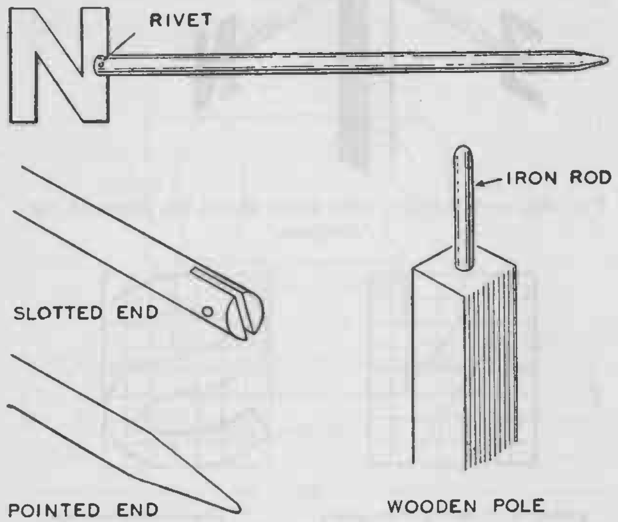


FIG. 267.—One end of each rod is pointed and the other is slotted. The letters are riveted or soldered into the slotted ends of the rods. The vane is set upon an iron rod driven into the top of the pole.

to make a pattern for the letters which will have the right proportions. Make four rectangles, three inches high and different lengths, as indicated, on a sheet of paper and divide each rectangle into the same number of squares as are shown in the drawing. You can then sketch the letters in by noting where the lines forming the letters meet the little squares in the illus-

tration. Paste the paper patterns on the sheet metal as a guide and cut the letters out with a pair of tin-snips.

Each one of the iron rods used to support the letters should be about thirteen inches long. One end should be pointed so that it can be driven into the pole under the weathervane. The other end is slotted for a distance of about one-half an inch to receive the letter. The bottom of the letter should be inserted in the slot and the latter squeezed tightly shut. The letters can be secured by soldering them to the rod or by drilling a small hole through both the rod and the letter and inserting a rivet which is afterwards hammered tight.

Bore four holes, 90 degrees apart, near the top of the pole and of just the right size so that the rods can be driven in snugly. You will have to set the pole in such a position so that the arm carrying the letter "N" points to the north, the "S" to the south, etc. This is easily accomplished with the aid of a compass. The weather vane is now such that you can accurately observe the direction of the wind and jot it down on your weather report.

The Anemometer—An Instrument for Measuring the Velocity of the Wind

The Velocity of the wind is measured by means of an instrument called an *anemometer*. It consists of a vertical rod having four horizontal arms mounted at the upper end and free to rotate. Each arm carries a hemispherical cup at the extremity. When the wind blows, the anemometer will revolve at a speed dependent upon the force of the wind. The velocity of the wind may be calculated by counting the number of revolutions which the anemometer makes.

The amateur observer can easily estimate the velocity of the wind without any instruments or apparatus with the aid of the following table.

Velocity of the Wind in Miles per Hour	DESCRIPTION
1.	Light Air. Scarcely perceptible movement of the air.
4.	Light Breeze.
10.	Gentle Breeze. Stretches a flag. Moves the leaves of trees.
17.	Moderate Breeze. Moves the small branches of trees.
24.	Fresh Breeze. Moves the larger branches of trees and the stems of plants.
32.	Strong Breeze.
40.	Moderate Gale.
48.	Fresh Gale.
56.	Strong Gale } Storm.
67.	Whole Gale } Storm.
82.	Storm.
100.	Hurricane.

However, such a method of ascertaining the speed at which the wind is blowing is of course not very accurate and depends to a great extent upon the judgment of the observer.

Any boy can make an anemometer which will enable him to determine the speed of the wind more accurately.

How to Make an Anemometer

The hemispherical cups used on the regular type of anemometer would be very difficult for the young experimenter to make and so it is suggested that they be built in the form of cones. Cut four circles, seven inches in diameter out of sheet tin and then cut a section equal to one-quarter of the circle out of

each. Bring the edges together until they overlap about one-eighth of an inch at the circumference and solder the seam together. The result should be four cones about five inches in diameter across the open end.

Each of the cones is to be mounted on the end of a horizontal rod. Two pieces of five-sixteenths inch round steel rod each

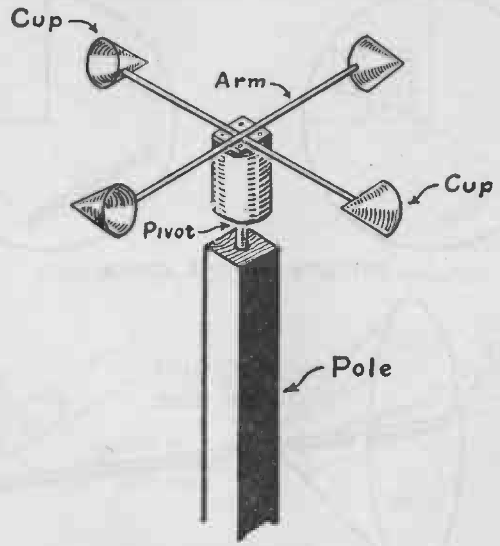


FIG. 268. — A homemade anemometer.

thirty-four inches long are required for the arms. Cut one of them exactly in half.

Drill a hole in each of the four cones, about one-half an inch back from the edge, into which the ends of the arms will slip. Pass the ends of the rods into these holes until they strike the opposite side of the cones in a corresponding position and solder them securely in place as shown in the illustration. Two cones should be mounted upon the long rod and one on each of the short rods. The two cones mounted on the ends of the long rod should face in opposite directions.

The illustration in Figure 270 shows how the arms are supported. *A* and *B* are the two short arms. *C* is the long arm and *D* is a piece of sheet iron or sheet brass, one and one-half inches square and one-eighth of an inch thick. The rods are securely fastened to *D* by riveting. The under side of each of the rods

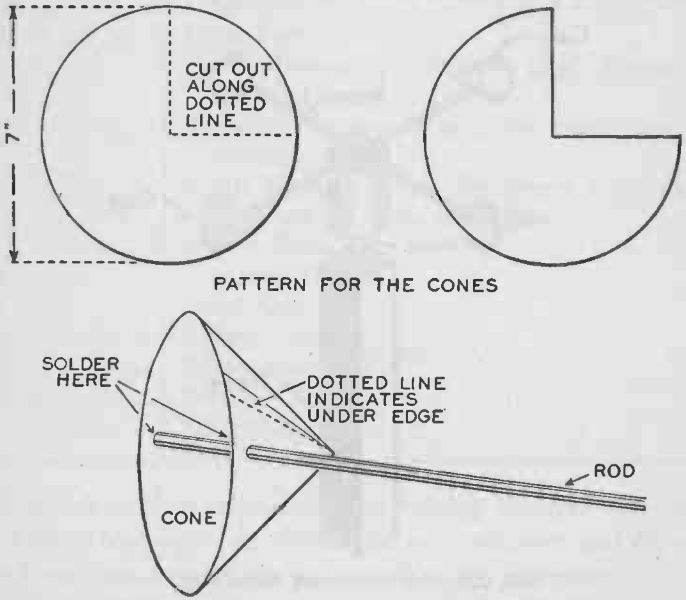


FIG. 269. — The pattern for the cones is a circle with a quadrant cut out as shown. A cone is soldered on each of the four rods.

A, B, and *C* are filed flat so that they will rest on *D* and then fastened firmly in position by several small rivets. Use care to see that the center of the rod *C* is exactly in the centre of the plate *D*. The open ends of the cones must be placed so that the wind can blow into each in turn as the arms spin around.

The brass piece *D* is fastened to the top of a hardwood cylinder about two and one-quarter inches in diameter and three

inches long by means of four screws passing through the holes *H, H, H, H,* in the metal. A three-eighths inch hole should be bored through the axis of the cylinder before *D* is screwed on top.

The anemometer is now ready to mount on the top of a short length of five-sixteenths inch iron rod, slightly rounded

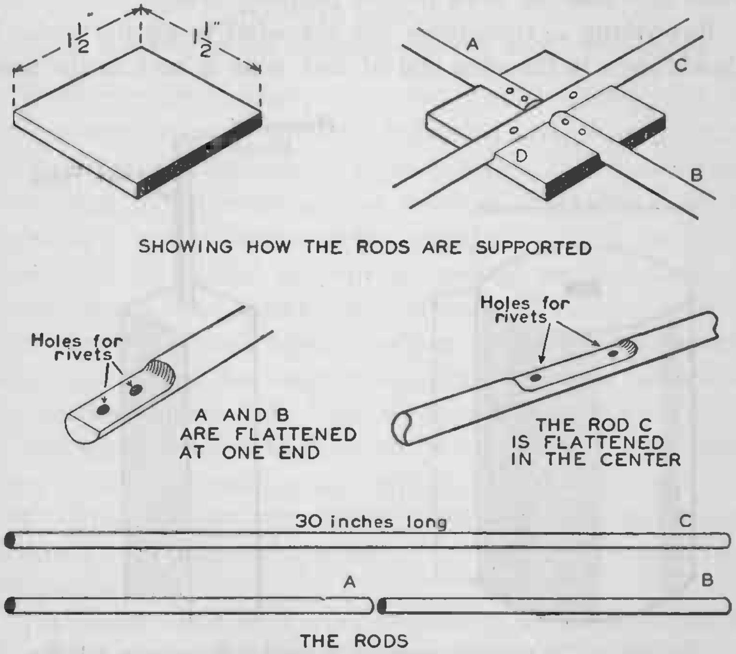


FIG. 270. — Details of some of the metal parts of the anemometer.

at the upper end and driven into the top of a strong pole. The rounded end of the rod will rest against the under side of *D* and form a bearing upon which the anemometer revolves. The pole should be mounted on the roof or in some place in the yard where it will be as high above ground as possible and where the wind will have a clear course to reach the apparatus. Some position where it may be conveniently viewed from the window is preferable.

Paint the tin cones and the rods, etc., so as to protect them from the effects of the weather. Paint three of the cones a light color and the fourth one dark so that it may be easily distinguished as it whirls around. Put some grease on the pivot and make sure that the arms revolve perfectly freely.

Everything is then ready for the wind to do its work. It should blow in the open end of each cone in turn as the arms

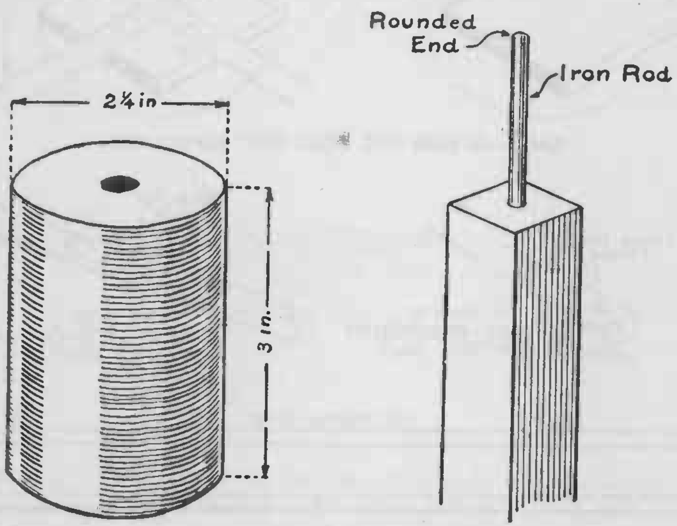


Fig. 271. — The rods and cones are fastened to the wooden cylinder and the cylinder is set upon an iron rod driven into a pole. The upper end of the rod should be rounded.

spin around and send the anemometer turning merrily when the breeze blows briskly. The dark cone will enable you to count the revolutions easily and with the aid of a watch you can find out how many times it goes around in a minute. If the revolutions are faster on one day than they are on another

you will know that the wind is stronger, and if they are fewer you will know that the wind is not so strong. The anemometer will show very much smaller changes in the velocity of the wind than it is possible to perceive without the aid of such a device.

Wind Pressure

What it means to the Engineer. How it may be Measured.

Wind pressure is a very important consideration to the engineers who design or build tall buildings, bridges, etc. Structures of that sort offer such a large surface to the effects of the winds that the pressure against them in an ordinary breeze amounts to many thousands of pounds. A wind having a velocity of fifty miles an hour is nothing unusual during a storm. Such a wind would exert a pressure of about *seven hundred and fifty pounds* upon a surface of one hundred square feet. An area *ten feet long by ten feet wide* has a surface of one hundred square feet. Gales sometimes reach a wind speed of one hundred miles an hour and exert a pressure of about *three thousand pounds* upon a surface of one hundred square feet. From this you can readily form some idea of the tremendous wind pressure upon the sides of a tall skyscraper during a storm.

The construction of a wind-pressure gauge is as simple as that of the weather vane and anemometer already described. It consists of a flat surface, mounted in much the same manner as a weather vane, and arranged so that the pressure of the wind against the surface is indicated on a spring scale.

The surface may be a sheet of heavy tin or a thin board about a quarter of an inch thick. It should be twelve inches square. A wooden cleat, ten inches long and one and one-half inches wide is fastened across the centre of the back of the surface to stiffen it. If the surface is made of wood, the cleat should run across the grain so as to eliminate warping or splitting.

A wooden dowel, twenty-four inches long and half an inch in diameter is driven in a hole in the centre of the cleat so that it is at right angles to the surface of the disk.

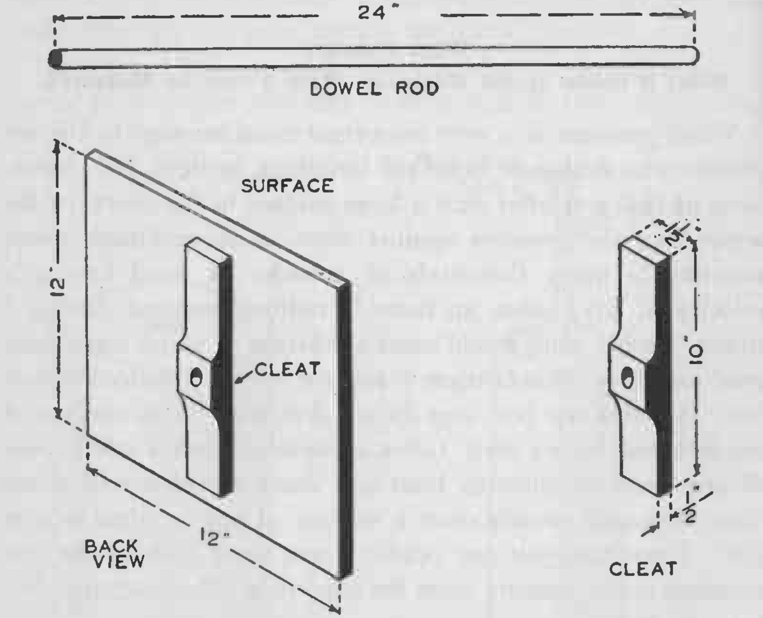


FIG. 272. — Details of the surface for the wind pressure gauge.

The wind vane which keeps the surface headed up against the breeze, is a piece of board, twenty inches long, five inches wide and three-quarters of an inch thick.

Two screw eyes, *A* and *B*, are inserted in the end for receiving the rod upon which the apparatus swings. The diameter of the holes in the screw eyes should be such that they are just large enough to slip over a three-eighths inch iron rod and swing freely. A strip of one-eighth inch brass or iron, three

inches long and three-quarters of an inch wide is fastened to the top edge of the vane by means of two screws and allowed to project over the end of the vane about one inch. The upper end of the rod upon which the vane swings, rests against the under side of this bearing.

The wooden dowel fastened to the back of the surface slides back and forth in two screw eyes, *C* and *D*. A spiral spring

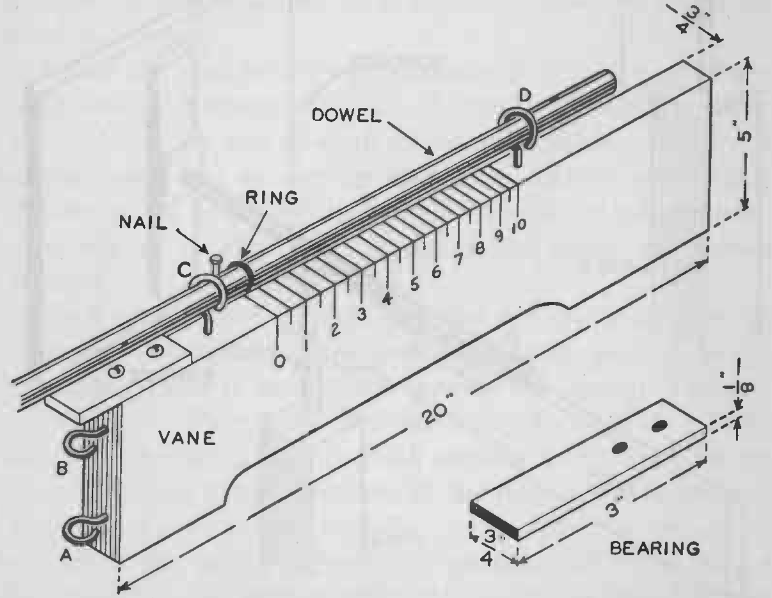


FIG. 273. — Details of the vane and the bearing for the wind pressure gauge.

made of stiff wire is placed over the dowel rod, between the back of the cleat and the screw eye, *C*. A little experimenting will probably be necessary in order to secure a spring of just the right tension because if the spring is too strong, the wind will not be able to move it and if it is too weak, an ordinary breeze will push the rod back so far that the apparatus will not be able to indicate the pressure of a strong breeze.

The gauge is now ready to *calibrate* or mark so as to show the particular wind pressure to which any movement of the dowel corresponds. Push the surface in towards the screw eye, *C*, until the spring touches both the screw eye and the back of the

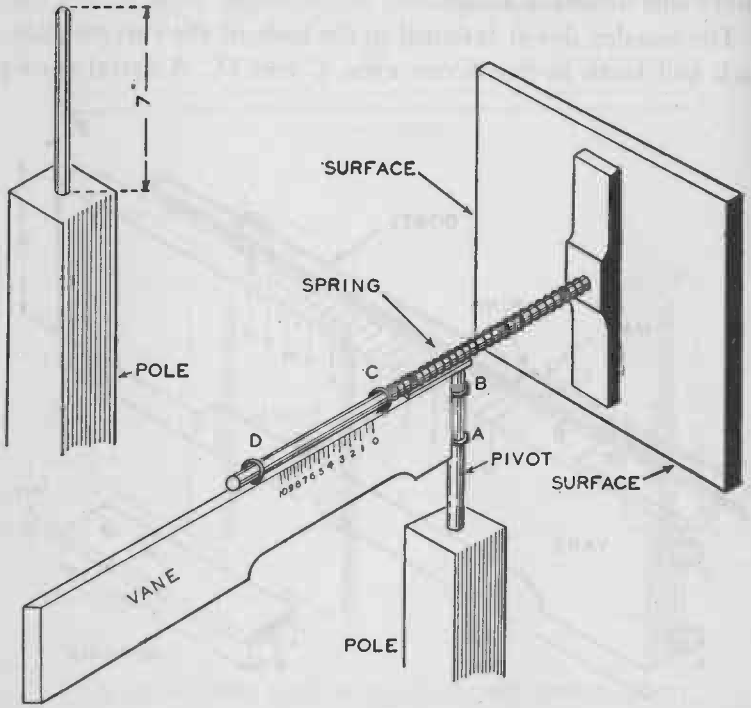


FIG. 274. — The pivot upon which the wind pressure gauge swings is an iron rod set into the top of a pole.

cleat but is not compressed or squeezed at all. Then drive a wire nail through the dowel rod close against the opposite side of the screw eye, *C*, so that the surface cannot move forward away from the spring.

The apparatus operates as follows; the wooden vane will swing around with the breeze so that the wind always blows

directly against the surface. The pressure of the wind against the flat surface will tend to compress the spring and move the dowel rod back. The stronger the wind, the greater will be the pressure and the farther the rod will move.

A wind of any certain velocity will always exert a certain amount of pressure against each square foot of flat surface. Therefore if we know how much pressure the wind exerts upon any certain area it is easy to ascertain the speed at which the wind is blowing.

Fasten the vane securely by clamping it in a vise or temporarily nailing it against the side of your work-bench or table. Tie the hook of a pair of small spring scales to the opposite end of the dowel rod to that on which the surface is mounted. Pulling on the scales will indicate the number of pounds pressure required to move the rod against the spring any certain distance.

Mark a black ring around the dowel rod and a line directly underneath on the top of the vane showing the position of the ring when there is no pressure against the spring. Call this point "zero." Then pull on the scales slightly until the pointer indicates one-half a pound. Mark another line directly on the top of the vane directly underneath the ring on the dowel rod. Then pull a little harder until the pointer indicates one pound and mark this point. Repeat this operation until you have a line indicating the amount which the rod moves back for each one-half pound of pressure against it from zero to ten. You can then carry the lines down the side of the vane a short distance and mark the figures below them to which they correspond.

The wind-pressure gauge should be set on the end of a blunt iron rod driven in the top of a pole which is in some accessible place exposed to the wind. The rod should be exactly vertical and the apparatus should swing freely. It is a good plan to lubricate the screw eyes with a little grease so that all the friction is eliminated as far as possible.

The following table shows the pressure in pounds which winds of different velocities exert upon one square foot of surface. Since the surface on the gauge just described equals one square foot, it will be easy to gain a fairly accurate idea of the speed at which the wind is blowing by examining the indicating mechanism to find how far the rod is being pushed back; then refer to the following table.

MILES PER HOUR	VELOCITY FEET PER MINUTE	FEET PER SECOND	PRESSURE ON ONE SQUARE FOOT	CHARACTER OF WIND
1	88	1.5	.003	Barely observable.
2	176	2.9	.012	Just perceptible.
3	264	4.4	.027	
4	352	5.9	.048	Light Breeze.
5	440	7.3	.075	
6	528	8.8	.108	Gentle, pleasant wind.
8	704	11.7	.192	
10	880	14.7	.3	Fresh Breeze.
15	1320	22.	.675	Brisk Breeze.
20	1760	29.4	1.2	Stiff Breeze.
25	2200	36.7	1.875	Very brisk breeze.
30	2640	44.	2.7	High Wind.
35	3080	51.3	3.675	
40	3520	58.7	4.8	Very high wind.
45	3960	66.	6.075	Gale.
50	4400	73.4	7.5	Storm.
60	5280	88.	10.8	Great storm.

The Moisture in the Atmosphere

The atmosphere surrounding the earth is composed principally of air and water vapor. The air itself does not undergo

any change as far as its quantity is concerned but the amount of water vapor is, by the ceaseless processes of evaporation and condensation, always changing.

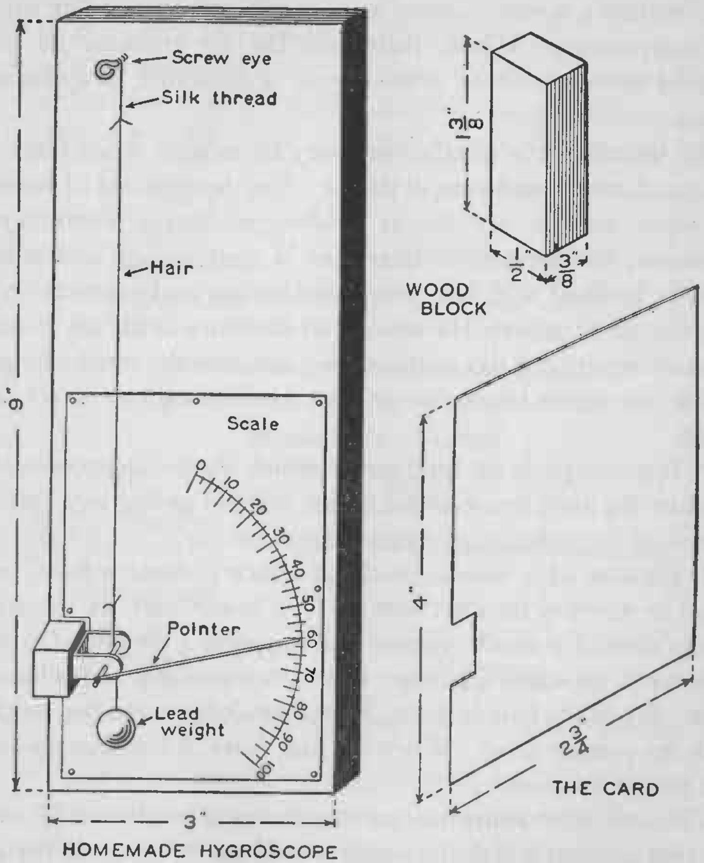


FIG. 275.—A homemade hygroscope for measuring the moisture in the air. For further details see Figure 276.

Water vapor is constantly being added to the atmosphere from the surfaces of lakes and rivers, snow and ice, from moist ground, and from plants. The evaporation of water into the atmosphere increases in warm weather or with a rise in temperature, because the amount of moisture which the air can absorb is increased with the temperature. The atmosphere can only contain a certain definite amount of water, depending upon the temperature. When, therefore, the air contains its full load of moisture, or in other words is *saturated*, evaporation ceases.

No instrument is usually necessary to indicate when there is an abundance of moisture in the air. The discomforts of humid or moist weather are plainly evident without a *hygroscope*. However, the boy who is interested in meteorology and scientifically inclined will find great satisfaction and pleasure in a hygroscope to indicate the amount of moisture in the air so that he can compare one day with another and note the small changes which our senses themselves are not keen enough to detect unaided.

A hygroscope is an instrument which shows approximately whether the air is more or less moist, without giving any indication as to the quantity of moisture present.

It consists of a wooden back on which is fixed a hair, fastened at the top to a set screw. The lower part of the hair passes around a small cylinder and supports a weight. On the cylinder is attached a pointer which moves along a graduated scale. When the hair is moist, it becomes longer and the weight pulls the pointer down. When the hair dries, it becomes shorter and the needle rises.

The scale over which the pointer moves is graduated by calling that point at which the needle would stand, zero—if the air were completely dry and the point at which the pointer stands when in air completely saturated with moisture, 100.

How to Make a Hygroscope

The wooden back is nine inches long, three inches wide and three-quarters of an inch thick. It is planed or sand-papered smooth and given two coats of shellac as a finish.

A small wooden block, one and three-eighths of an inch high, one half an inch wide and three-eighths of an inch thick is glued in a notch cut in the lower left-hand side of the wooden back.

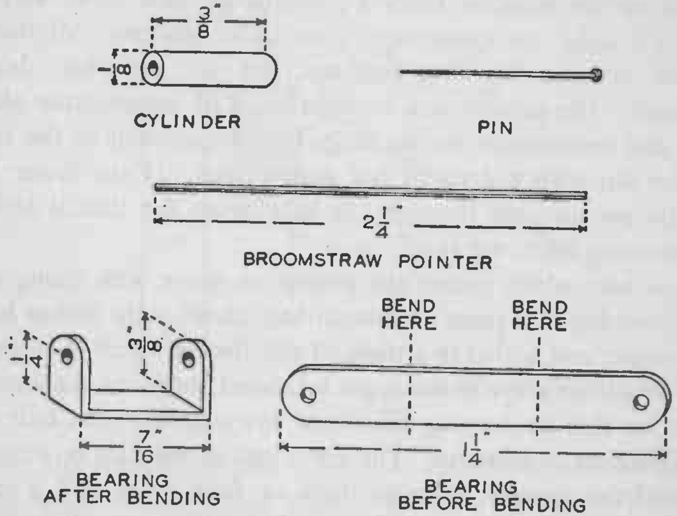


FIG. 276. — These details of the hygroscope are explained in the text.

The bearing for the pointer is formed by a U-shaped piece of strip metal which may be brass or tin, fastened to the side of the block. It is three-sixteenths of an inch wide and one inch and one-quarter long. The ends are rounded slightly and the strip bent into the shape and according to the dimensions shown in Figure 276. The dotted lines indicate the proper places for bending. The two small holes, *H* and *H*, should be only just large enough to pass an ordinary dressmaker's pin which is used as the shaft to support the pointer. The shaft passes through a small wooden cylinder, three-eighths of an inch long and one eighth of an inch in diameter. It may be necessary to make several of these little cylinders before you secure one which will not split when you drive the pin through. A little care and patience will solve the problem, however. The pin should pass through the axis of the cylinder so that when it revolves it will turn perfectly true and not wobble. The bearing is fastened to the wooden block by means of two small screws, "gimp" tacks, or escutcheon pins. The wooden cylinder is placed between the two bearings and the pin then driven through. The pointer is a straight piece of broomstraw about two and one-quarter inches long, firmly cemented to the head of the pin with a drop of hot sealing-wax. If the lower end of the pin projects through the bearing so far that it strikes the wooden back, cut it off.

The hair which causes the pointer to move with changes in the humidity is a piece of human hair about eight inches long. The upper end is tied to a piece of silk thread which is fastened to a small screw eye in the upper left-hand corner of the wooden back, so that by turning the screw eye carefully, the hair can be tightened or loosened. The lower end of the hair is wrapped around the wooden cylinder three or four times and a small weight hung on the end. The weight may be a small lead ball about one quarter of an inch in diameter or slightly larger. Make a deep cut in the ball by hammering in the sharp edge of a penknife. Place the end of the hair in the cut and then squeeze the ball together with a pair of pliers.

The bearing should be perfectly free, so that touching the hair with the finger will cause the pointer to move. A piece of stiff white cardboard is cut according to the shape and dimensions shown in Figure 275 and fastened to the bottom of the hygroscope for the scale. The square notch cut in the left-hand

side will allow the card to fit around the wooden block which supports the bearing.

The Scale is Graduated by first enclosing the hygroscope in a large jar or stone crock with several strips of moist blotting paper hanging near the hair but not touching it. The hair will lengthen under the influence of the moisture and after a lapse of six or eight hours the hygroscope should be removed from the jar and a pencil mark made on the scale directly under the

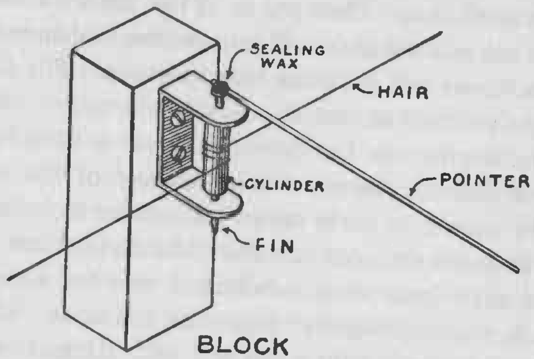


FIG. 277. — This sketch shows how the parts of the hygroscope are assembled.

tip of the pointer. If the pointer is not at the bottom of the scale, move the screw eye slightly so as to loosen the hair and allow the pointer to drop to the most desirable position in which to locate the 100 mark.

Allow the hygroscope to remain in the bright sunshine in the open air for several hours until the pointer has resumed its normal position. Dry the jar or crock out thoroughly and then place the hygrometer back in it, this time together with a dish of *fused calcium chloride* instead of the blotting paper. Calcium chloride is known as a *hygroscopic* chemical because it has the power of absorbing moisture from the air. Fused calcium chloride is not very expensive and can be obtained at any chemical supply house. Its chemical composition is such, that it might be called a "brother of salt." Ordinary salt also has the property of absorbing moisture from the air as all of us know who have ever tried to use a salt-shaker during damp weather or at the seashore. Ordinary salt is not hygroscopic to the same degree as fused calcium chloride however and cannot be substituted for the latter in graduating the hygroscope.

If the calcium chloride is not thoroughly dry, place it in a warm oven until it is. Then put it in the jar with the hygroscope. The calcium chloride will remove the moisture from the jar in a few hours and cause the hair to shrink. The jar should be kept tightly closed so that the outside air cannot enter.

After the hygroscope has been in the jar several hours, the pointer will indicate the maximum dryness of the air and a pencil mark should be made under the pointer to indicate zero. The space between zero and 100 should be divided into ten equal spaces and each space then subdivided into ten equal smaller spaces, each representing one degree on the scale. These lines should be neatly made with a pen and ink. Extend every tenth graduation a little farther than the others and number them, 0, 10, 20, 30, or whatever value the position indicates.

What Dew is and how it is Formed

Has your mother ever told you not to play in the grass in the evening because the dew would wet your feet? Those tiny beads of water probably spoiled many a good wrestling match or game of tag. To you they were only a nuisance; the dew is, however, an important provision of Nature and it took learned men many hundreds of years to find what these simple drops of water really were and to solve the mystery of whence they came. During long periods of drought, the moisture provided by the evening dew is all that prevents vegetation from completely drying up.

The atmosphere around the earth contains, as we know, a great deal of water vapor. This vapor greatly impedes and cools the rays of the sun so that we are not burned on a hot summer's day as would be the case if the air were perfectly clear and free from moisture. The terrible heat of a desert is largely due to the fact that there is no moisture in the atmosphere there and the sun's rays find no interference in their path.

During the day while the sun is shining, the earth absorbs a great deal of heat and at night, when the earth has passed out of the sunlight, it radiates this heat. This same moisture in the air which interferes with the heat of the sun coming to us during the day and prevents us from burning up, offers an obstruction to the earth's heat escaping at night and prevents us from suddenly becoming so cold that we would otherwise be frozen in a single summer's night.

Those objects such as sticks, stones, plants, grass, etc., on the surface of the earth, absorb or radiate heat more quickly than the air and so are the first to lose their heat at night and to become cooled. They cool off so quickly that their temperature falls below that of the atmosphere. The layer of air which is in immediate contact with these chilled bodies becomes cooled also.

Now one of the laws of Nature is that cool air cannot absorb and retain as much moisture as warm air, and so these chilled layers of air, just above the surface of the earth, deposit a portion of the vapor or moisture which they contain, in the form of minute globules of water, just as the air in a room deposits some of its water on a pitcher or glass of ice water.

The state of the sky and the wind exercise a great deal of influence on the formation of the dew and the amount deposited. If the sky is cloudless, the earth radiates much more heat than on a cloudy night, therefore, becoming very much more chilled, there is an abundant deposit of dew. But if there are clouds in the sky, they in turn radiate heat towards the earth and prevent the earth's heat from passing out into the planetary spaces so that bodies on the surface of the earth only undergo a feeble chilling and no deposit of dew takes place.

A gentle breeze increases the amount of dew, because it renews the cold air frequently, but a strong wind on the other hand produces the opposite effect, for, although it moves the air about, it does not allow the air to remain in one place long enough to become cooled.

Frost is formed when the temperature drops so low that the dew freezes.

Why Moisture Collects on the Window Panes in Cold Weather

Have you ever noticed how moisture collects on the inside of the window panes during the winter time but not usually in the summer? The formation of this moisture on the windows takes place in the same manner as that of the dew on the ground. The air in the room contains moisture, during both the summer and the winter, but in warm weather the glass panes are no cooler than the air inside. In the winter, however, the cold air outside, cools the window panes and chills the air next to them on the inside of the room. This air then cannot retain the load of moisture which it was carrying before it was chilled, and so gives it up to the cold windows and they become wet and steamy.

On an extremely cold day, the moisture freezes and forms the beautiful frost designs attributed to Jack Frost.

This same process is the explanation of why we are able to "see our breath in winter." The air is inhaled into the lungs, warmed and charged with moisture. When it is exhaled into the cold air it is suddenly chilled and the moisture condenses forming a white vapor which we are able to see.

The Dew-Point

It has already been explained that when a layer of air comes into contact with a cold object, as for instance, the window pane or a pitcher of ice water, the air loses part of its moisture, the latter collecting on the glass in the form of dew. When the temperature rises again, the dew disappears. The temperature which is halfway between the point at which the dew *forms* and that at which it *disappears* is called the *dew-point*. In other words it is the temperature at which the moisture in the air is in a sort of equilibrium, that is ready to form into dew or ready to evaporate, depending whether the temperature rises or falls.

The dew-point varies from day to day according to how much moisture there is in the air.

It practically determines the lowest temperature which may be expected during the night. It is therefore possible, by determining the dew-point, to foresee the approach of frost or low temperatures liable to injure vegetation in the garden and to accordingly take proper precautions to provide against it.

The dew-point is another interesting observation for you to add to your work as a weather prophet and to the record on your weather-chart. It is quite a simple matter to determine the dew-point early in the evening and so foretell the lowest point to which the thermometer is liable to drop during the night.

You will need two ordinary thermometers. The bulb at the bottom of one should be wrapped with two or three layers of white muslin which hang down below the bulb about two inches. Fasten a small pill-bottle or medicine vial to the base of the thermometer so that the neck is about an inch below the bottom of the bulb and stuff the lower end of the muslin into the bottle. Wet the muslin with water and fill the bottle nearly full. The bottle will act as a reservoir and keep the muslin which is wrapped around the bulb continually moist. This thermometer is now what is known to scientists as a "wet-bulb"

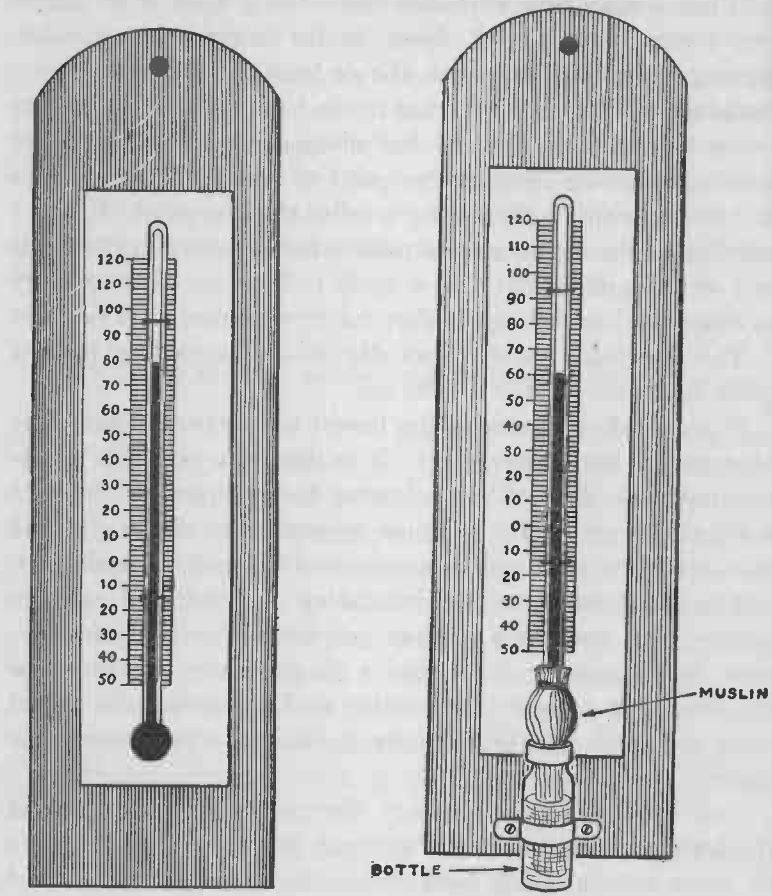


FIG. 278. — An ordinary Fahrenheit thermometer is shown at the left and at the right, the same thermometer converted into a "wet bulb" thermometer.

thermometer. Hang the two thermometers, one with the wet muslin around the bulb and one without, alongside of each other in a sheltered spot on the porch or just outside of the

window where they can be conveniently seen. Unless the air is saturated with moisture the wet-bulb thermometer will always indicate a lower temperature than the other. This is due to the evaporation of the moisture on the muslin. The drier the air, the greater will be the difference between the two thermometers.

The temperature of the dew-point may now be very easily obtained with fair exactness with the aid of the following table. The numbers in the right hand column are what are known as *Glaisher's factors.* Factors are given for varying degrees of temperature up to 85 degrees Fahrenheit, as indicated in the left hand column. In order to find the dew-point subtract the temperature shown by the wet-bulb thermometer from the temperature of the dry-bulb thermometer. Multiply the difference between the two by the factor in the table, corresponding to the dry-bulb temperature. Then subtract the product from the dry-bulb temperature and *the answer is the DEW–POINT.*

In order to make the method of performing this calculation more clear, we will assume that the temperature of the dry-bulb thermometer is 80 degrees and that of the wet-bulb is 70 degrees.

80 (Dry-bulb temperature)
Subtract 70 (Wet-bulb temperature)
10 Difference.

The factor for 80 degrees (dry-bulb temperature) is 1.6.

10. Difference
Multiply 1.6 Factor
16. Product
80 (Dry-bulb temperature)
Subtract 16 (Product)
64 degrees—The dew point

GLAISHER'S FACTORS

Dry-bulb Temperature Fahrenheit	Factor	Dry-bulb Temperature Fahrenheit	Factor
Below 24 degrees	8.5	34—35 degrees	2.8
24—25 "	6.9	35—40 "	2.5
25—26 "	6.5	40—45 "	2.2
26—27 "	6.1	45—50 "	2.1
27—28 "	5.6	50—55 "	2.0
28—29 "	5.1	55—60 "	1.9
29—30 "	4.6	60—65 "	1.8
30—31 "	4.1	65—70 "	1.8
31—32 "	3.7	70—75 "	1.7
32—33 "	3.3	75—80 "	1.7
33—34 "	3.0	80—85 "	1.6

How to Make a Weather-Cottage

The Hygroscope which has been described in some of the preceding pages is only one of the many interesting devices in which advantage is taken of the fact that certain substances are affected by changes in the amount of moisture in the air, called *absorbtion hygroscopes.*

To this class of hygroscopes belong the chimney ornaments, one of the most common forms of which consists of figures of a man and a woman, so arranged in a little house that when it is damp, the man comes out and when it is dry the man goes in and the woman comes out.

These little "weather-cottages," as they are known, are founded on the property which a twisted string of catgut possesses of untwisting when moist and of twisting when dry. The figures of the man and woman are mounted on a little

turntable which is suspended on a violin string. A violin string is made of catgut and will absorb moisture from the air

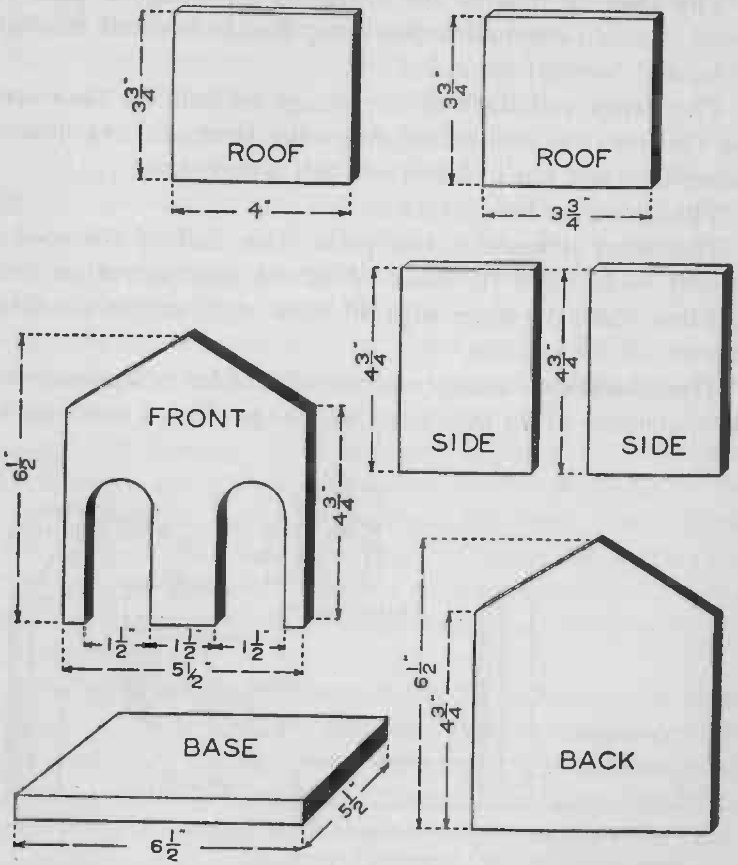


FIG. 279. — The wooden pieces which make up the weather cottage.

when it is damp and untwist, thus causing the man to come out. When the air becomes dry, the string twists tighter and the turntable revolves causing the man to go in and the woman to go out.

It is a simple matter to make a weather cottage out of the wood from some old boxes.

The Base or floor of the cottage is a rectangular piece of wood, six and one-half inches long, five inches and one-half wide, and one-half an inch thick.

The Front and Back of the cottage are both the same size, but the front has two arched doorways, three and one quarter inches high and one inch and one-half wide cut out.

The Sides are both identical.

The Roof is made in two parts. One half of the roof is slightly wider than the other. Nail the narrow one on first, and then plane the upper edge off at an angle so that the other part of the roof will fit.

The Chimney is made from a small wooden cube, measuring three-quarters of an inch along each edge. Saw a notch in the bottom so that it will fit on the peak of the roof and glue it firmly in position, three-eighths of an inch from the front edge. When the glue has dried, bore a quarter-inch hole down through the centre of the chimney and through the roof below.

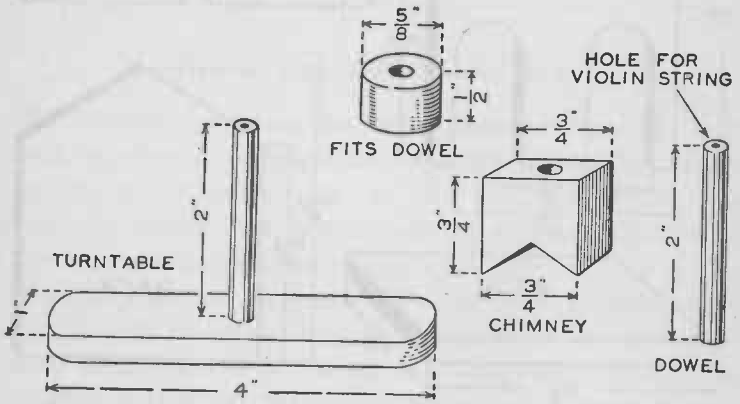


FIG. 280. — Details of the chimney and turntable for the cottage.

The Turntable is a strip of wood four inches long, one inch wide, and one-quarter of an inch thick. The ends are rounded. A quarter-inch hole is bored in the centre and a piece of dowel stick of the same diameter and two inches long, driven in and glued. The upper end of this dowel should have a small hole drilled down through the axis for about one-half an inch. The lower end of the violin string is wedged and glued in this hole.

The upper end of the violin string is glued in the end of a piece of one-quarter inch dowel, two inches long. This dowel passes through the hole in the chimney and should be adjusted so that the turntable swings about three-sixteenths of an inch above the floor of the cottage. When you find the right position, wedge the dowel in the chimney with a small splinter of wood. Bore a quarter-inch hole in a piece of five-eighths inch dowel, half an inch long and slip it over the end of the dowel which projects through the chimney. Push it down snugly against the top of the chimney and glue it in position so that after the wedge which holds the dowel in position, has been removed, the turntable will still remain the proper distance above the floor. This arrangement permits the top of the chimney to be turned with the fingers so that the hygroscope may be properly adjusted.

The Man and the Woman should be about one and three-quarter inches high. They may consist of small "paper dolls" pasted on heavy cardboard or of the small "china dolls" which may be purchased at a toy store. The realistic appearance of the figures may be greatly improved by painting with water colors or dressing with tissue-paper clothes.

Glue them on opposite ends of the turntable so that the centre of each figure is one and one-half inches from the centre of the turntable and will pass through the centre of the door. The figures should balance on the turntable. This can be accomplished by adding a small piece of metal or tinfoil to the high side. Neither of the figures or the turntable should touch any part of the cottage as they swing around.

Smear some glue over the base or floor of the cottage and then sprinkle on some sand. After the glue has dried, brush

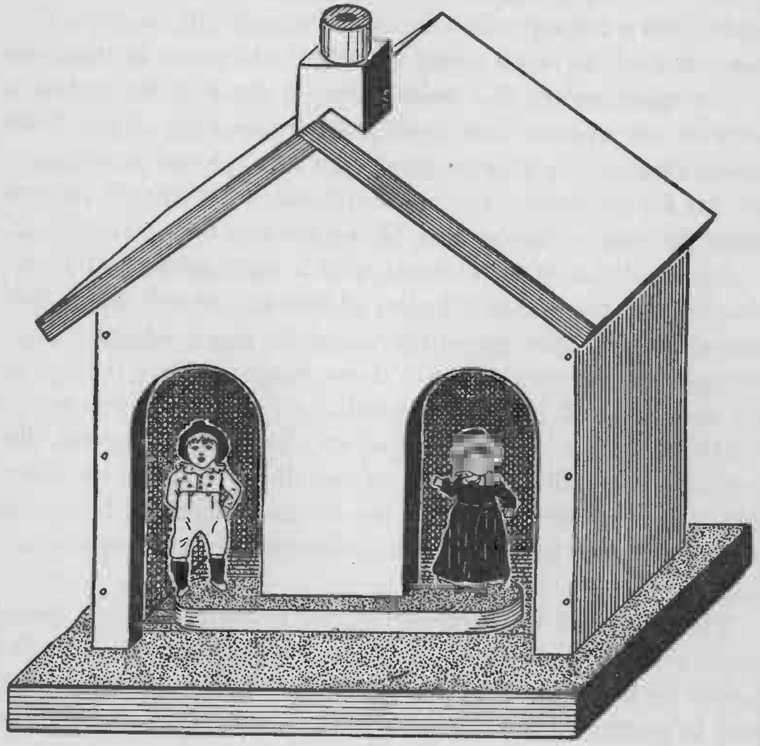


FIG. 281. — The completed weather cottage.

off the surplus sand. Paint the cottage and the turntable and it is finished. It will merely be necessary to turn the top of the chimney so that the proper adjustment of the turntable is secured and then after that the little man and woman will be faithful weather prophets. Whether the man comes out in

damp weather and the woman comes out in dry or vice versa will depend upon which direction the strands in the violin are twisted or upon which end of the turntable you place the respective figures.

A Floral Barometer

Certain chemicals undergo a very marked change when under the influence of moisture. One of these, chloride of cobalt, possesses the power of changing its color when the moisture

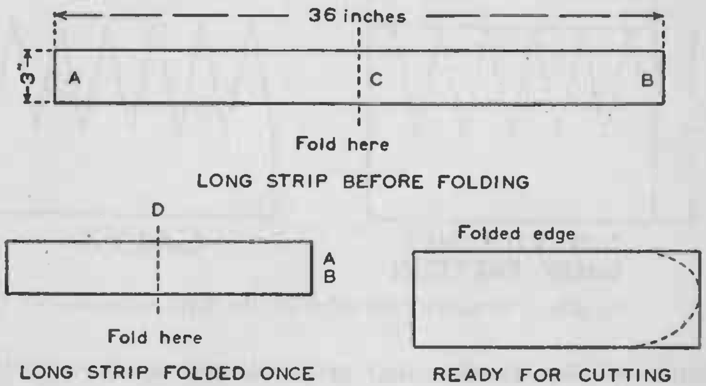


FIG. 282. — The petals of the floral barometer are cut from a long strip of paper folded and trimmed as shown above.

in the atmosphere varies. This property of cobalt can be turned into practical account by making a bouquet of artificial flowers which will vary their color with changes in the humidity.

Some tissue-paper flowers will be needed to form the bouquet. About one-half of them should be *pink* and the other half *blue*. Tissue-paper flowers are very easy to make. Take a strip of pink crepe paper about thirty-six inches long and three inches wide and fold it in the center as shown by the dotted line, *C*, in Figure 282. Then fold it in the centre again as at *D*, Figure

282 and repeat this until you have folded the strip five times. You will now have thirty-two thicknesses of paper folded up into a small flat bundle. Make a pencil mark as indicated by the dotted line and cut around it with the scissors, taking care that the folded edge and not the outside edge is on the side indicated in the illustration. After cutting, unfold the strip and it will show sixteen petals. Curl the edges of each petal by scraping them between the edges of the scissors and your

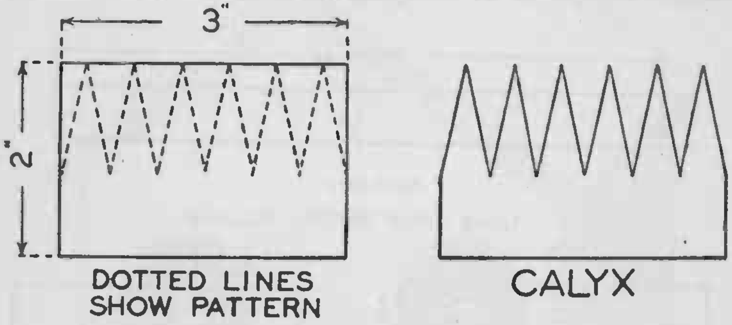


Fig. 283. — Pattern for the calyx for the floral barometer.

thumb. Gather the first four petals closely together and then gradually gather the others in around so as to form a flower.

Cut six sharp points in a strip of green crepe paper, three inches long and two inches wide, and then wrap them around the outside of the flower, at the bottom, so as to form a calyx. Fasten one end of a piece of stiff wire to the flower to form a stem and then wrap the wire with green crepe paper and the flower is done.

You should make several flowers from pink paper and several from blue. You may make any sort that you wish provided that you use these two colors.

Purchase a small quantity of *chloride of cobalt* at a drug store and dissolve it in a little water. Then dip the flowers

in the solution and let them dry. If the solution is not very strong, it may be necessary to dip them several times, letting them dry after each bath. After the flowers have dried, they are ready for use.

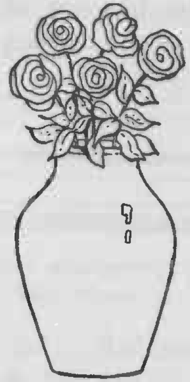


Fig. 284. — The floral barometer. The flowers change color with changes in the humidity.

When the weather is going to be damp, the flowers will retain their natural color, that is, the pink flower will remain pink and the blue flowers blue. However, when dry weather approaches, the pink flowers will change to purple and the blue flowers to green.

How to Make a Chemical Weather Glass

Perhaps you have often seen the curious looking glass tube, known as a *weather glass* and by which it is possible to a certain extent to foretell the weather, hanging alongside of the thermometer on a front porch and have wondered what it is and how it works.

It is a *chemical* "weather glass" and is very easy to make at home.

You will first require an ordinary glass test-tube. One measuring five inches long and about five-eighths of an inch in diameter will be about the right size, although it is not essential that the tube should be of any certain length or diameter. A

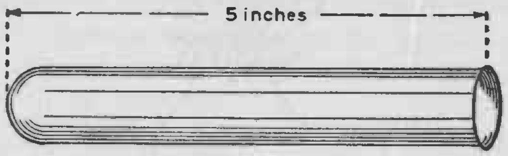


FIG. 285. — The test-tube used in making the weather glass.

wooden back, six and one-half inches long, three inches wide, and half an inch thick or for that matter of any proper size upon which to mount the tube, should be made and given two coats of shellac or varnish as a finish. The tube may be fastened to the back by means of two small sheet-brass or tin straps.

Those boys who may be lucky enough to possess or have access to a fairly sensitive pair of balances can mix the chemical solution, with which the glass is to be filled, themselves if they wish. Inasmuch, however, as the chemicals will have to be purchased at a drug store, it will probably be just as well to have the druggist weigh them out accurately and make the mixture for you. The solution should not cost over twenty-five cents if you supply your own bottle. It consists of

2 ounces of water
2 ounces of alcohol (absolute)
½ dram of ammonium chloride
½ dram of potassium nitrate
2 drams of camphor.

All these substances are common chemicals and not expensive. You are probably familiar with *camphor* and know what it is. *Absolute alcohol* is alcohol which is perfectly free from water. *Ammonium chloride* is also known as sal ammoniac and you may possibly have used it before in making a battery. *Potassium nitrate* is sometimes also called *saltpeter*.

These chemicals must all be mixed in their proper proportions, according to the formula given above, or the weather glass will not operate properly. The solid ingredients may

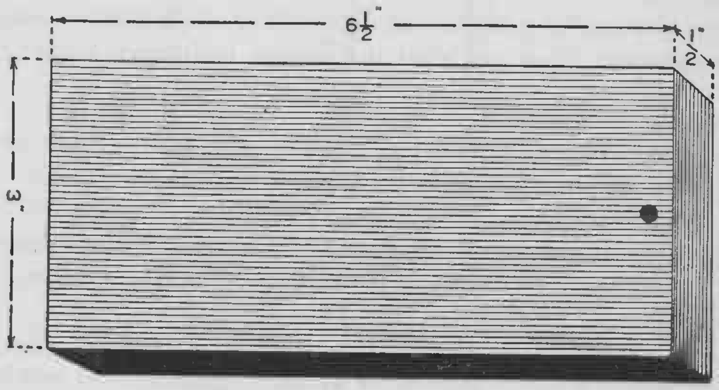


FIG. 286. — The wooden back for the weather glass.

not dissolve quickly. If so, they may be assisted by shaking the bottle. When the mixture has properly dissolved, fill the test-tube to within about three-quarters of an inch from the top and close it with a cork so that no dust or dirt can get in.

The tube is now ready to be mounted on the wooden back, and hung up ready for use. It may, of course, be hung wherever you wish, but the best place is where it will be exposed to the north and in a shady place out of the direct rays of the sun. The glass should be provided with a small scale, made of a strip of paper, fastened to the wooden back with shellac.

Draw a line on the scale about one inch and one-quarter from the bottom of the tube and mark it "FAIR." Mark two other lines, one about one inch and one-eigthth and the other two and one quarter inches above the bottom line. Mark the middle line "CHANGE" and the top "STORMY." After the scale has been marked and has thoroughly dried, it should be given a coat of white shellac or varnish to protect it from the weather.

The appearance of the liquid will change when the weather is going to change. On some days it will be clear, on others somewhat milky and then again on other days, full of snow-like crystals. Here are what the various indications mean:

CLEAR LIQUID—Fair weather.
CRYSTALS NEAR BOTTOM—Fair weather, with humid air in summer and heavy frost in winter.
DIM LIQUID—Storm.
CRYSTALS RISING IN TUBE AND APPROACHING POINT MARKED "CHANGE"—A change in the weather. Probably a storm.
TUBE FULL OF CRYSTALS—Storm.
CRYSTALS SINKING IN TUBE AND PASSING POINT MARKED "CHANGE"—A change in the weather. Probably clear weather.

Of course you will wonder how the weather causes the appearance of the liquid in the tube to change. The reason is very simple. Suppose that you mix some ordinary salt with water. The first salt will dissolve, but if you keep on adding more to the water, the point will soon be reached at which *no more salt will dissolve*. The solution is then said to be *saturated*. If you warm the solution so that it becomes slightly hot, you can add more salt and it will dissolve. If then you let the solution cool off, the salt which dissolved and disappeared when the solution was warmed, will appear again in the bottom of the liquid in the form of large crystals. This shows that a solution

which is warm will dissolve more salt than one which is cold. Another peculiar fact about solutions is that certain ones will *absorb* water from the atmosphere on a damp day and *evaporate* slightly on a dry day.

The solution in the chemical weather glass is very *critical*, that is, very slight changes in temperature, in the amount of

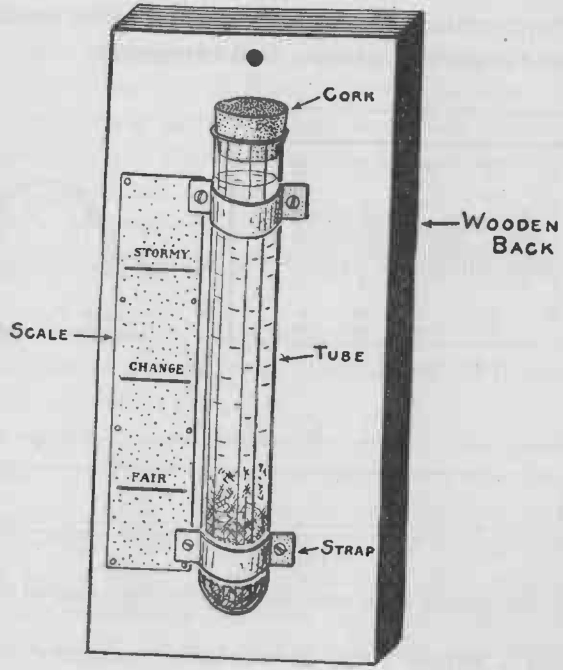


FIG. 287. — The completed weather glass.

moisture in the air, etc., affect the amount of chemical salts, (*potassium nitrate and ammonium chloride are salts*) which the liquid can *hold in solution* and on some days the liquid will consequently be clear and on others full of crystals, depending upon the weather.

How to Make a Mercurial Barometer

The construction of a simple mercurial barometer is not beyond the abilities of a boy, but the directions must be carried out with the greatest accuracy and the work performed with all possible care.

Factory-made barometers are fitted with various devices to increase their accuracy which the amateur scientist must forego in favor of simplicity and ease of construction.

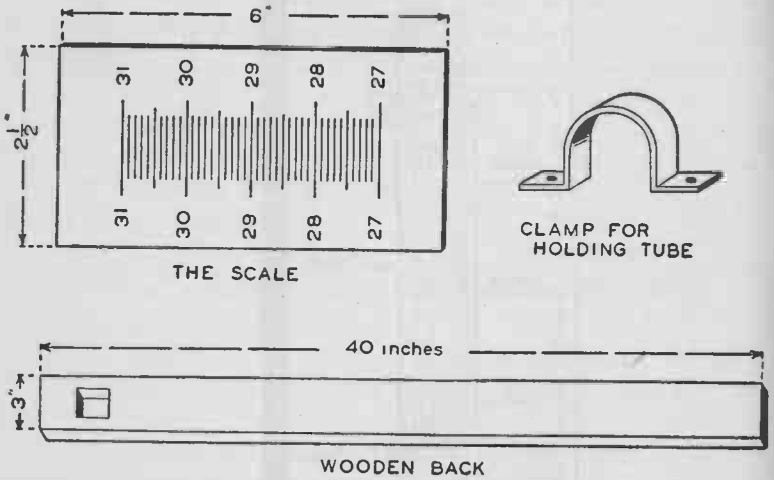


Fig. 288. — The wooden back, scale and clamp for the mercurial barometer.

To make a simple form of mercurial barometer, a strong glass tube, thirty-four inches long and having an inside diameter of about three-sixteenths of an inch is required. It is not absolutely necessary for the internal diameter of the tube to be exactly three-sixteenths of an inch. If the tube is much narrower, however, the mercury will move very sluggishly and if it is larger there is no advantage. A tube made of greenish-colored glass is best. Pure white glass owes its trans-

parency to a chemical called *lead oxide*. If such a tube is filled with mercury, a chemical action takes place between the lead and the mercury, causing the latter to stick to the glass and preventing it from moving freely up and down. The walls of the tube should be strong, at least three-thirty-seconds of an inch thick. A thicker wall is preferable.

Cleaning the Tube. Before the tube can be used it must be thoroughly cleaned. Pour warm water through it and then pull through a string having a small piece of cloth tied to the end. After the tube is clean, it should be dried. This may be done by tying a piece of clean, soft cloth to the end of a string and pulling it through the tube a few times.

Sealing the Ends. One end of the tube must be sealed by heating it in a Bunsen burner. This is an operation which will require a little skill and experience, although it is not hard to perform.

It may be well to practise a bit by first trying to close one end of several short lengths of tube before the barometer tube itself is attempted.

When sealing the end of a tube, at first hold it above the flame and revolve it so that it becomes evenly heated and there is no danger of the glass cracking because of becoming hot too quickly. Gradually bring the tube nearer to the flame until the tip is finally in the upper part. The tube should be continuously and slowly revolved. When the glass has reached the melting point, the end of the tube will commence to close together. The heating should be continued until it is completely sealed and rounded over.

The Wooden Back. The tube is now finished and ready to be mounted on the wooden back. This is a board, forty inches long, three inches wide, and three-quarters of an inch thick. The upper end is rounded to improve its appearance. A shallow, half-round groove down the centre will permit the glass tube to

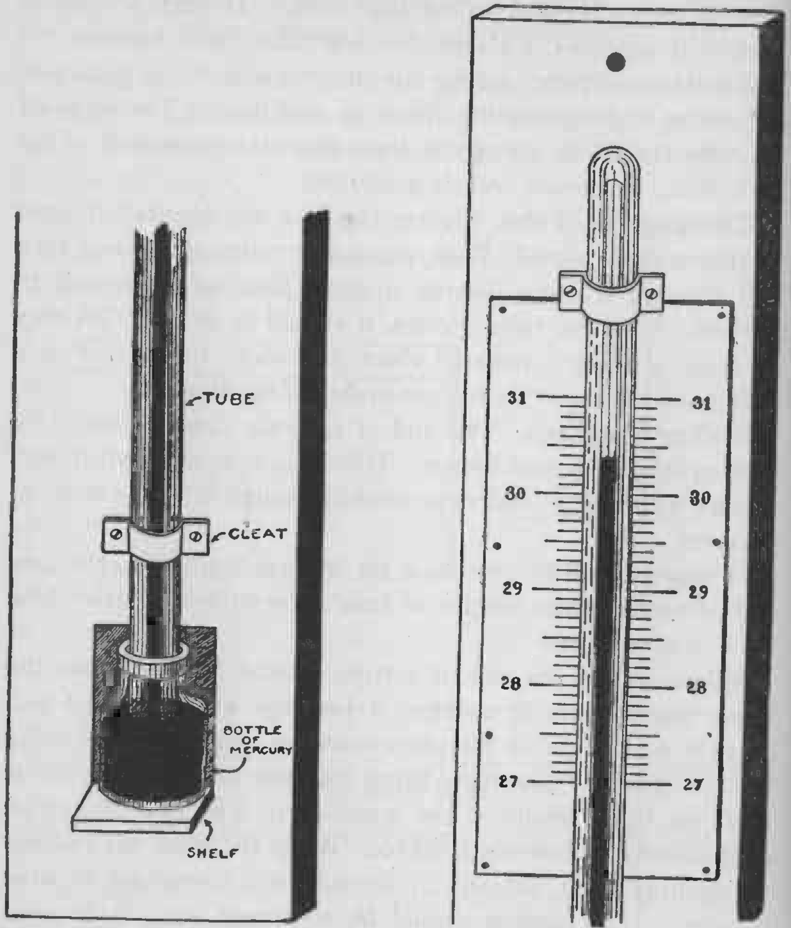


FIG. 289. — At the lower left is shown the lower end of the barometer and at the right, the upper end.

be fastened firmly in position by two small brass straps which extend over the tube and are clamped to the board by means of small wood screws.

A hole is cut near the bottom of the board to accommodate

a small bottle. This bottle serves as the mercury cistern. The size of the hole in the board will depend upon the size of the bottle which is to be used. A bottle a little over one inch in diameter, an inch and one-half high, and having a neck which is only large enough to allow the end of the glass tube to slip through freely, is the most desirable. Fasten a little shelf to the backboard, so that the top of the shelf is even with the bottom of the hole and helps to support the bottle.

After all the parts have been fitted and tried in place, the tube is ready to fill with mercury. Follow these instructions very carefully.

Filling the Tube. Only redistilled mercury should be used for the barometer.

Pour enough melted beeswax into the bottle to form a layer, one-eighth of an inch thick when it has cooled. Warm both the tube and the mercury slightly by passing them back and forth over a Bunsen burner or alcohol lamp. Then pour the mercury into the open end of the tube through a paper funnel. Pour the mercury in very slowly or it may crack the tube. The tube should only be filled to within half an inch of the top. Place the forefinger over the open end of the tube and tilt it first one way and then the other so that the bubble of air runs up and down the tube and gathers up as much as possible of the other air which is contained in the tube. Then turn the tube up and entirely fill it with mercury. Place the finger over the open end again and invert the tube, taking care still to keep the end tightly closed with the finger The open end of the tube should be stuck below the surface of a small cup of mercury so that no air can enter and the finger then removed so that some of the mercury can run out of the tube and *form a vacuum* at the top. Then close the end of the tube again with the finger and tilt it back and forth several times, allowing the bubble to gather air. This operation should be repeated two or three times so as to insure all air being expelled from the tube. Otherwise the barometer will not be accurate.

After you are certain that the tube does not contain any more air, fill it up with mercury until it overflows. Then invert the glass bottle which is to be used as the cistern and place it over the open end of the tube. Press it down so that the beeswax in the bottom makes good contact with the end of the tube and seals it so that no mercury can escape nor air enter.

Hold the bottle and the tube firmly together and invert them so that the bottle is at the bottom. Place the bottle on its little shelf and put in enough mercury to make the depth about three-quarters of an inch above the bottom of the bottle. The tube may now be raised a trifle so as to lift the open end out of the wax, and then fastened in place by clamping it with the brass straps and screws. Pack a little clean cotton in the neck of the bottle around the tube, and the barometer is finished except for the scale.

The Scale is laid out on a piece of white cardboard, six inches long and two and one-half inches wide. The scale itself is four inches long, each inch being divided into tenths. The bottom division on the scale is numbered "27." The upper end of the first inch is marked "28," the second "29," the third, "30" and the fourth "31."

In order to locate the scale accurately, it will be necessary to hang the barometer beside a standard factory-made instrument which is known to be accurate. Place the scale behind the tube and tack it in such a position that the division line corresponding with the line at the top of the mercury in the standard barometer is at the top of the mercury in the homemade barometer.

CHAPTER X

ATOMIC ENERGY

BEFORE dawn on July 16, 1945 a group of eminent scientists gathered behind a barricade in the desert lands of New Mexico and waited for the climax of the most important single experiment ever attempted by mankind. At 5:30 A. M. the sky many miles away from the watchers was rent by a dazzling burst of light brighter than the noonday sun. The first atomic bomb had been exploded. The world was on the threshold of a new era, the Era of Atomic Energy.

Less than two months later, Aug. 6, 1945, more than four square miles in the center of the city of Hiroshima, Japan were blown off the face of the earth by the blast of a single atomic bomb. In an instant a small bit of matter had been changed into seething, undiluted energy that melted sand and rock and sent a great volcano of radioactive vapor, gas, flame, dust and debris billowing above the clouds. Eight days later Japan surrendered. World War II had ended but civilization was now confronted by the greatest problem it had ever encountered. That problem is how to control and restrict to legal and humane use a force that could quickly eliminate the human race.

When at atomic bomb explodes a small amount of matter is changed into an enormous amount of energy. That statement is not a contradiction of the statement made in Chapter I that matter and energy can neither be created or destroyed. Matter and energy are not different things but rather different manifestations of the same thing. When matter is changed into energy, nothing is destroyed or created, it is merely changed.

The idea that mass can be converted into energy and energy into mass is not a new one in the scientific world. Radium has been converting its mass into energy since the world began and this fact has been known to scientists since shortly after radium was discovered. There is much evidence that the sun converts about 4 million tons of its mass into energy every second. It is only recently that science found out how to do what radium and the sun apparently have been doing for millions of years.

Nuclear Fission. In order to change mass into energy it is necessary to SPLIT ATOMS. The splitting process is called *nuclear fission.* When nuclear fission takes place large atoms split apart and there results atoms of lesser weight and the release of a vast amount of energy.

The energy thus released is enormous. More than 4 decades ago Einstein worked out a mathematical equation which showed what a fantastic amount of energy could be produced by the conversion of a small amount of matter. For example, if 10 ounces of matter could be entirely converted, the energy released would be equal to that secured by burning 1,000,000 tons of coal.

Ever since man learned how to use fire he has been able to split MOLECULES. When coal, gasoline or any substance is burned MOLECULES are split and energy is released in the form of heat. The heat can be used for warmth, cooking, industrial processes, power and other useful purposes. A great many chemical reactions are MOLECULE splitting actions. A great many of the materials used in the world are produced by splitting MOLECULES so as to obtain certain desired atoms and then joining the atoms in new combinations so as to form new MOLECULES. But not until recently has it been possible to split ATOMS.

The First Atom Splitter. Professor Ernest Rutherford of the famous Cavendish Laboratory of the University of Cambridge was the first person to intentionally and knowingly smash an atom. In 1919 Rutherford filled a glass tube with nitrogen and by the use of a tiny amount of radium salt was able to split some of the nitrogen atoms. There was no great flash or explosion when Rutherford performed this first successful atom-smashing experiment. Only a few nitrogen atoms were split. No one outside the laboratory knew that anything unusual had happened. But two things of tremendous importance had occurred. First, energy had been released from atoms in the splitting process. Second, splitting nitrogen atoms had not only released energy but produced OXYGEN and HYDROGEN. Rutherford had succeeded in transmitting one chemical element into another, something that men had always dreamed of doing but never accomplished before.

In order to understand something of nuclear fission, it is necessary to examine an atom closely, to investigate its structure.

Our knowledge of the construction of the atom is less than twenty years old, some of it only half that old. But it seems to be accurate knowledge, not guesswork. It has been secured with the aid of X-rays, spectroscopes, scales, mathematics and other scientific tools.

The Structure of an Atom. It is known that every atom has a center or nucleus composed of a group of small particles called protons and neutrons (except the hydrogen atom, the nucleus of which is a single proton). A proton bears a positive electrical charge. A neutron has no charge, it is neutral. Surrounding the nucleus of every atom are one or more zones in which electrons whirl in orbits around the nucleus at enormous speed, thousands of miles per second. There are never more than seven zones around the nucleus of an atom and never more than thirty-two electrons in one zone.

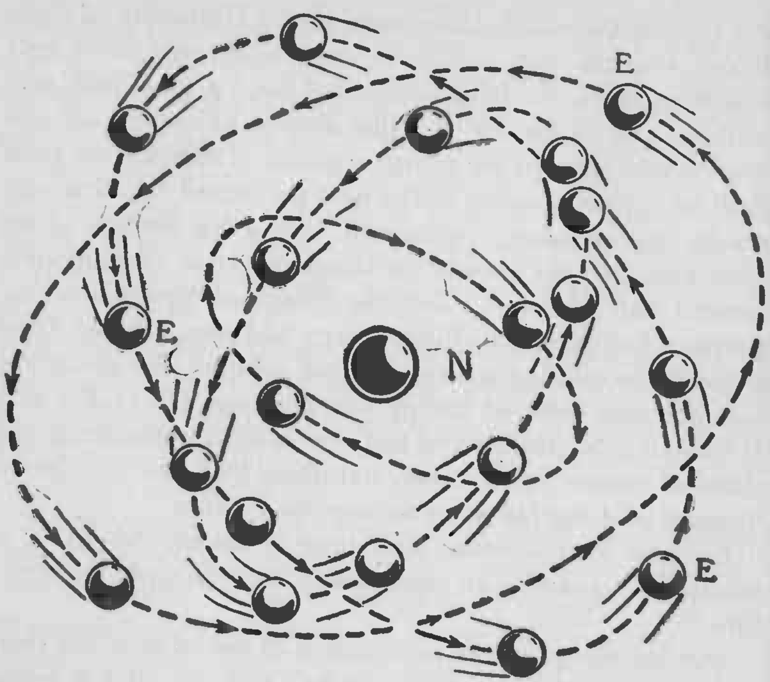


FIG. 290. — Diagram of the Calcium Atom. N indicates the nucleus around which the planetary electrons, E, revolve in four orbits indicated by the dotted lines.

Hydrogen is the simplest atom. It has one proton in its nucleus and a single electron whirling around in a single orbit. The simple structure of its atom makes hydrogen the lightest element. The atoms of the heavier elements are more elaborate. Uranium, the heaviest, has 92 electrons whirling around its nucleus.

The electron which is part of an atom's structure is the fundamental negative electrical charge. It is infinitesimally small, yet has been measured and weighed. A single electron weighs only .0000000000000000000000000009 gram. When electrons stream through a wire, they constitute an electric

current. About 6 *billion billion* pass through a lighted 100-watt lamp per second.

Radium is one of the heavier elements. It is called radioactive because from this wonderful substance comes invisible radiation known as alpha, beta and gamma rays. The alpha rays or particles are atoms of helium, bearing an electrical charge, which shoot out into space at velocities as high as 10,000 miles per second. The beta particlees are electrons which may move at velocities near the speed of light. The gamma rays are electromagnetic waves, much like super X-rays and kin to radio waves and ordinary light.

Radium itself sends out no beta or gamma radiation of importance. But when radium is sealed in a glass tube several products which are the offspring of radium's activity are formed and these substances emit all three varieties of radiation with great vigor.

After Rutherford performed his first atom splitting experiment, it was known that in the radioactivity of radium, scientists had a piece of heavy artillery with which to bombard atoms. By aiming the flying alpha particles from radium at various elements one of these atomic bullets would occasionally smack into the nucleus of an atom of those elements. It would knock something out of that nucleus, in each case tiny particles of hydrogen bearing a positive electrical charge. Smashing the nucleus of an atom was not easy. The nucleus was held together by a tremendous binding energy.

Atoms are so numerous, in even a small amount of matter it would seem that releasing their atomic energy might solve man's constant quest for sources of power. Calculations showed that the binding energy in one gram of helium is enough to light a 100-watt electric lamp continuously for approximately 220 years. Many scientists were led to try their hand at atom smashing. Radium had pointed out the method to use. Blast atoms with all types of particles travelling at high velocity and once in a while the nucleus of an atom would be hit and smashed. As methods were improved huge electrical machines took the place of tiny bits of radium.

The best machine for atom smashing proved to be that called the cyclotron, invented by Professor E. O. Lawrence, an American physicist. The high speed projectiles shot at atoms by the cyclotron are protons, alpha particles and a particle called a deuteron. The deuteron is the nucleus of a hydrogen atom which has a neutron in addition to the usual proton. Professor Lawrence shot deuterons at rock salt and produced radioactive sodium which is sodium like any other sodium from a chemical standpoint but possesses exploding nuclei which give off electrons and gamma rays. It was found possible to make almost all of the elements radioactive by this same method. But although the cyclotron grew from a machine not much larger than a man's hand to a huge monster weighing several thousand tons, it handled only infinitesimal amounts of any element. It would require millions of years to transmute one pound of one element into another with the cyclotron. Considered from the standpoint of volume or quantity, science was a long way from releasing enough atomic energy to heat and light our homes and drive the machinery of our industries.

But the atomic bomb that brought Japan to her knees and the basic knowledge which will undoubtedly produce power plants deriving their energy from the atom came from these experiments.

The turning point in the search for atomic energy came in 1939 when it was discovered that a particular kind of uranium, called uranium-235 was the key.

During World War II it was learned by the Allies that the Germans were working feverishly to add atomic energy to their weapons with which they hoped to enslave the world. There

was only one thing to do, namely enter the race of scientific discovery and lend every possible effort to win it. The United States had a large number of able scientists in the needed spheres of knowledge and had tremendous industrial and financial resources to further the undertaking. Our own scientists were marshalled, a number of British scientists were transferred to this country and a budget of $2,000,000,000 was provided for the project.

The whole story of the enormous research carried out is a long one. The problems which loomed seemed too great to solve. But they were solved. Here in America, we won the race. It is not possible in this short chapter to name all the scientists, laboratories, engineers and industrial companies who played important parts in the work.

Early in the project it was realized that there were two possible sources of atomic energy in large amount. One was a variety of uranium, already mentioned, and the other a new chemical element called plutonium.

In 1934 Dr. Enrico Fermi, working in Rome, bombarded the atoms of some of the heavy elements with neutrons and found it was possible for the nucleus of an atom to capture and incorporate a neutron into itself. He found that capture of a neutron took place with greater frequency if the neutron was slowed down by permitting it to first pass through water, or some other substance rich with hydrogen. The heaviest of the elements, uranium, gave an amazing result when bombarded with neutrons. It turned into a new element, a man-made element which was named neptunium.

Neptunium proved to be a very unstable element. It gave off an electron and turned into still another new man-made element named plutonium.

Plutonium is ordinarily quite contented. It is stable and behaves itself until you bombard it with neutrons. Then it blows itself to pieces. Its atoms split into atoms of less weight and release vast quantities of energy. This is the sort of nuclear fission the bomb makers were looking for.

The common kind of uranium is known as Uranium-238. There is also a scarcer kind called Uranium-235. Uranium-235 behaves like plutonium. It undergoes nuclear fission. Its atoms release an enormous amount of energy when they split. Slightly more than two pounds of uranium-235 under proper control could generate enough heat to produce electric power for a city of 1,000,000 people for an entire day. It would require 6 million pounds of burning coal to produce the same heat energy.

The vast organization which produced the atomic bomb developed methods of refining and purifying uranium and of producing plutonium on a commercial scale. They discovered how to use uranium-238 and uranium-235 in an arrangement called a pile to produce plutonium. Unbelievable amounts of heat are generated by such piles and it is probable that a method of using this heat to produce steam for conventional turbo-generators will be developed.

At present, no method for the direct utilization of atomic energy for power purposes is known.

Uranium is a heavy, silvery-white metal. Uranium ore is rare. Only a few lucky countries have deposits. To date it is the only key with which man can unlock the fantastic power of the atom.

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