COYNE
Electrical and Radio School
CHICAGO ~ ~ ILLINOIS

ESTABLISHED 1899

ELEMENTARY ELECTRICITY

Sections One, Two, Three, Four and Five

Purpose of This Reference Set

This material has been prepared with great care by the school, to provide for our students and graduates a reference set that will be practical, brief, and simple to study along with the shop course, and convenient and dependable to refer to for help and data on their work in the field.

It is prepared by the school Instructors, executive teaching staff, and Superintendent, all practical men with wide experience in their various subjects and work, and who thoroughly know the students' problems, and needs while in the course, and their needs out on the job afterwards. In this, we have also been assisted by noted electrical engineers of some of the greatest electrical concerns in the country.

The material is simply worded, non-technical, and well illustrated with diagrams and photographs. Every ambitious student will find it extremely interesting and valuable, and easy to study.

The student should understand that this set is not a necessary or compulsory part of the regular course, and is not needed to complete the course. The regular course of shop work and lectures is entirely complete without it. And while it does not cover exactly or in detail the same material as the lectures, it does cover the same general subjects arranged in about the same order as the shop course. And any student who will spend a few minutes per day in study of the sections pertaining to the work he is covering in the shop course, will find it a great help in clearing up various points, by presenting them from different angles.

By this study during the course, he will become familiar with the location of the various subjects and sections which will make it very easy to use for reference on problems that arise in his work in the field after graduation.

Another good reason to study this set along with the course, is that your instructors in the shop departments will then be able and glad to assist you with any points in it that are not clear, and help you compare it with your daily work in the shops.

A great amount of time and money have been spent to make this reference set complete and practical, and we hope it will prove of great value to every student while here, and later in the field.

H. C. LEWIS,
President.

THE ELECTRICAL FIELD

USES AND APPLICATIONS OF ELECTRICITY, AND GREAT OPPORTUNITIES FOR TRAINED MEN

The electrical industry is one of the greatest in the world today. It is a comparatively young industry, and it was only about 50 years ago that we commenced to use electricity to any great extent. Yet today there are many billions of dollars worth of electrical machinery and equipment in use in this country alone, and new electrical equipment is being manufactured at a rate of hundreds of millions of dollars worth per year.

In practically every country in the world, electricity is coming into greater use, at a rate so tremendously fast, that it is impossible to predict the extent and size of this great industry for even a few years ahead.

Every student of electricity should be vitally interested in the great size of this industry, and the various thousands of uses to which electricity is being put today. It gives him certain assurance that he has plenty of opportunities to "cash in" on every bit of training he can obtain.

There are so many different branches of electrical work today, that the trained man can choose almost any kind he desires.

INDUSTRIAL POWER AND LIGHT

Industrial plants and factories all over the country use electric power by the millions of horse power, and are over three-fourths electrified at fraction of one horse-power to many thousands of present. Electric motors, ranging from a small horse-power each, turn the wheels of these great factories and mills.

Almost every new plant that is built is completely equipped with electric power machinery because it is so much cleaner, quieter, safer, and more efficient than any other power.

Electric lights by the millions brighten the modern factory to speed up the work, and make safer and better conditions for employees.

Electric furnaces melt our finest steels and metals. Electric arc welders, spot welders and butt welders replace riveting, bolting and casting in the faster and better construction of our manufactured metal products today. Electric enameling ovens and heat treating furnaces are also coming more and more into use, by the thousands of kilowatts each year.

Many thousands of men are required to install, operate and maintain this power, lighting, and heating equipment in these shops and factories.

TRANSPORTATION

In transportation we find electricity used on a vast scale. Electric street cars, elevated and subway trains in our cities, and electric interurban lines between towns are common. And the great railway lines are electrifying more every year. Powerful, silent, electric locomotives and motors, pull many trains over hundreds of miles of the most difficult mountain railways, as well as the level runs.

Then there are the electric block signals on every principal railway in the country, and the automatic electric train control equipment now being installed on many lines, to say nothing of the train lighting, air conditioning and many other uses. Even on the seas, we have great battle ships using as much as 180,000 horse-power of electric energy each, just to drive their propellers. Merchant marine ships also use hundreds of thousands of horse-power of electrical machinery.

COMMUNICATION

Electricity operates our many millions of telephones, making it possible to talk to our friends, or conduct our business over a few miles, or across the ocean, as we please. These and our vast telegraph systems require thousands more of electrical men in pleasant, fascinating work, to install and maintain them.

Then we have the radio industry, just another branch of electricity, and while it is only a few years old, we have millions and millions of radio sets bringing education and entertainment to our homes throughout the country today.

And now the new fields of auto radio, public address, sound and television.

The demand for trained electrical service men in these branches is enormous.

Many streets in the larger cities are electrically lighted at night, almost as bright as day light. Special electric lighting beautifies the outside of the great skyscraper buildings. Electric signs with thousands of lamps in each of the larger ones, flash their advertisements in all colors.

ENTERTAINMENT

Our marvelous motion pictures of today, with their great entertainment and educational value, are made possible by electricity. Great electric lamps of from 1,000 to 50,000 watts each, light the studios for the photography. Electric projector machines reproduce them in the theatres, and the beautiful stage and theatre lighting effects add their part electrically.

The talking movies are also electrical devices which are simple enough to those who have thorough practical training in electricity and radio.

AUTOMOTIVE AND AVIATION ELECTRICITY

Every one of our many millions of automobiles, trucks and tractors, use electricity. It ignites the gasoline, starts our cars, operates the lights, horn, radio and other conveniences on the modern motor cars. Electrical experts who can repair the trouble of these electrical systems and their electrical units, including the storage batteries, can draw good pay or run a very profitable business of their own.

Aviation is another great field, requiring many more trained electrical men each year, to take care of the ignition equipment of these great airplane engines. The landing and flying lights and electrical instruments on the plane, the radio beacon and communication equipment, air port lights and route beacon lights, all require trained electrical men in the finest kind of work.

HOME LIGHTING AND CONVENIENCE DEVICES

In our homes electricity gives us plenty of clean, convenient light, beautifying the home, and saving our eyes when we read and study, and actually giving us many more useful hours each day.

Then there are the electric fans, toasters, heaters, vacuum cleaners, washers and ironers, refrigerators, kitchen utensils, and dozens of other electrical convenience devices saving time and eliminating drudgery in the home.

These things are no longer limited to the city homes alone. Farm and rural electrification is one of the fastest growing branches of this industry. Hundreds of thousands of farms are electrified today, with their own private plants, or from lines of the power companies. The modern farmer is beginning to use electricity to save time and earn money for him, just as the business man or factory owner does in the cities.

So we see that electricity is rapidly becoming a great part of our entire life and civilization. And it is literally true as the late Dr. Steinmetz said, "that if we were to remove the electric wires from the world today, our civilization would look like a sieve."

Now, this brief review of some of the most important uses of electricity serves to show us what a great industry it is, and what a variety of different branches the trained man has to choose from.

GREAT OPPORTUNITIES FOR TRAINED MEN

The field and uses of electricity increase at such a rapid rate each year, that it requires approximately 60,000 additional men yearly, to install, operate and maintain all this equipment.

This is several times as many men as Coyne School and all of the leading colleges in the country can train in electricity each year. Thus you can readily see that for many years to come there is certain to be a great demand for practically trained men.

So if you have carefully read and thought over this brief description of the electrical industry, I am sure you can see that there is no field of greater opportunity for fascinating, steady work at good pay, and with real opportunities for advancement. Electricity offers all these to the ambitious man, who will study and train to become a qualified and efficient electrical worker.

The following material in this reference set, has been prepared in simple practical form, to make easy the things about electricity that remain so mysterious to the ordinary untrained man.

I believe every ambitious student who is not afraid to study and do his part, and who takes pleasure in adding to his practical knowledge of electricity, will enjoy his study of every page of this set.

And I can assure any student that when he has properly completed his shop course in all departments at Coyne, and the material of this set, he will have a splendid practical knowledge and training. And he can feel very confident of his ability to undertake and handle most any kind of electrical installation, operation, or maintenance work, and make a real success at electricity.

E. L. RICHARDS,
Shop Superintendent.

ELEMENTARY ELECTRICITY

SECTION ONE

ARTICLE 1.

The very important purpose of this section is to acquaint you with the general nature of electricity, how electrical energy may be produced in commercial form, and the fundamental laws and rules by which we control electricity and its various useful effects.

It is not necessary for the practical man to try to obtain an exact definition of electricity, or exactly what it is in terms of detailed scientific theory. But is well to understand that we consider electricity to be in and throughout everything. In fact all matter is considered to be made up of electricity, or electrons in continuous whirling motion. These electrons compose the very atoms of matter, which themselves are so small that we cannot see them even with the most powerful microscopes.

So we find that electricity is a natural force or element, present in all things, and we do not create or produce it, but instead we have merely learned how to generate electrical pressure to set the electricity in motion.

2. FORMS OF ENERGY

In this way we transform some of our various forms of energy into electrical activity or energy, and use this electricity to carry and give up or reproduce its energy wherever we want it in useful forms, such as light, heat or power.

For example in Figure 1, we have the latent energy of coal, which was stored in it ages ago by the sun, given up by burning or combustion. This burning of the coal produces heat energy. The heat boils the water and changes it into steam under pressure in the boiler, and from here we pipe it to an engine.

Under control of proper valves, the steam expands in the engine cylinder pushing the piston, turning the wheel and giving up its energy in the form of useful mechanical power.

Then we use this power by means of a belt, to drive a dynamo which generates electrical pressure and sets electricity in motion in commercial form. This electricity flows silently and incredibly swift through little wires to the lamp, where it is again changed into glowing incandescent heat or light.

So you see it is simply a cycle of transformation of one kind of energy to another. And electricity being so much cleaner, more convenient and efficient is why it is preferred to all other forms of heat, light or power. We can, of course, use water power, wind power, and gas or oil engines as well as steam, to drive our electric generators, and we will take these up later.

3. STATIC AND DYNAMIC ELECTRICITY

Now before we go further in this phase or part of our work, let us consider the two different forms or conditions of electricity we have to deal with.

These two kinds of electricity as they are often called, are **Static** and **Dynamic** electricity.

Static Electricity refers to electricity at rest, in the form of charges, or not flowing in the usual commercial form.

Dynamic Electricity is electricity in motion, or flowing through wires and devices in our usual commercial form. This is by far the most common in the work of the average electrical man, and will be the kind the greater part of this reference set deals with. But Static Electricity is quite often encountered in our work also, and every thoroughly trained man should have a general knowledge of its nature, how it is produced, and how to control it.

4. STATIC EXPERIMENTS

One of the simplest examples of static electricity, is the rubbing of amber with wool flannel, which causes it to become charged and attract small bits of paper, wood or pith.

This was discovered about 600 B. C. by a Greek. The Greek word for amber being Elektron, and the Latin word Electrum, the name Electricity was given to this charged effect.

It was about 22 centuries later, in 1600 A. D. that Dr. Gilbert, an English physicist, discovered that other materials such as glass, hard rubber, wax, etc., would become charged by rubbing with silk, wool or fur. These will also attract bits of paper, string, etc.

Try this by rubbing your comb or fountain pen briskly on your coat sleeve, and then bring it near to very small bits of thin dry paper.

5. POSITIVE AND NEGATIVE CHARGES

We can probably best understand how this occurs, if we refer briefly to the electron theory of matter again. All matter is supposed to be made up of atoms, consisting of a **Positive** nucleus or center, and negative electrons whirling around this positive nucleus.

In normal uncharged bodies of matter, these positive and negative forces are equal or balanced. And when we briskly rub two unlike bodies together, the theory is that some of the free electrons of the surface of one body are removed to the other. This creates an unbalanced condition, with one body having a shortage of negative electrons, and the other an excess. The body with the shortage of negative electrons, is said to be **Positively** charged, and the

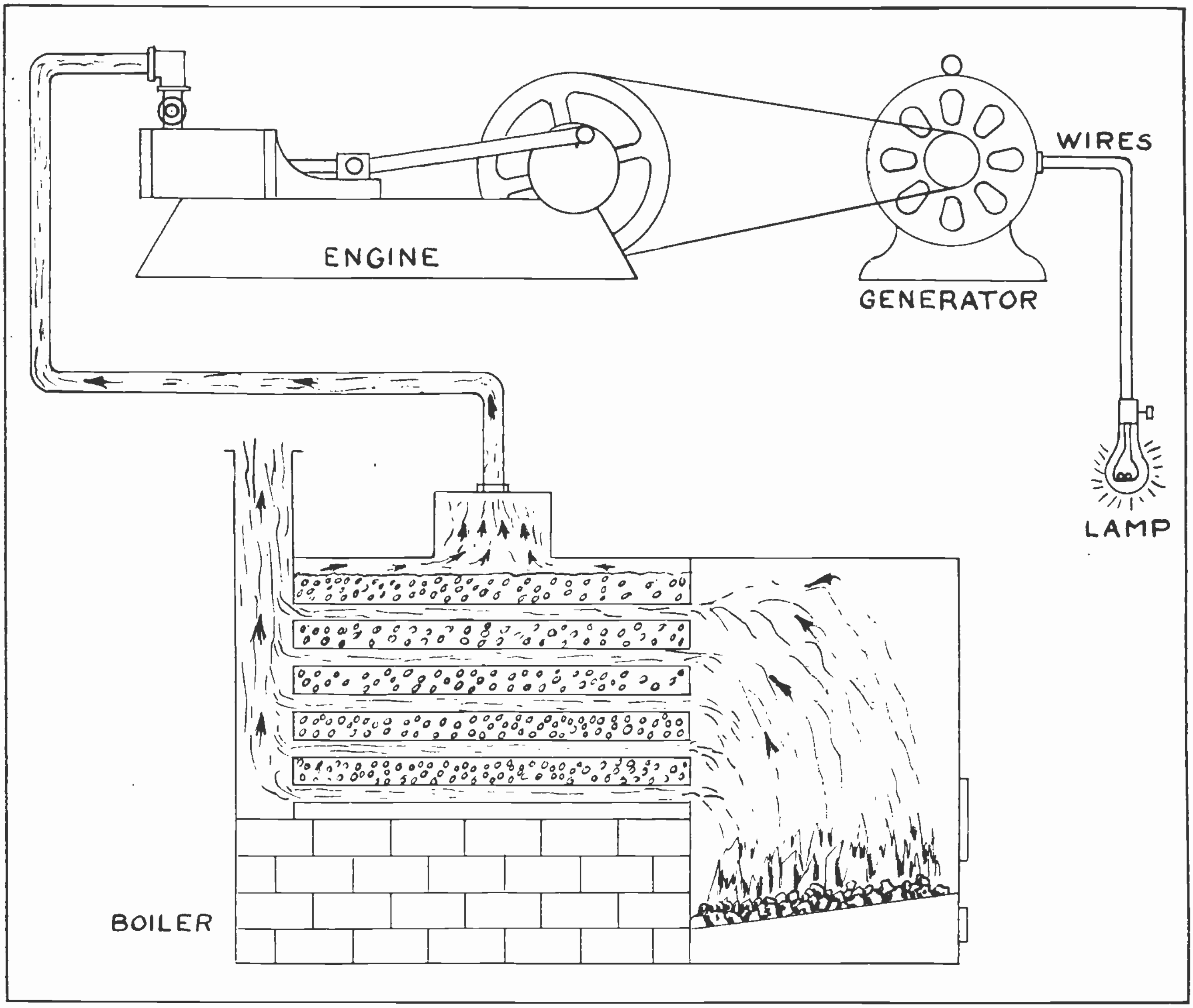


Fig. 1. Sketch showing how heat energy of coal is changed into mechanical energy by the engine, then to electrical energy by the generator, and into heat and light again by the lamp.

one with the excess of negative electrons is **Negatively** charged. So much for the theory by which static charges occur or are produced.

We now see that we can set up opposite conditions of charge on different bodies, and we call them **Positive** and **Negative.** When we set up such a condition, we say there is a difference of potential or electrical pressure between them, and this pressure tends to cause electricity to flow and balance them up again.

Now, if we take a piece of amber which has been negatively charged, and bring it into contact with two suspended pith balls, as in Figure 2A, the pith balls will both take on or absorb negative charges. Objects of this nature will often take on a charge from a short distance. This is called an **Induced** charge.

6. STATIC REPULSION AND ATTRACTION TION

Now, as soon as the two pith balls have been given like charges, we note that they immediately push apart or repel each other. And they will also repel each other if both are positively charged, as we can prove by giving them a positive charge from a glass rod which has been rubbed with silk. But if we charge one pith ball negatively from the amber, and one positively from the glass, they will at once draw together or attract each other. (See Fig. 2B.)

This proves one of our most important electrical laws, as follows: **Like Charges repel each other** and **Unlike Charges attract.**

This law of electricity should be memorized, as it is very important, and many electrical devices have their operating principles based on it.

7. STATIC MACHINE

A number of very interesting and valuable demonstrations of this law, and the nature and effects of static electricity, can be made with a static machine such as used in the elementary department of your shop course.

The static machine is shown in Figure 3. It is simply a device to produce strong charges of static

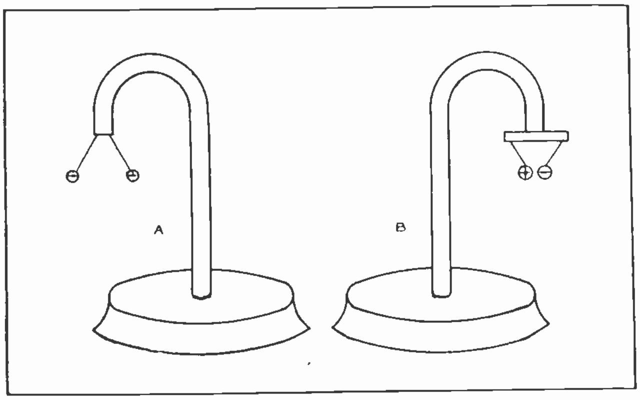


Fig. 2-A. Pith balls with like static charges repel each other.
Fig. 2-B. Two balls with unlike charges attract each other.

electricity, for various experiments and tests. With it we can produce charges many times stronger than by rubbing the amber, glass, or hard rubber rods.

As you will note in Figure 3, the static machine consists of one stationary glass disk, on the back of which are fastened some tinfoil strips. To these foil strips are attached little wire brushes, extended around to touch a row of metal buttons, which are placed around the edge of a rotating glass disk, which is revolved close to the stationary one.

These little metal buttons or carriers, convey the little charges collected, to the metal system of the machine. When the rotating disk is driven at high speed by means of a hand crank, belt and pulleys, a charge is gradually built up by what is called induction, as the metal buttons are whirled rapidly by the foil plates and little wire brushes. This gradually builds up a positive charge on one of the metal spheres or electrodes and a negative charge on the other.

It is possible to build up charges of such high pressure or voltage, that a discharge in the form of a spark will take place between the two electrodes.

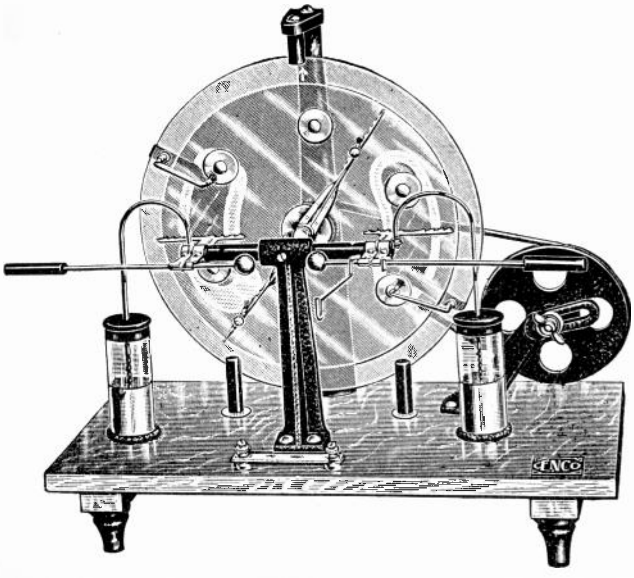


Fig. 3. Static machine, for producing strong charges of static electricity. When the disks are rotated rapidly a spark an inch or more in length can be produced.

This discharge tends to equalize or again balance the positive and negative charges.

Sometimes these machines can be made to produce sparks an inch or more in length, which represent charges of several thousand volts. But these charges are not dangerous, because they are of such small quantity, or actual amounts of electricity.

If we attach simple Leyden jar condensers to each of the electrodes of the static machine, we can get it to store up or accumulate in them, much larger amounts of electricity. Then when the discharge occurs it will be a very hot snappy spark, and will give quite a shock to anyone touching the terminals.

8. CONDENSERS

These condensers, which are used to store up electricity in the form of static charges, are made in many different shapes and sizes, but all on the same principle. The Leyden jar type consists of an inner and outer metal jar or cylinder of thin copper, brass, or foil, separated by a glass jar. (See Figure 4.)

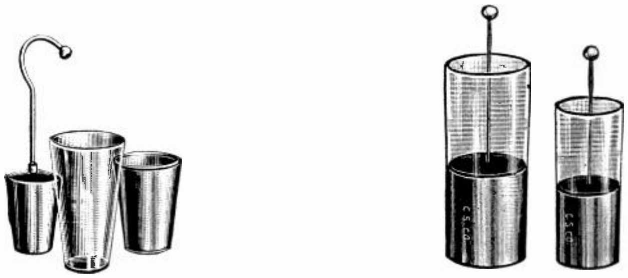


Fig. 4. Two types of Leyden jar condensers.

This provides two conducting surfaces of metal, separated by an **Insulator** or **Dieletric**, in the form of glass. (An insulator or dielectric is any material which prevents the flow of electricity. These will be explained later.)

When the terminals of a static machine or source of electric charge are connected to the two metal jars or elements, these will distribute a charge over the surface area of the glass which they cover. Then after the condenser has been so charged, we can discharge it by connecting a wire from one metal element to the other.

Condensers are often made with flat plates of foil or metal, stacked and separated by flat plates of glass, rubber or mica. Others are made of strips of foil and paper rolled together.

The area of the active or charged surfaces of the condenser, and the quality and thickness of the glass or insulation, determines the amount or quantity of charge it will take, or the volume of the spark when it discharges. A good thing to remember about any condenser is that the charge resides on the surfaces of the glass or dielectric, while it is charged. The metal elements simply act as conductors to distribute the charge over the surface of the glass while charging, and to collect it when discharging.

This can be proved by charging a Leyden jar condenser of the type with separable jars. Then carefully remove the metal jars with one hand only, and by inserting one hand inside the glass jar, and drawing the other over its outer surface you can get a discharge to your hand, in the form of small sparks.

Condensers of other types and their uses for power, radio and other purposes will be discussed later.

9. METHODS OF STATIC CONTROL AND PROTECTION

Now that we have an idea of the general nature of static electricity it will be well to consider some of the forms in which it is often encountered in every day life outside the laboratory. Also some of the methods of controlling, or protecting against it, because in some of the forms in which it is produced by nature, and in our industries, it can be very harmful if not guarded against.

For example, one of the most common occurrences of static in the home, is when we walk across a heavy carpet, and by rubbing or scuffing action of our feet we collect a strong charge on our bodies, from the rug. Then when we come near to a grounded radiator, or water pipe, or large metal object, a discharge takes place from our body to it, in the form of a hot spark, sometimes from half inch to an inch in length.

In many cases the only effects of this are the surprising little shocks or rather humorous incidents caused by it. But in some cases it becomes so bad it is very objectionable, and even dangerous. For example a person's body so charged can unexpectedly ignite a gas flame, or vapor over some explosive cleaning fluid.

Where rugs are the source of objectionable static it is sometimes necessary to weave a few fine wires into the rug, or provide a metal strip at its edges, and ground these by connecting them to a water or steam pipe. Or it may be reduced by occasionally dampening the rug a little.

10. EXPLOSIONS FROM STATIC

When handling any cleaning fluids of an explosive nature, one should be very careful not to rub the cloth too briskly, as this may produce sparks and ignite the vapors. In dry cleaning plants the various pots and machines should have all parts connected together electrically, and thoroughly grounded with a ground wire.

Another common occurrence of static in a dangerous place is on large oil trucks. These trucks running on rubber tires over pavements on dry hot days, collect surprising charges. To prevent the danger of this accumulated charge sparking to the operator's hand or a can near a gasoline faucet, and causing an explosion, these trucks should all carry a grounding chain with one end attached to the metal frame of the truck, and the other end dragging on the ground or pavement. This equalizes the charges, or lets them flow back to earth before they build up to dangerous values.

Passenger busses are also equipped with such ground chains or wires sometimes, to prevent the passengers receiving a shock from static charges, when stepping on or off the bus.

11. STATIC ON BELTS

High speed belts in factories and industrial plants are often sources of surprising static charges. The rapid movement of the belt through the air and over the pulleys, will often build up charges that are very likely to be harmful if not eliminated. In some cases these charges from the belts will flash over to electric motors or generators on which the belts are running, and puncture the insulation of the windings of these machines, causing leaks of the power current through this damaged insulation, which may burn out the machine.

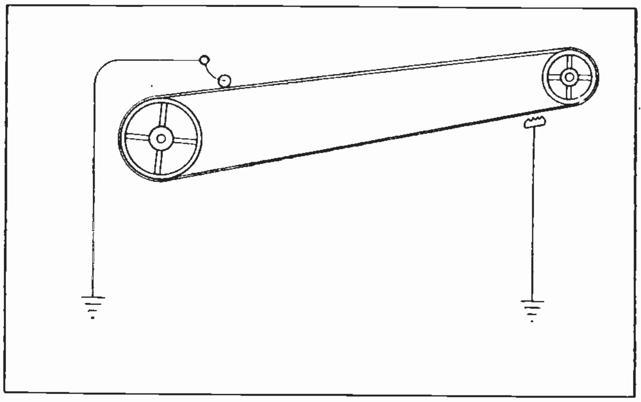


Fig. 5. Sketch showing how static can be removed from a belt, by use of either a metal comb or roller, and ground wire.

A workman around such belts may get such a shock from the static, that it will cause him to fall off a ladder, or to jump against some running machinery and be injured. These dangers can be eliminated by placing a metal roller on the belt, or a metal comb with sharp points near the belt, and then connecting these combs or rollers to earth, or a grounded pipe or metal framework, to carry away the charges before they become so large. The combs should be located from ¼ to ½ inch from the belt. The closer the better, as long as its teeth do not touch the belt. (See Figure 5 which shows both methods in use on a belt.)

Many serious fires and explosions of mysterious source in various plants, could have been prevented by a trained electrician with a knowledge of how static is formed and how to guard against it.

So you see, even in this first little section on static electricity alone, you are learning something which may be of great value to you on the job.

12. LIGHTNING

Lightning is probably the most sensational manifestation of static electricity that we know of.

Lightning is the discharge of enormous charges of static electricity accumulated on clouds. These charges are formed by the air currents striking the face of the clouds and causing condensation of the vapor or moisture in them. Then these small particles of moisture are blown upward, carrying negative charges to the top of the cloud, and leaving the bottom positively charged. (See Figure 6.)

Or the reverse action may take place by heavy condensation causing large drops of rain to fall through part of a cloud. Thus one side of a cloud may be charged positively and the other side negatively, to enormous pressures of many millions of volts difference in potential.

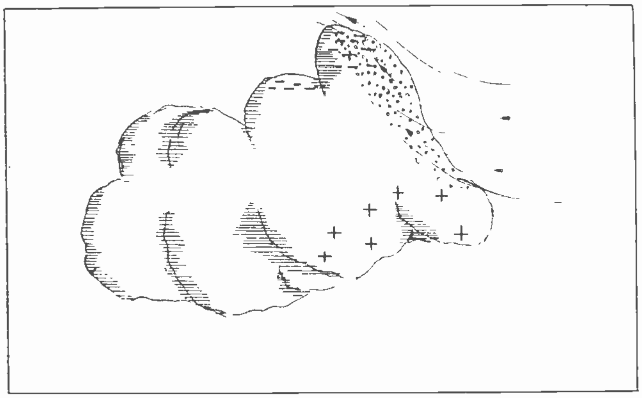


Fig. 6. Wind striking the face of a cloud, carries vapor and electrical charges to top of it.

When such a cloud comes near enough to earth, and its charge accumulates high enough, it will discharge to earth with explosive violence. (See Figure 7.)

The earth is assumed to be at zero potential. So any cloud that becomes strongly charged will discharge to earth if close enough. It is important to remember that whenever one body is charged to a higher potential or pressure than another, electricity tends to flow from the point of high potential to the low. The direction of this flow is usually assumed to be from positive to negative. It takes place very easily through wires when they are provided. But it is hard for it to flow through air, and requires very high pressure to force it to flash through air, in the case of sparks or lightning.

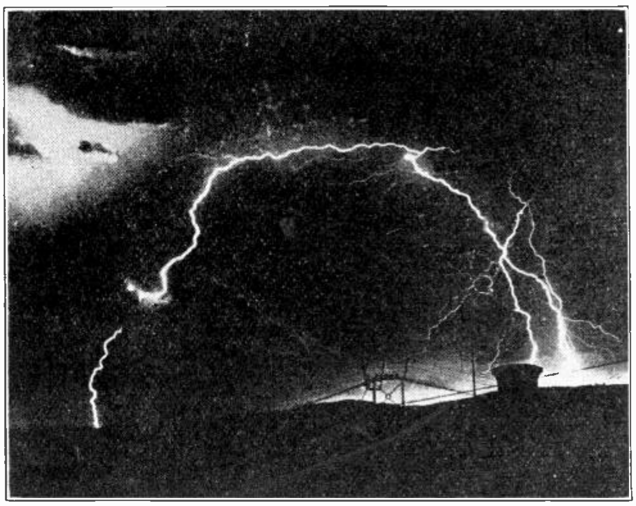


Fig. 7. Photo of a brilliant lightning flash at night.

Very often a side of one cloud will carry a negative charge, and the nearest side of another cloud a positive charge. When these charges become high enough a discharge will take place between the two clouds. (See Figure 8.)

13. FRANKLIN'S DISCOVERY

Benjamin Franklin with his kite and key experiment, about 1752, discovered that lightning was electricity, and would tend to follow the easiest path, or over any conducting material to earth.

He actually obtained sparks from a key on his kite line, to his fingers, and to ground. This led to the invention of the lightning rod, as a protection against lightning damage.

We say lightning "strikes" various objects such as trees, buildings, etc., because in its tendency to follow the easiest path to ground it makes use of such objects projecting upwards from the earth, as part of its discharge circuit or path.

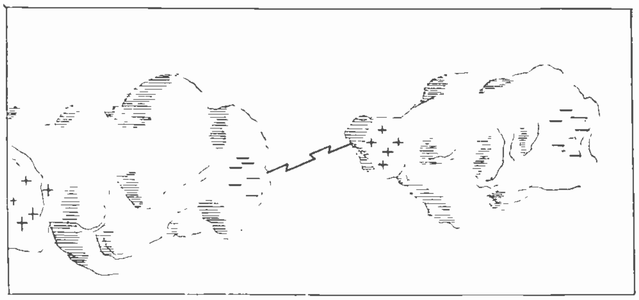


Fig. 8. Lightning flashing from one cloud to another, when clouds carry unlike charges.

Rain soaked trees, or trees with the natural sap in them are of lower electrical resistance than air and so are buildings of damp wood or masonry, or of metal. And the taller these objects are above the ground, the more likely they are to be struck by lightning.

When lightning does strike such objects, its intense heat vaporizes their moisture into steam, and causes other gases of combustion that produce explosive force. And this along with an electrostatic stress set up between the molecules of the material itself, causes the destructive action of lightning. This can be quite effectively prevented by use of properly installed lightning rods. (See Figure 10.)

14. LIGHTNING RODS

These rods are made of copper or material that is a good conductor of electricity. They should be installed on the tops, or very highest points of buildings or objects to be protected, and on all of the various corners or projections that are separated to any extent. These several rods are all connected together by a heavy copper cable, and then one or more ground cables of the same size, run from this to the ground by the most direct path. In running this ground cable, it should be as straight as possible, and if any turns or bends are made, they should be rounded or gradual bends.

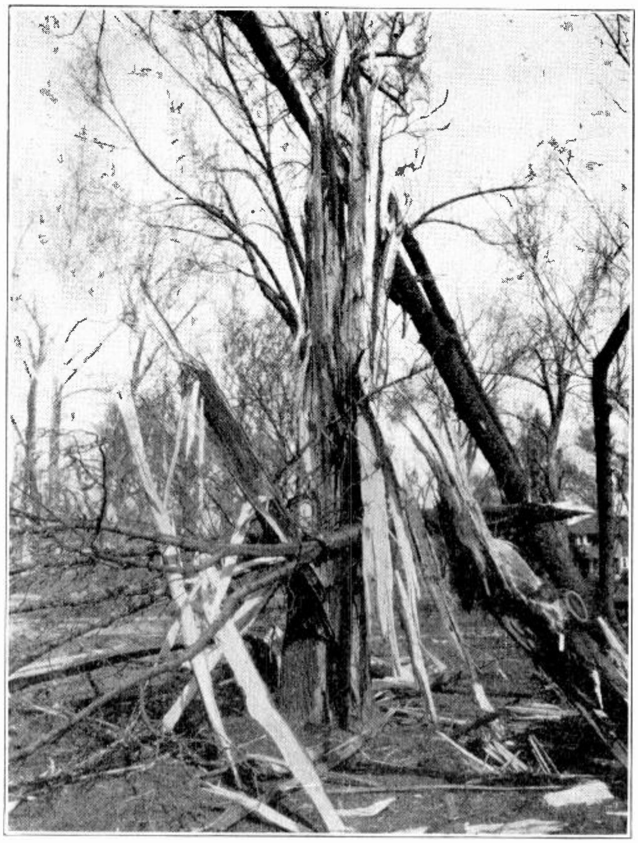


Fig. 9. Large tree shattered by lightning, showing the force and power of heavy lightning discharge.

The grounded end should be buried several feet in moist earth, or securely attached to a driven ground rod or pipe, or buried metal plate. The tips of lightning rods are usually sharply pointed, because it is easier for electricity to discharge to or from a pointed electrode, than a blunt one. These pointed rods, and heavy conductors of copper, form a much easier path to ground for electricity than the ordinary non-metal building does, and in some cases actually drain the atmosphere of small charges, before they become dangerously large. When a direct bolt of lightning does strike a rod, it usually flows through the cable to ground, doing little or no damage to the building, because the heavy charge of electricity flows through the good metal conductor without causing the terrific heat that it does in passing through air, wood, and other higher resistance materials.

Such rod systems have been proven to be a great protection, both by data collected on rodded and unrodded buildings in different parts of the country, and by actual tests in laboratories where several million volts of artificial lightning have been produced and used on miniature buildings.

Tests also prove that rods of a given height, protect a certain cone shaped area around them as shown in Figure 11. The diameter of this area at the base, is about three to four times the rod height. Many of the large oil reservoirs in western states are protected from lightning fires by installing tall masts around their edges, and sometimes with cables strung between the masts.

Electric power lines are often protected from lightning by running an extra wire above them on the peaks of the towers, and grounding it through each tower. (See Figure 12.)

More about protection of lines from lightning will be covered later under lightning arresters.

But in this section we have covered ordinary lightning protection, the general nature of static, and the methods of controlling it, in the places where it is most commonly found, in our homes and factories.

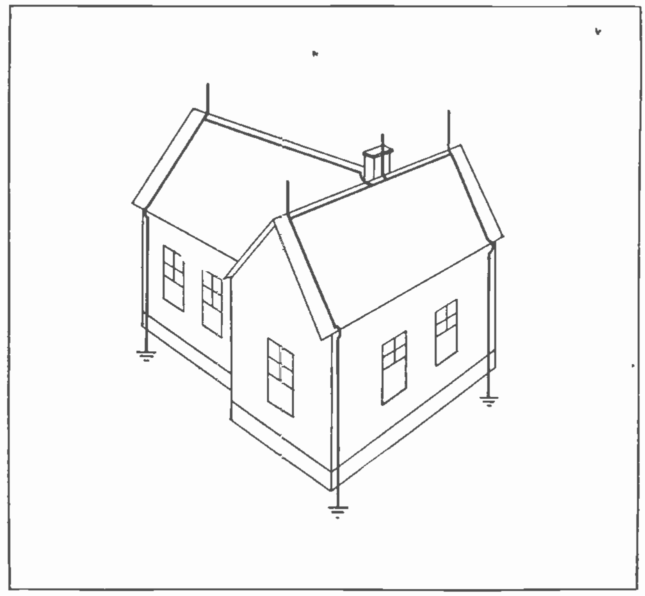


Fig. 10. Sketch of house equipped with lightning rods, to carry static and lightning safely to earth.

You will have many uses for the principles covered in this section, and they will help you to better understand certain things that will come up in your work in the field. Many of the hardest problems in "trouble shooting" on electrical systems, are easily solved by the trained man who knows these fundamental principles.

In the next section we will find out more about **Dynamic Electricity**, or the kind of "juice" that operates our motors, lights, etc.

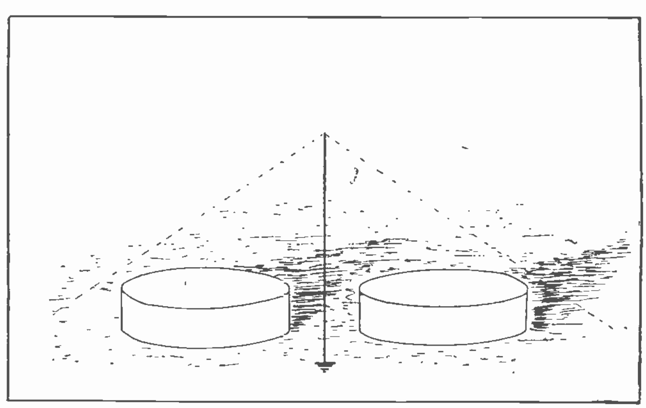
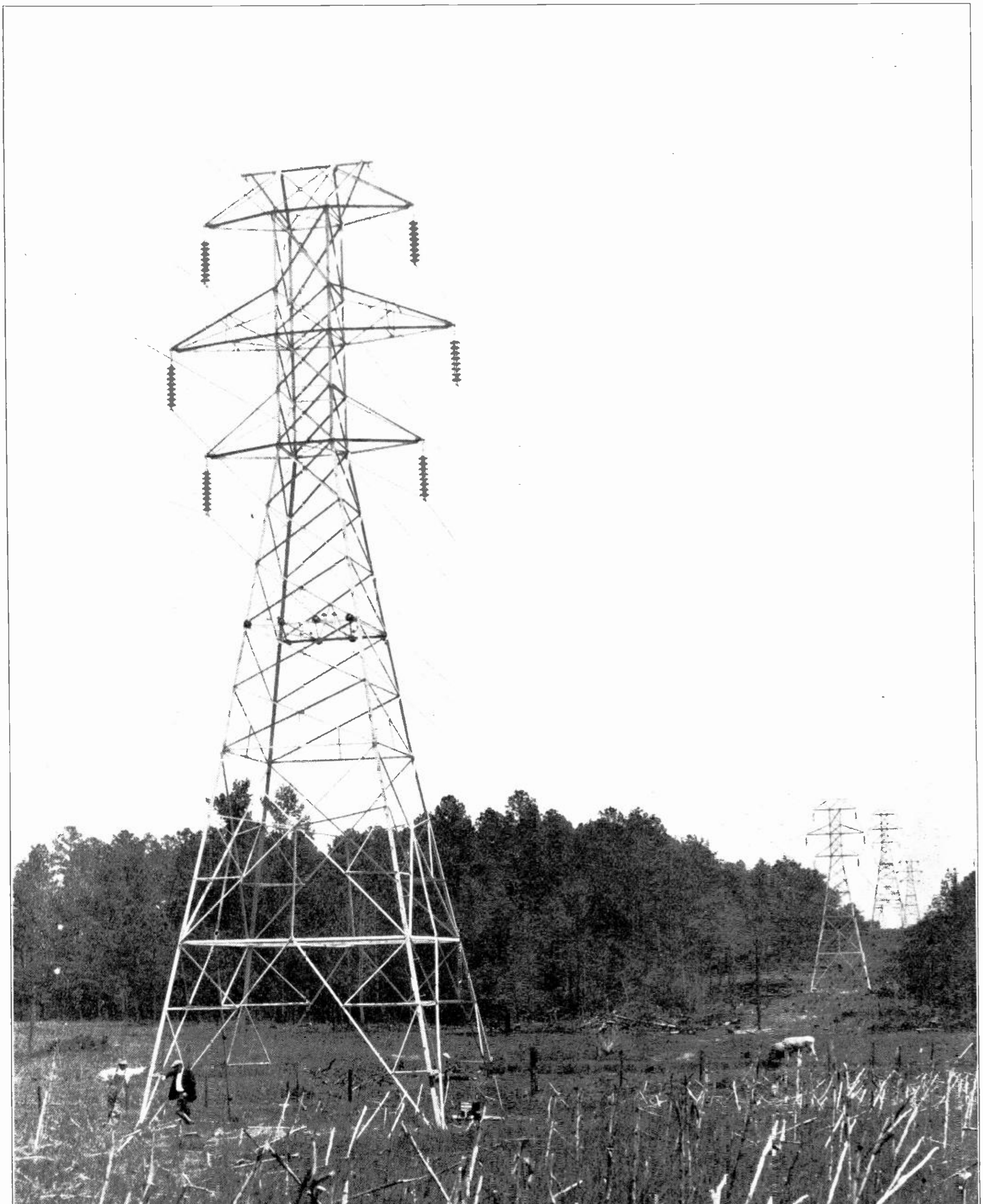


Fig. 11. Tall lightning rod used to protect oil tanks from lightning fires. The dotted lines show the area protected, and within which lightning will not strike.



Photo, courtesy of Walter Bates Steel Corp.

Fig. 12. High voltage transmission line. Note the two smaller wires on the very top of the tower. These are to protect the line from lightning, and are "grounded" through the tower.

ELEMENTARY ELECTRICITY

SECTION TWO

DYNAMIC ELECTRICITY

As we have said before, Dynamic Electricity is electricity in motion, or the kind that flows through wires, lines, motors, lamps, etc. This is the kind, or rather the condition of electricity we find most useful, and from which we get our heat, light and power.

So it is very important that we have a good understanding of dynamic electricity, and how it is produced, controlled and used.

We found that static electricity could be produced by rubbing or friction of certain materials, and that it could be accumulated or stored up in condensers or on certain surfaces or bodies. Also that when it discharges it usually takes the form of an arc or spark. Although in some cases we caused these discharges to flow to earth through wires.

So for the very short period during which an accumulation of static is discharging or flowing, it could be said to be dynamic.

But sources of static do not supply enough electricity or furnish it for long enough periods to be of much use to us, so we do not produce dynamic electricity in this manner.

15. ELECTRIC CURRENT FLOW

Remember we do not **Create** electricity at all, but merely **set it in motion.** When we say a generator produces a flow of current in a wire, it is assumed that it simply sets in motion some of the free electrons already in the wire.

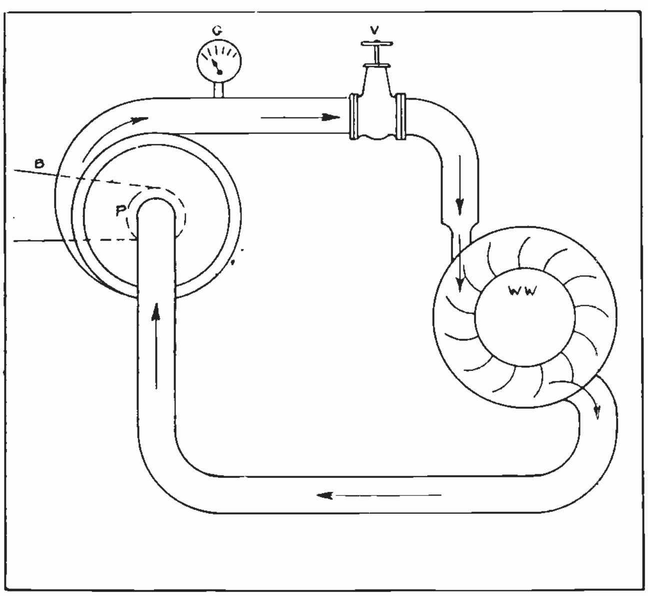


Fig. 1. Water pump supplying pressure to cause water to flow through pipe and operate water wheel. The purpose of the pump here is similar to that of a battery or generator in an electrical circuit.

It is well to consider dynamic electricity as very similar in many ways to water in a pipe line. For example, we can have water in a closed pipe line, and this water will have no movement, force or power, unless a pump is used to set up the pressure. (See Fig. 1.) In this illustration the pump (P) is the source of pressure to set the water in motion, and cause current to flow. The pump is driven by belt (B) and develops pressure to force the water through the pipe to the water wheel (WW). The gauge (G) indicates the amount of pressure developed by the pump, and the valve (V) will start, stop, and control the water flow.

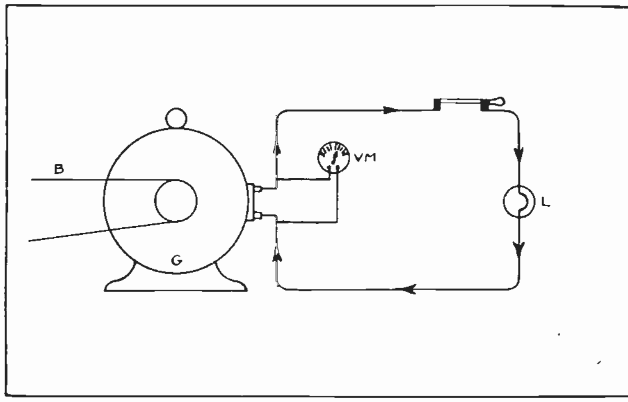


Fig. 2. Dynamo supplying electric pressure to force current to flow through the wires and lamp. No current will flow without a source of pressure or voltage.

In Fig. 2 an electric generator or dynamo (G) is shown producing electrical pressure to force current to flow through the wires to operate the lamp (L).

Here the volt meter (V.M.) indicates the amount of pressure set up by the generator, and the switch (S) will start or stop, the flow of current.

16. PRODUCING DYNAMIC ELECTRICITY

One of our first problems is to find out how to develop electrical pressure to set electricity in motion.

There are three methods of doing this, which are all common, and should be kept in mind. They are called the **thermal method, chemical method,** and **induction** or **mechanical method.**

The induction method is the basis of all our modern generators, and converts mechanical power into electrical energy. This method is by far the most commonly used of the three, but as both of the others also have many practical uses, we will cover them briefly first.

17. THERMAL METHOD

To generate electricity by the **Thermal Method,** we simply join the ends of two pieces of unlike metal together and heat them at the joint. (See Fig. 3.)

The heat acts differently on the different metals, and the activity it sets up within them will actually cause a small current of electricity to flow through the wires and meter attached, as shown in the figure.

We can use a piece of copper and one of iron for this device, or better still a rod of bismuth, and one of antimony.

These devices are called **Thermo Couples.** As they are only capable of producing very small amounts of electric current, and at very low pressures, we do not use this method for generating electricity for light or power.

However as the amount of electric pressure produced by a certain thermocouple is proportional to the amount of heat applied, these devices are very useful for measuring temperatures of ovens, furnaces, etc.

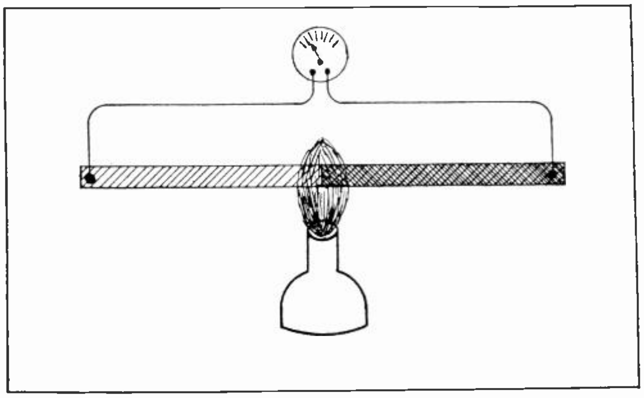


Fig. 3. Heating the joint of two unlike metals, produces a small amount of electric pressure and current flow through the meter in the circuit.

For this purpose a proper element or "couple" is enclosed in a non-combustible tube, so it can be inserted right into the flames or heat of a furnace.

Wires connected to the "couple" are brought out of the tube to a meter which can be adjusted and marked to read the temperature direct, in degrees. (See Fig. 4.)

18. CHEMICAL METHOD

The **chemical method** of producing electricity, is one with which you are probably more familiar, as this is the principle of our electric cells and batteries.

This source of electric supply is also very simple. It is based on the action of chemical solutions on various metals.

If we fill a jar with an acid solution, and immerse in it a piece of zinc and one of copper, the acid will immediately commence to act on these metals. And because the intensity and nature of its action is different on the two unlike metals, we again have a difference of electric pressure set up between the copper and zinc elements. If we connect them together with wires, and place a meter or lamp in this circuit, current will start to flow at once. (See Figure 5.)

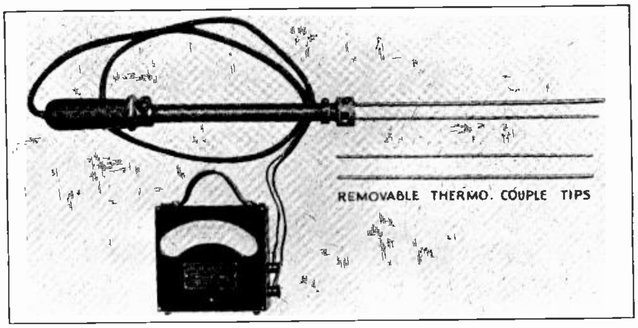


Fig. 4. Portable pyrometer for measuring high temperatures in ovens or furnaces, by use of "thermo couples."

Various kinds of metals and acids can be used. Even strong salt water will do with certain metals. But a solution of sulphuric acid, and the copper and zinc elements produce higher electric pressures than many other combinations, and are more commonly used.

Such devices are called **Primary Cells,** and a group of them connected together is called an **Electric Battery.**

It is interesting to know how the discovery of this form of electric source came about.

In the 17th Century, an Italian scientist named Galvani, discovered that frog legs would twitch and react to sparks of static electricity.

In 1779 Alessandro Volta in performing some experiments, accidentally discovered that pieces of metal with an acid soaked cloth between them would produce an electric spark.

He stacked up piles of metal disks, spaced with wet pieces of cloth, and developed our first known electric battery, from which he obtained quite strong currents and small arcs. And we find that many of our most important electrical devices of today, were discovered or developed from some such simple experiments.

Nowadays we have not only the wet primary cell, but also convenient dry cells, and large storage batteries, using this principle.

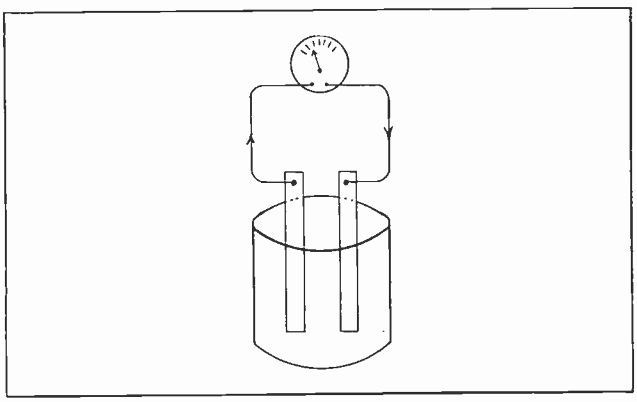


Fig. 5. Simple electric cell. Chemical action on the copper and zinc strips produces electric pressure.

These devices are used by the millions, to supply small amounts of electricity for various uses today.

Each type will be taken up thoroughly in a later section on cells and batteries.

19. MECHANICAL OR INDUCTION METHOD

The **Mechanical Method** of producing electricity is also very simple in principle, and it is this method that is used in all our great power plants today.

If we simply take a magnet as in Fig. 6, and quickly move a piece of wire between its poles, the wire will have an electric pressure induced in it.

Any magnet has between its poles a field of invisible lines of force. These are shown by the dotted lines in the Figure.

Only about one hundred years ago, a man named Michael Farady, discovered that moving a wire rapidly through these lines of force in a position to cut across their path, would generate electricity in the wire.

This can be proven by connecting a meter to the ends of the moving wire, by means of other wires as shown in Figure 6.

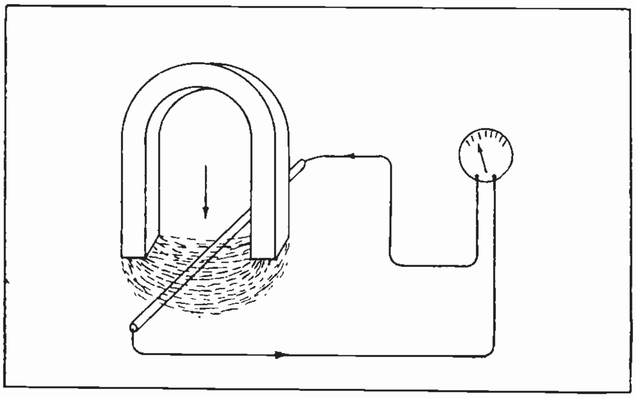


Fig. 6. Moving a wire through a magnet field induces pressure in the wire, and causes current to flow in the meter circuit.

Every time the wire (A) is moved up or down, through the magnetic field, the meter needle will indicate a flow of current.

The **direction** of this induced current changes, as we change the **direction** of movement of the wire. The **amount** of electric pressure set up by this type of device depends on the **strength** or **density** of the magnetic lines of force, and the **speed** with which the wire is moved through them.

Now if we were to mount a number of wires on a revolving armature, and spin them rapidly, between powerful magnets, we can produce considerable amounts of dynamic electricity by this method. (See Fig. 7.)

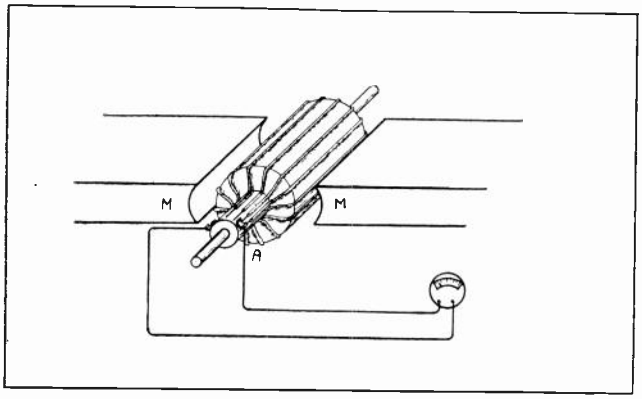


Fig. 7. Elementary type of armature A, with wires mounted on it to revolve in a strong magnetic field from magnets M, M.

It is in just this manner that our great power plant generators of thousands of horse power are made.

We will take up in detail their principles of operation and construction in a later section.

CONDUCTORS AND INSULATORS

20. CONDUCTORS

Now that we know how electricity can be produced, we must consider how to get it from the generators or source of supply to the places and devices where we wish to use it.

To do this we use proper electrical **Conductors** or wires.

We have found that electricity will pass or flow through some materials very easily while with others it is very difficult to get electricity through them at all. And we have good use for both.

In order to use electricity, we must be able to provide a good easy path for it to flow from the generators, to our lamps and motors which it is to operate. We must also be able to confine it to these proper paths, and prevent its wasteful or harmful leakage where materials or persons might come in contact with the wires.

The materials that carry electricity easily, we call **Conductors** and use the best of them to carry it where we want it to go.

21. INSULATORS

Those materials that tend to prevent the flow of electricity or not allow it to pass through them, we call **Insulators**, and use them to confine electricity to the proper conductors, and to prevent it leaking or flowing to other objects or places where we do not want it.

No material that we know of is a perfect conductor or insulator of electricity, but some are much better than others in each case. Both are so necessary and important in the use and control of electricity that a few of the best of each are given in the following lists:—

CONDUCTORS	INSULATORS
Silver	Glass
Copper	Mica
Gold	Porcelain
Aluminum	Enamel
Zinc	Rubber
Bronze	Wood (dry or oiled)
Platinum	Bakelite
Nickel	Fibre
Steel	Paper (dry or oiled)
Iron	Oil
Lead	Waxes
German Silver	Air
Mercury	
Water (ordinary)	
Carbon	
Acids	

The conductors and insulators in this list are all used to some extent in electrical machines and devices.

Silver is one of the best conductors known, but because of its very high cost, and certain mechanical properties, it is not much used.

Copper is also an excellent conductor, and is by far the most commonly used in all electric lines and machines.

You will note that most of the conductors are metals, although ordinary water with its usual impurities is a fair conductor, and acids are also.

All the insulators are non-metallic. Glass and Mica are two of the best insulators, and rubber is also excellent. Rubber is most commonly used in insulating electric wires, because of its flexibility, allowing them to bend freely without damaging the insulation.

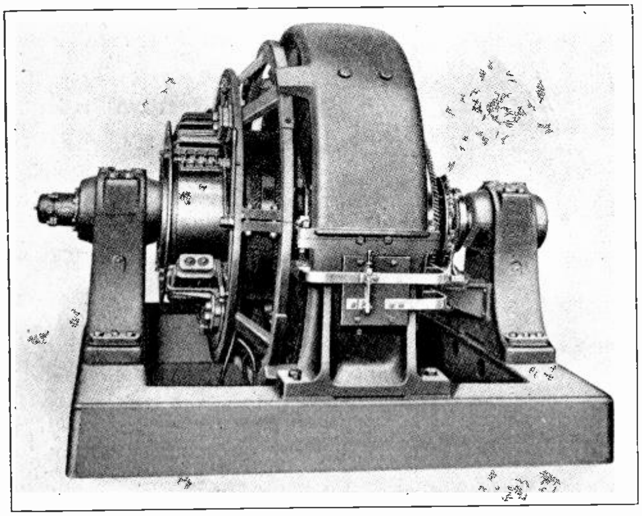


Fig. 8. Photo of a large generator, which produces its voltage by induction.

22. INSULATED WIRES

A good example of a conductor and insulator properly used together is the common rubber covered copper wire. The copper providing an excellent path for the electric current to flow through, and the rubber an excellent insulator to confine it to the wire, and prevent its escape where the wire might otherwise touch metal objects or earth. (See Fig. 9.)

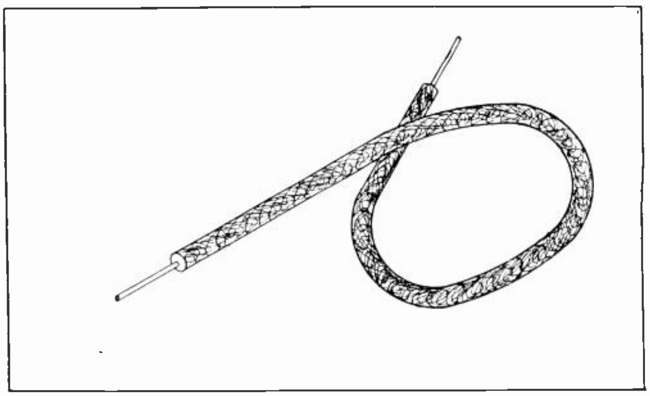


Fig. 9. Sketch of insulated wire. The copper wire is covered with rubber, and cotton braid.

23. ELECTRIC CIRCUITS

In order to use electricity with any device, we must always provide a complete **Circuit** or path, for the current to flow from the generator or source, to the device using it, and then back again to the generator. (See Fig. 10.)

This endless path or circuit includes the coils or windings inside the generator, the line wires from the generator to the lamp, motor or other device, and any switches or instruments that may be in the circuit anywhere.

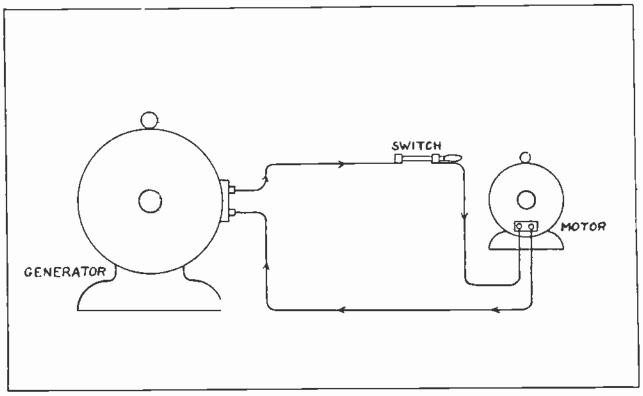


Fig. 10. Complete electric circuit. The current flows over the top wire from the generator to the motor, then back along the lower wire to the generator.

Current will only flow when all parts of this circuit are complete, all switches closed, and all wires connected. To start or stop the flow of electricity and the operation of the devices, we only need to close or open the switches provided.

All line wires, switches, and coils within the machines are made of conducting material, usually copper.

All these wires, coils, etc. must be insulated, usually with rubber, cotton or oil, and sometimes with air only, on certain parts.

So we can readily see the importance of a knowledge of common conductors, insulators and circuits, in the use and handling of electricity.

In later sections we will take up more of the exact properties of various conductors and insulators, and various types of circuits.

24. EFFECTS OF DYNAMIC ELECTRICITY

How are we going to make use of this electricity which we have learned how to produce and convey from the generators to our electrical devices?

First we must know something about the useful effects of electricity and how to obtain them.

Dynamic electricity flowing through a circuit from any generator or source, can produce four valuable effects, if we know how to obtain them.

These are called the **magnetic, heating, chemical** and **physiological** effects.

25. MAGNETIC EFFECT

Whenever electricity flows through any wire or conductor, it sets up around that conductor a field of whirling magnetic lines of force. These lines are invisible and we cannot feel them. But we can prove they exist by placing a magnetic compass needle near the wire. (See Fig. 11.)

As soon as current is started in the wire, the needle will be deflected from its true North and South position.

The direction and amount of movement of the needle will depend on the direction and the amount of current flowing.

For example, if we reverse the direction of current in the wire, the compass will deflect in the opposite direction. If the current is increased or decreased in the wire, the needle will increase or decrease its amount of deflection accordingly.

This magnetic effect of dynamic electricity is of the greatest importance, as it is the one that we use in all generators, motors, and electro-magnets.

If we wind a coil of insulated wire around a core of soft iron and pass an electric current through the coil, the iron will become strongly magnetized at once, from the magnetic lines set up around the turns of wire.

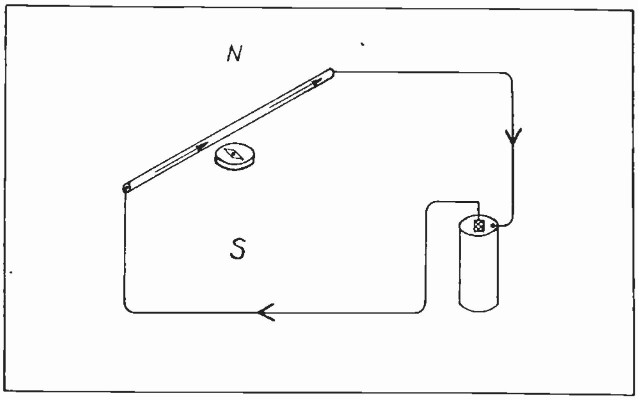


Fig. 11. Showing a compass needle deflected from its north and south position, by the magnetic flux around a wire carrying current.

These electro magnets have thousands of uses in electric lifting magnets, relays, bells, controllers, motors, generators, etc. We will make a very thorough study of them and this magnetic effect of electricity a little later.

A good demonstration that you can easily make of this useful effect of electricity, is to wind a few turns of insulated wire around a nail, bolt, or screwdriver, and connect the coil ends to a dry cell.

As soon as the circuit is closed the iron will become magnetized and attract other nails, tacks, etc. But as soon as the wire is disconnected from the cell, the iron loses most of its magnetism.

The practical man can often find many small, handy uses for this knowledge in his daily work.

26. HEATING EFFECT

Electric current flowing through a wire always produces a certain amount of heat in that wire.

In copper wires of low resistance this heat may not be noticeable, but if we overload them or cause too much current to flow, even copper wires will become hot and burn their insulation or possibly melt.

When we want to create heat from electricity, we apply high enough pressure to cause current to flow through high resistance wires or coils, such as iron or German silver wire. And because of their high resistance, a moderate amount of current will cause them to become red hot, or even white hot in some cases.

Our electric toasters, flat irons, waffle irons, table grills, portable heaters, electric ranges, ironers, soldering irons, etc. are all examples of this method of producing electric heat.

Large baking and enameling ovens, heat treating furnaces, etc., in industrial plants, use this principle.

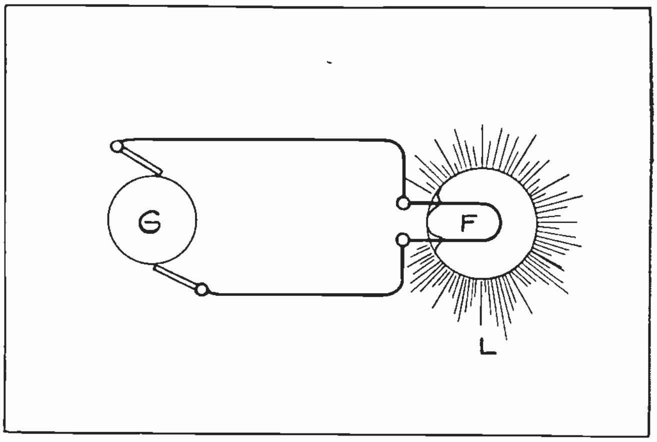


Fig. 12. Electric current flowing through filament wire in the lamp, produces intense heat and light.

27. ELECTRIC LIGHT

The incandescent lamp operates on the same principle.

Here we have a wire of tungsten metal, which is high resistance, and will not melt at white heat. This filament wire is enclosed in a glass bulb from which the air has been drawn to prevent it burning. Then current is forced through it in the right amount to bring it to white hot or incandescent heat, so it radiates light. (See Fig. 12.)

An electric arc produces heat and light on about the same principle. In this case instead of using a high resistance wire, we use voltage high enough to force current through air and the gases formed by

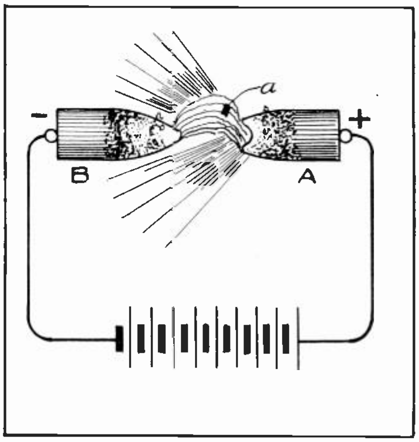


Fig. 13. Electric Arc formed by current between carbon electrodes.

the arc. This mixture of air and gas is very high resistance, and the current flowing in the form of an arc produces the highest temperatures made by man. (See Fig. 13.)

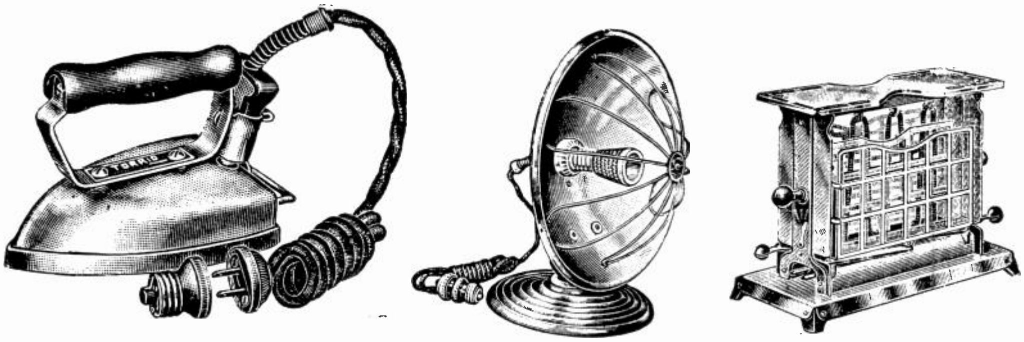


Fig. 14. Ordinary electric flat iron, glow heater, and toaster, all devices using the heating effect of electricity.

Great furnaces of this type using carbon electrodes from 12 inches to 30 inches in diameter, and 6 to 12 feet long, and thousands of amperes of electric current, melt tons of steel in our steel mills.

The arc was one of the first forms of electric light. And many large arc lamps are in use today, for street lights, flood lights, search lights, etc.

So we see that the heating effect of electricity is also very important to know how to use.

Fig. 14 shows several devices which use electric heat, produced by current flowing through high resistance wires.

28. CHEMICAL EFFECT

When electricity is passed through various chemical solutions it has the power to decompose them. And if we immerse two pieces of metal in an acid solution, and allow current to flow from one to the other through the solution, it will carry away particles of the metal at which it enters the liquid and deposit them on the other metal. This is the method and effect used in electro-plating, and is used very extensively in covering cheaper metal objects with gold, silver, chromium, nickel, etc. (See Fig. 15.)

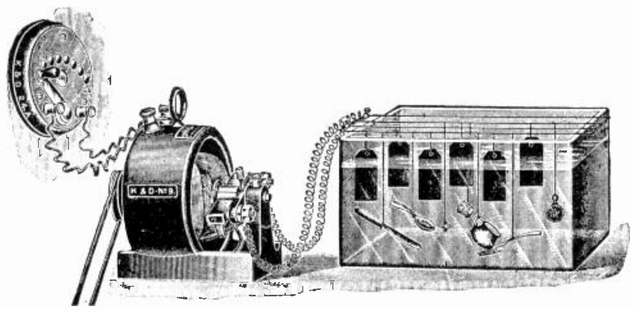


Fig. 15. Small electro-plating outfit, consisting of generator, rheostat and plating vat.

This action is also called **Electrolytic** action, and is used in the refining and purifying of some of our metals.

Another example of the chemical effect of electricity is in the charging and discharging of our storage batteries.

29. PHYSIOLOGICAL EFFECT

This effect of electricity is less commonly used than those above mentioned, and it usually refers to the effect of electricity on the human body.

We all know that if we touch live electric wires we feel a shock, or the effect of electricity on our nerves and muscles. If the voltage is low, this may be only a mild and somewhat pleasant sensation. If the voltage is high and from a heavy power wire, the shock may be injurious or even fatal. So it is best to always be very careful in handling electric wires and equipment.

Doctors and hospitals use the shocking effects of electricity, properly controlled, for very beneficial treatments of certain body disorders and diseases.

They also use the heating effect and chemical effect of electricity, by applying metal plates or electrodes to various parts of the body, and passing carefully controlled currents of either direct or alternating curent, through affected parts of the body.

So this physiological effect of electricity is also very important in its modern and proper use.

ELEMENTARY ELECTRICITY

SECTION THREE

ELECTRIC UNITS AND SYMBOLS

In dealing with electricity, we must have definite units to measure it and express it in certain quantities.

We have units of measurement for water, steam, coal, money, groceries, etc. and we need them for electricity, as it is as common and necessary today as many of these other items.

We speak of water in pints, quarts, or gallons, all of which are units of different sizes, and which we easily understand because we are familiar with the size and amount of each.

We speak of steam in pounds pressure, and degrees of heat. Coal is measured by the pound, or the larger unit called the ton, money in dollars and cents, groceries by the pound or dozen, etc.

So we can see that we need to have these definite units of measurement to deal with all the things we us in our daily life. And the man who intends to use electricity, should know the units for its measurement, those which measure its effects, and the important factors in electrical circuits.

There are only a few of the more common units needed by the practical man in ordinary work, and they are easy and simple to use.

With these units you can determine the amount of current flowing in a line, or through a motor or lamp. Also the amount required to operate a given machine or device, and its cost of operation as well.

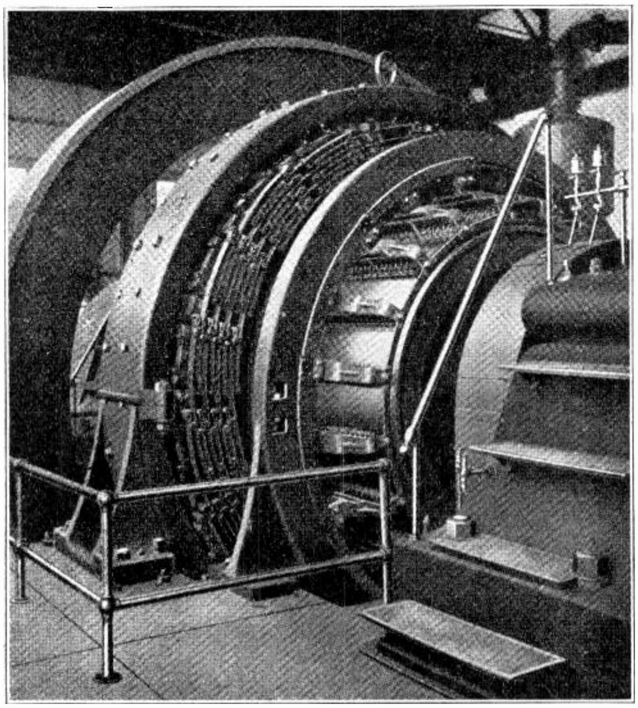


Fig. 1. Large D. C. generator. It is rated as follows, 2000 Kw., 250 V., 8000 I. After carefully reading the pages on units and symbols, you should easily understand this rating.

It is not necessary to memorize all these units at once, but you should study them carefully, to get a good understanding of the meaning and use of each. Then by practicing their use you will soon have them fixed in your memory.

Of course we know that we cannot weigh or measure electricity as we do coal or water. So we measure its effects, and establish our units in this manner.

30. ELECTRIC QUANTITY

The Coulomb is the practical small unit of electrical quantity. We determine this quantity by the chemical effect of electricity flowing through a device called a "voltameter." (See Fig. 2.)

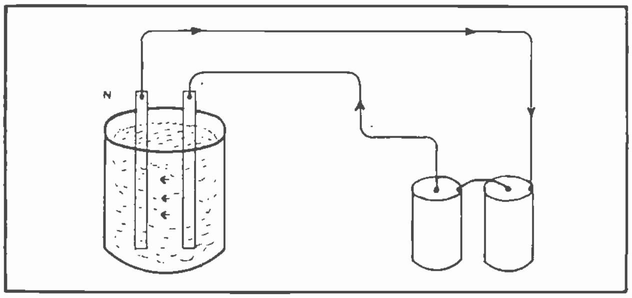


Fig. 2. Sketch of a "voltameter," or device for measuring electric quantity by work done on a plating principle.

Here we have two pieces of copper immersed in a solution of copper sulphate, and a battery connected to them and passing current through the solution from one electrode to the other. As you have already learned, this will cause some copper to leave the positive plate and deposit on the negative plate.

Of course the more electricity we pass through this device, the more copper it will deposit, or the more work it will do. So by carefully weighing the amount of copper transferred, we can set a certain unit of electric quantity. This unit of one Coulomb is the amount required to deposit .0003293 gram of copper from one plate to the other. Or with silver, to deposit .001118 gram, from a standard solution of silver nitrate.

These are very small amounts and are odd figures, and need not be remembered. But it serves to illustrate the method of measuring electrical quantity by its effect or work done.

31. ELECTRIC CURRENT

The Ampere is our unit of electric current or rate of flow. It is a unit you will use much more often than the Coulomb.

An electric current of one ampere is flowing when electricity passes through a circuit at the rate of one Coulomb per second. So we see this unit considers both quantity and time, and tells us just how fast the current flows. Knowing the amount of current in amperes gives us some idea how much work we could expect it to do in a given time.

For example we say a gallon of water is a unit of quantity, and compares to a Coulomb of electricity. But if we say water is flowing at the rate of so many gallons per minute or per second, then we can get an idea how much work it would do, or how much we would get in an hour or a day at that rate.

We say a certain lamp uses ½ ampere, or that a motor uses 50 amperes, which means that they require a continual rate of flow of those amounts of current to operate them.

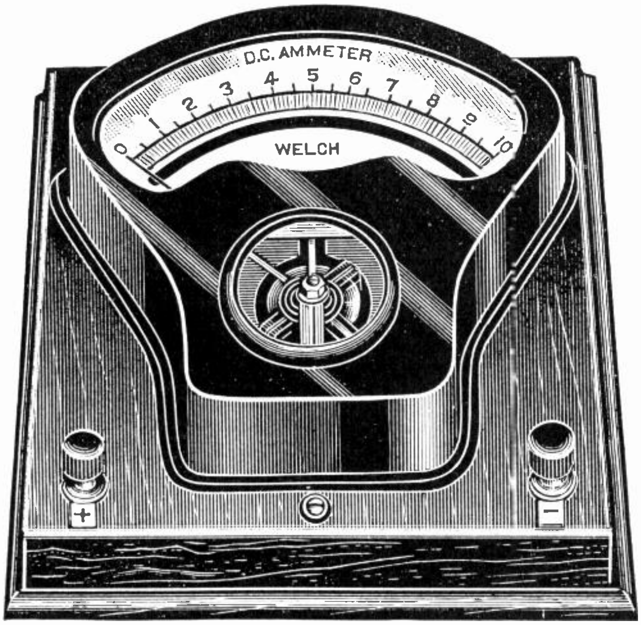


Fig. 3. Portable ammeter, used to measure electric currents.

The current of any circuit or device can be measured with an ammeter such as shown in Fig. 3. The practical man will have many occasions to use this device and the unit **Ampere** in his electrical work.

32. ELECTRIC PRESSURE

The **volt** is our unit of electric pressure, and is used to measure or express the amount of pressure required to force a given current to flow.

As we have already learned, all electric wires or conductors offer some resistance to the flow of current. So we must have electric pressure to cause current to flow in any circuit or device.

This pressure is often called **Electro-Motive-Force** (Abbreviated E. M. F.), and meaning the force that moves electricity. It is also sometimes called **Potential.**

So we say a certain battery produces 6 volts pressure, or a generator produces 110 or 440 volts pressure. Or that a power line has 220,000 volts potential or pressure. This gives us an idea of the amount of electro-motive-force available, the same as if we said a boiler produces 300 pounds of steam pressure, or a pump 100 pounds of water pressure.

One volt is the exact amount of pressure required to force one ampere of current through one Ohm of resistance. The voltage of any machine or circuit can be measured with a voltmeter. See Fig. 4, which shows a photo cut of a voltmeter.

33. ELECTRICAL RESISTANCE

The **Ohm** is the standard unit of electrical resistance, by which we measure or compare the resistance of any electrical circuit or device.

Remember every wire and device has some resistance to current flow, as we have no perfect conductors. Naturally this resistance limits or controls the flow of current, the same as friction in a pipe or a partly closed valve, would limit and control water or steam flow.

So it is very important that we know the unit to measure and determine the resistance of electrical circuits and machines.

The standard Ohm, is the resistance of a column of mercury, 106.3 centimeters long and 1 square Millimeter in cross sectional area. Or this is 41.85 inches long and about 1/25th inch in diameter. This standard resistance is taken always at 32 degrees Fahrenheit, or Zero degrees centigrade, because the resistance is not the same at all temperatures.

34. FACTORS GOVERNING RESISTANCE

It is important to remember that the resistance of any conductor depends on the kind of material, its length, area, and temperature.

For example we know that copper wires are of much lower resistance than iron or steel wires. And the longer a wire is, the greater will be its resistance. The larger it is in cross section or area the lower will be its resistance. And with all of our common metals the resistance will increase slightly as their temperature increases. Carbon and certain liquids are exceptions to this rule, and their resistance gets less as their temperature increases.

It is interesting and convenient to know that a piece of No. 10 copper wire 1000 feet long has a resistance of about one ohm. A No. 10 wire is about 1/10th of an inch in diameter.

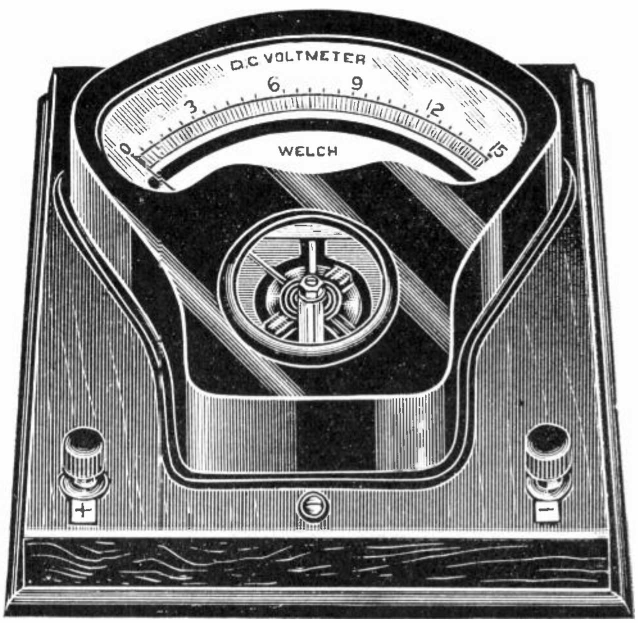


Fig. 4. Portable voltmeter used to measure electric pressures or voltages.

Number 14 wire such as commonly used in house wiring, has about 2.5 ohms resistance per thousand feet.

A piece of No. 30 copper wire 10 feet long has about one ohm resistance, while a piece of No. 30 German Silver wire only 6.2 inches long will have about one ohm resistance. Note carefully the difference in resistance of these various wires according to their size, length and material, and it will help you get a better understanding of how the wires and their resistance will tend to control the current flow.

A little later we will give a definite law or rule explaining this relation between current and resistance.

The resistance of wires and materials can be measured with an ohmmeter, and other instruments which will be explained later.

35. SPECIFIC RESISTANCE is a term we use to express and compare the resistance of various materials. To do this we of course take pieces of the same size of each material. Usually this piece is one cubic centimeter in size, or sometimes one cubic inch. The centimeter is about .4 of an inch.

The specific resistance of any metal or material means the resistance to flow of electricity through a centimeter cube of this material, from one side to the opposite side.

The resistance of a piece of ordinary metal of this size is usually a small fraction of one ohm, so is expressed in **Microhms,** meaning millionths of an ohm.

The following table gives the specific resistance of some of our common materials. It is not necessary to memorize these, but is well to observe and compare the specific resistance of several of the materials familiar to you, such as copper, aluminum, iron, mercury, etc.

In this manner you can get an idea of their comparative values as electrical conductors, and you can always refer back to this table whenever you need to know or use any of these values.

Specific resistance of various common materials, at 0 degrees centigrade:

MATERIALS	Specific resistance in Microhms. Centimeter cube	Inch cube
Silver (Annealed)	1.49	.587
Copper (Annealed)	1.59	.627
Copper (Hard)	1.62	.638
Gold	2.20	
Aluminum	2.61	
Zinc	5.38	
Phosphor Bronze (Commercial)	8.48	3.34
Bronze	17.80	
Platinum (Annealed)	8.98	3.54
Nickel (Commercial)	9.90	
Steel (Soft)	11.80	
Steel (Wire)	13.50	
Steel (Hard)	45.60	
Iron (Pure)	8.85	
Iron (Wrought)	13.80	5.45
Iron (Cast-soft)	74.40	
Lead	19.80	
German Silver	33.10	
German Silver Wire	20.90	8.24
Mercury	94.07	
Water (Ordinary)	1200. to 12,000.	
Carbon	400. to 1150.00	
Carbon (Arc)	5100. to 7600.00	

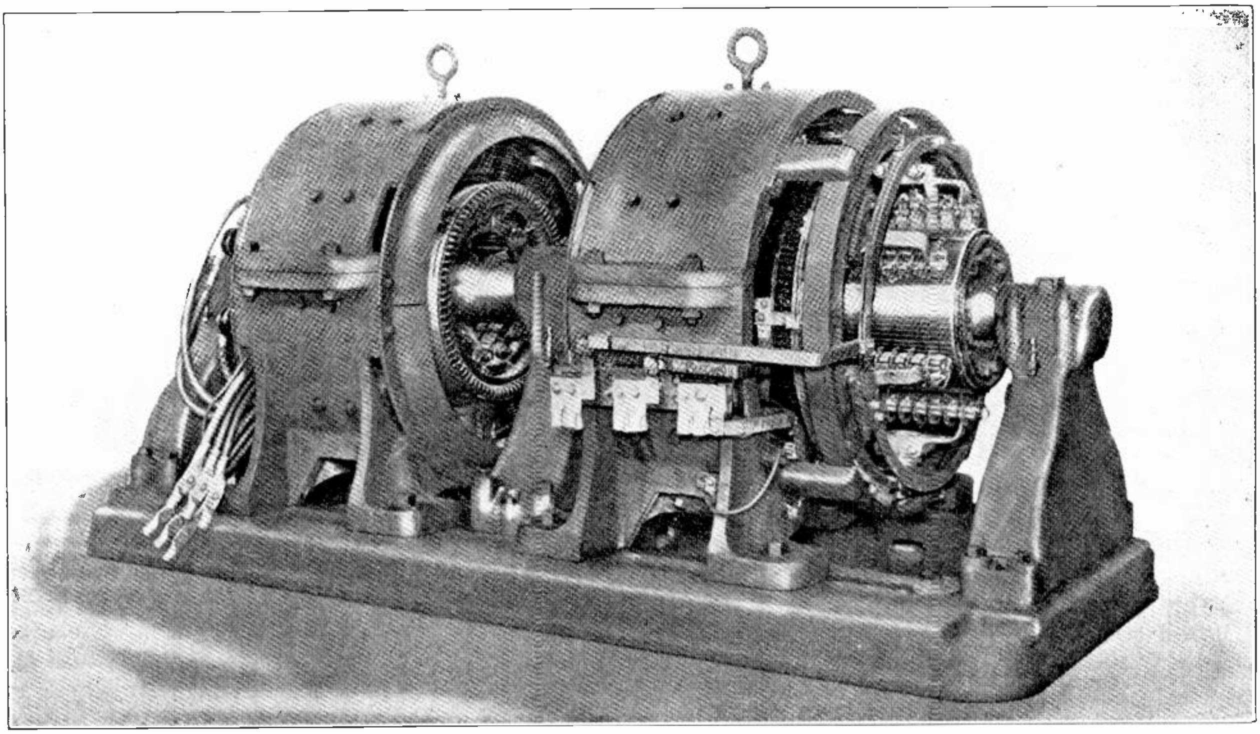


Fig. 5. If this machine is rated at 500 Kw., how many horse power is this equal to?

36. **THE MHO** is the unit of conductance, and expresses the conductivity of a wire, or the exact opposite of resistance. Its use will be explained later.

37. ELECTRIC POWER UNITS

The **Watt** is our unit of electric power. And this is the unit by which we determine the amount of heat, light, or power we can get from electricity. It is also the unit by which we rate the power produced or consumed by many small electrical devices.

One Watt is the amount of power produced by one ampere flowing under a pressure of one volt.

It requires 746 watts to make one horse power. So we can see that the watt is too small a unit to deal with our larger amounts of electric power. For this use we have the **Kilowatt,** or 1000 watts. The prefix "Kilo," is used with many electric units at times, and always means 1000.

One Kilowatt is equal to approximately 1.34 H. P.

The horse power is the power required to lift 33,000 pounds, one foot in one minute, or 550 pounds, 1 foot in one second. It is often referred to as 33,000 foot pounds per minute.

The **Watt Hour** is a commonly used unit, and means the power used at the rate of one watt, for one hour continuously.

The **Kilowatt Hour** is the larger and more common unit, and means the power used at the rate of one kilowatt, for one hour. The kilowatt hour is the unit used to buy and sell electric power, and electricity is commonly sold for so many cents per kilowatt hour.

For example, suppose you were asked to find the cost of operation of a 10 H. P. motor for 50 hours, with electricity costing 6 cents per kilowatt hour.

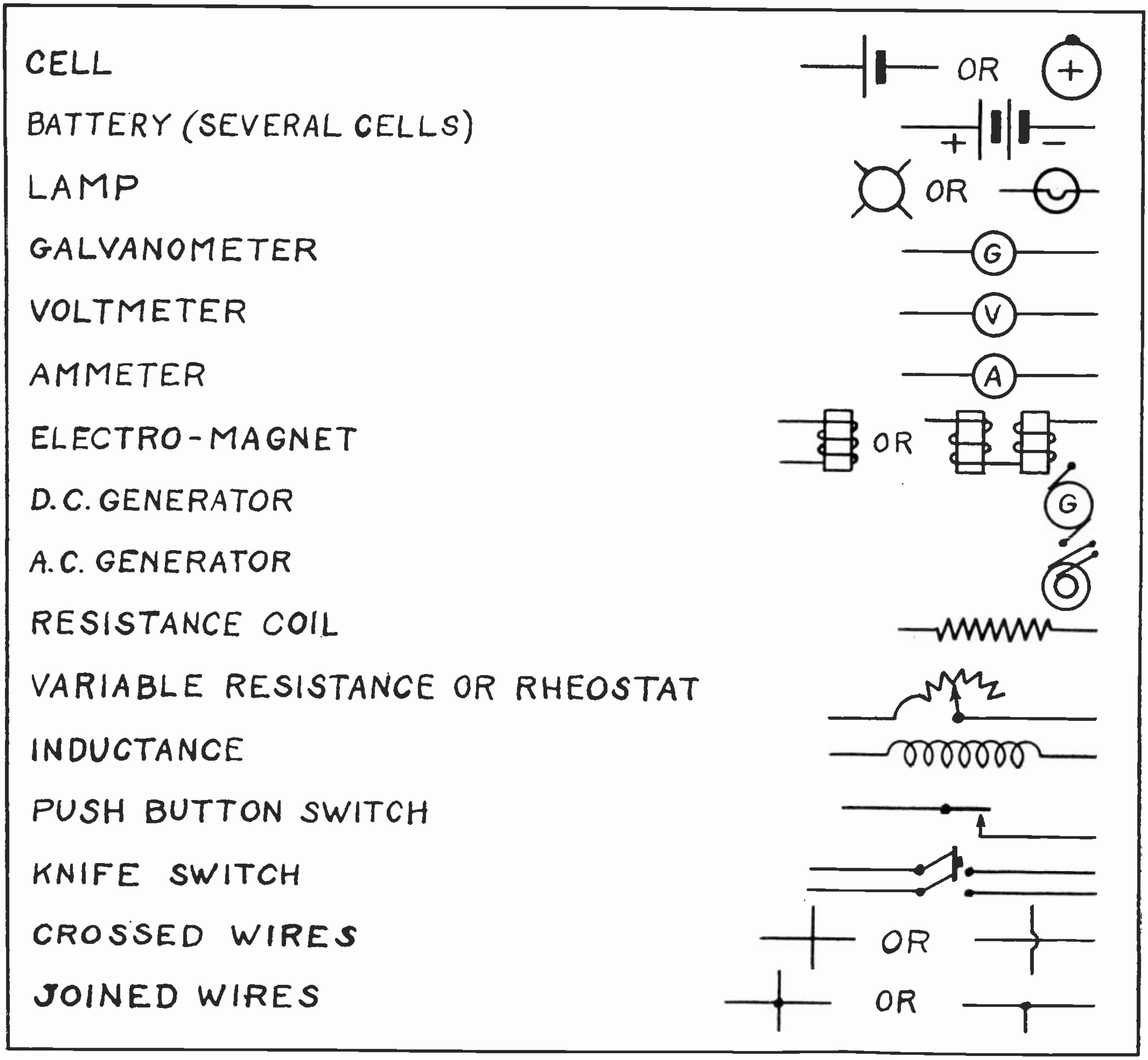


Fig. 5B. Some of the most common symbols used in electrical diagrams.

If one H. P. is equal to 746 watts, then a 10 H. P. motor will use 10x746 or 7460 watts. Then to change this to kilowatts, we divide 7460 by 1000, or 7460 divided by 1000 equals 7.46 kilowatts.

For a period of 50 hours this would use a total of 50x7.46 or 373 kilowatt hours.

Then 373x.06 equals $22.38 total cost.

We have not considered the efficiency of the motor in this problem as this will be taken up later.

38. SYMBOLS

For each of these units, we have just learned, we have a symbol or abbreviation which we use in writing them in problems or specifications on the job. These symbols are very easily learned and remembered with a little practice in using them, and will save a great amount of time for the practical electrician, the same as our abbreviations for other commonly used terms, such as lb., oz., ft., in., qt., Jan., Feb., Mar., etc.

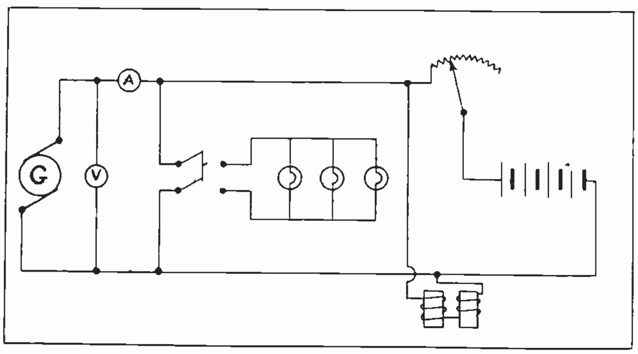


Fig. 6. This diagram shows the use of some of the symbols given in Fig. 5B. How many can you recognize?

To make it more convenient to remember the names of these important electrical units and their symbols and also easy to refer to them for reminders, we have arranged them all together in the following group.

Read them over several times to help fix them in your memory;

Symbols	Units	Use
Q	Coulomb	Unit of electrical quantity.
I	Ampere	Unit of current flow.
E	Volt	Unit of electrical pressure.
R	Ohm	Unit of electrical resistance.
G	Mho	Unit of electrical conductance.
W	Watt	Unit of electrical power.
KW	Kilowatt	Larger unit of electrical power.
KW. HR.	Kilowatt-Hour	Unit of electrical power for a given time or unit of electrical work.
H. P.	Horsepower	Unit of mechanical power.

746 W. equals 1 H. P.
1 KW. equals 1.34 H. P.

A few other common symbols used to represent electrical devices in circuit diagrams, are shown in Figure 5-B, so you will be able to recognize and understand them in the sketches used from now on.

The units and symbols covered in this section may seem somewhat dry at first, and are probably less interesting than the work on machinery will be. Remember, however, you will understand the machines much better if you know these few practical units and symbols well.

ELEMENTARY ELECTRICITY

SECTION FOUR

OHMS LAW

Ohms Law is one of the most important laws of electricity that the practical man can know, and yet it is very simple. This law is named after a German scientist, George Ohm, who in his experiments discovered the definite relation between **pressure, current,** and **resistance** in electrical circuits, and put it in the form of a simple statement or rule.

When you obtain a thorough understanding of Ohms Law, it will be much easier to understand the operation of all electrical machines, and circuits.

You have already learned that in order to use electricity in any way we must have circuits, to carry it from the generators to the machines or devices, and also through the devices themselves.

In every live electrical circuit there are always present the above mentioned three factors, pressure, current and resistance. All circuits have some resistance, and therefore, to cause current to flow through them we must have pressure or electromotive-force.

38-A. EXPLANATION AND APPLICATION OF OHMS LAW

According to Ohms Law **the current in any D. C. circuit is always directly proportional to the pressure, and inversely proportional to the resistance.**

The first part of this rule means that if we increase or decrease the voltage or pressure applied, the current will increase or decrease the same amount, if the resistance remains constant.

For example if 100 volts will force 10 amperes through the resistance of a certain circuit, 200 volts would send 20 amperes through it, or 50 volts, 5 amperes, etc.

The second part of the law means that if we increase the resistance of a circuit, the current decreases, or if we decrease the resistance the current will increase, if the voltage remains constant. Thus the term "inverse proportion."

For example, if we have a current of 10 amperes flowing through a circuit of 30 ohms resistance, and change the resistance to 60 ohms, then 5 amperes will flow. Or if we change the resistance to 15 ohms, 20 amperes will flow.

39. CONTROL OF ELECTRICITY

The above shows us how to obtain any desired current for a certain device or work, by regulating the voltage of our generators, or the resistance of the windings of the device.

And on this law or principle are based the majority of ordinary electrical calculations made by the practical man, so it is well worth a little reviewing to get it thoroughly understood.

If we compare Ohms Law for electricity with the principles of water flow in pipes, and use just common reasoning with it, as we do with other things we are more familiar with, it should be easily understood. (See Fig. 1.)

Here we have a pump driven by an engine, and producing pressure which causes the water to flow. The friction of the water moving through the pipe, and the smaller section of pipe (A), and partly closed valve (B), all offer resistance or opposition to the flow of water. And the more we increase this resistance by reducing the size of the pipe or valve opening, the less water will flow. But if we increase the pressure supplied by the pump, then more water will flow.

Electrical circuits operate similarly. (See Fig. 2.)

Here we have a generator driven by an engine, and producing electrical pressure or voltage which causes the current to flow. The resistance of the wires, the rheostat and lamp, all tend to oppose the flow of current, and if we use smaller wires or a higher resistance lamp the current will decrease. But if we speed up the generator and increase its voltage the current would increase.

The voltmeter (V) and ammeter (A), in the electrical circuit measure and show the pressure and the current in volts and amperes, just as the pressure gauge and flow meter in the water circuit measure the pressure in pounds, and the flow in gallons per minute.

40. CONVENIENT SIZE OF ELECTRIC UNITS

Another very interesting fact is that **one volt pressure is just exactly enough to cause one ampere of current to flow through one ohm of resistance.**

This of course is not accidental, but is the way those who developed these standard units made them of convenient relative sizes. This greatly simplifies all electrical work and calculations.

For example if one volt will force one ampere through one ohm, then it is easy to see that two volts would force two amperes through the same resistance of one ohm. Or ½ volt would only force ½ ampere to flow through one ohm.

If one volt will force one ampere through one ohm, then if we increase the resistance to two ohms a volt could only force ½ ampere to flow. If we reduce

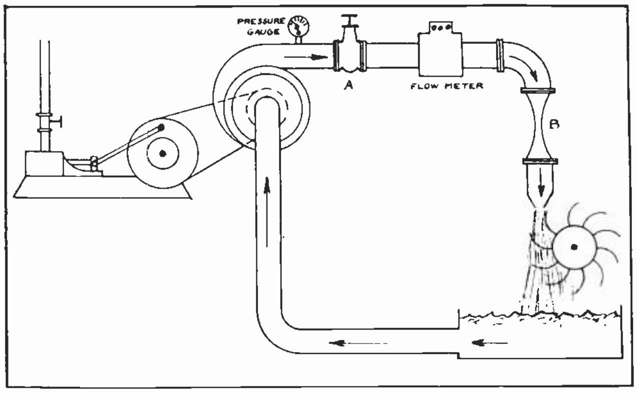


Fig. 1. The amount of water flow in this system can be increased by increasing the pump pressure. But it will decrease if we increase the opposition of the valve, or small section of pipe.

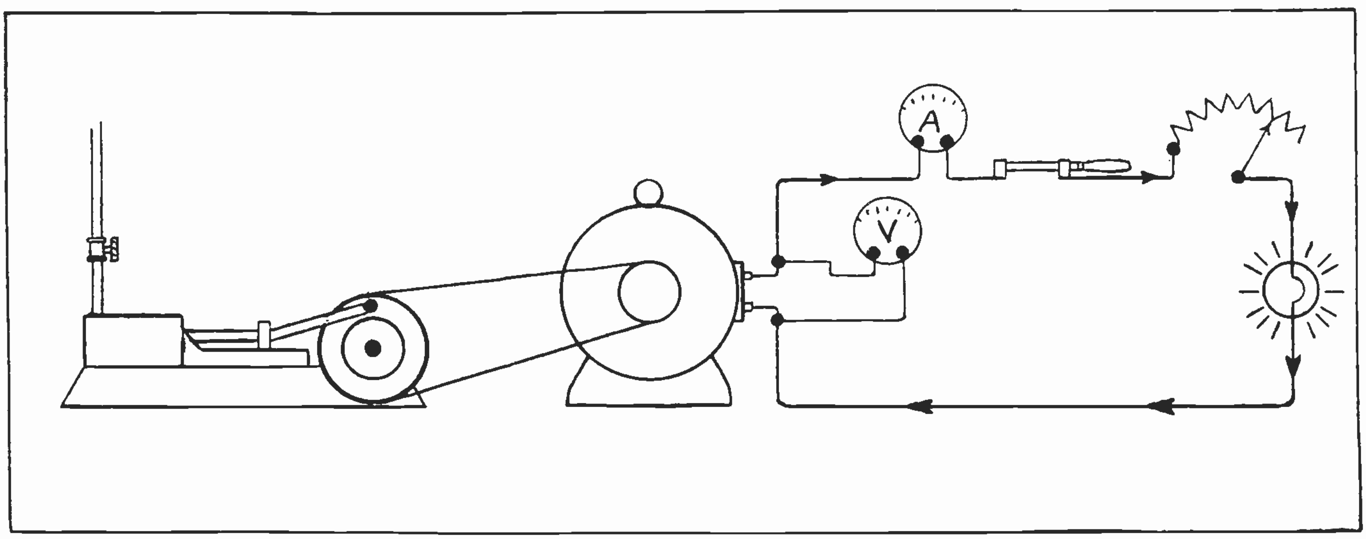


Fig. 2. The electric current flow in this circuit will be increased if we increase the generator voltage, or decreased if we increase the resistance of the wires, rheostat, or lamp.

the resistance to ½ ohm, the one volt could force two amperes to flow.

41. OHMS LAW FORMULAS

From this simple relationship between the size of these units and the discovery of the effect of pressure and resistance, we obtain the following formulas called **Ohms Law Formulas.**

$$I = \frac{E}{R}, \qquad E = I \times R, \qquad R = \frac{E}{I}$$

In which:

I=current in amperes.
E=pressure in volts.
R=resistance in ohms.

These are simply little abbreviated sets of instructions which tell us exactly how to proceed with certain electrical problems.

Remember that when any two factors are placed one above the other and a line between, it means to divide the upper one by the lower.

For example suppose you have to find the amount of current that would flow through a lamp of 5 ohms resistance when a pressure of ten volts is applied to it. (See Fig. 3.)

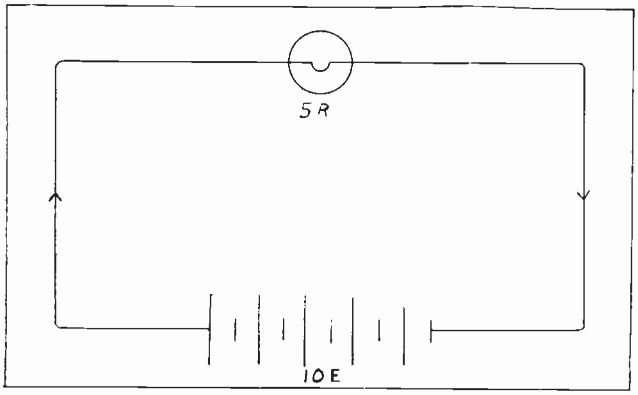


Fig. 3. Ten volt battery supplying current to a 5 ohm lamp. Can you find how much current would flow, without an ammeter?

If you have an ammeter handy to connect in the circuit you can measure this current. But if no ammeter is available you can calculate the current in even less time, by the use of the first formula.

$$I = \frac{E}{R}, \text{ or } I = \frac{10}{5} \text{ or 2 amperes.}$$

This would apply equally well to a motor or device of higher resistance and on higher voltage circuits. Whenever you know the voltage applied and the resistance of a device, you can quickly determine the amount of current that will flow through it.

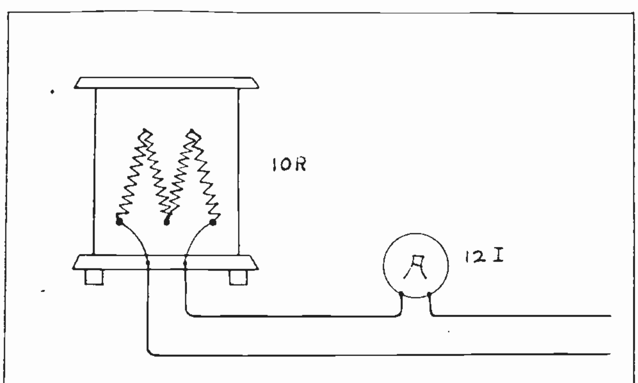


Fig. 4. Electric heater of 10 ohms resistance draws 12 amperes. Can you tell the voltage of the line?

Then suppose you were told that a certain electric heater, as in Fig. 4, had a resistance of 10 ohms and required 12 amperes to operate it. What voltage should this device be operated on? This can be determined by the use of the 2nd formula, $E=I \times R$, or $E=12 \times 10$ or 120 volts.

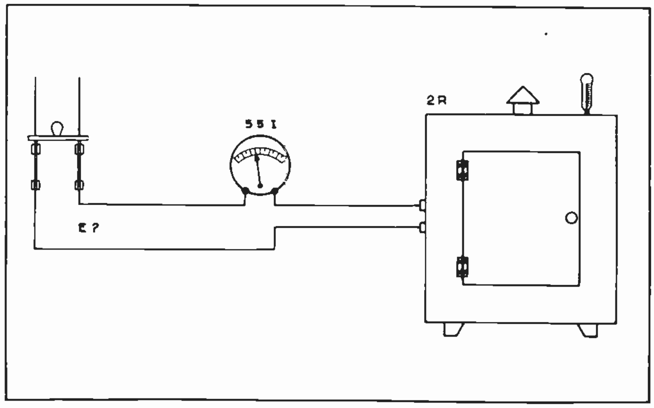


Fig. 5. The ammeter shows 55 amperes flowing through an oven of 2 ohms resistance. Ohms Law formula makes it easy to determine the voltage of the line.

Or in another case, you have an electric oven operating as in Fig. 5, and its resistance is known to be 2 ohms. An ammeter in its circuit shows that a current of 55 amperes is flowing. But you have no voltmeter. The voltage of this circuit can be determined by the same formula as used in the heater, $E=I \times R$, or $E=55 \times 2$ or 110 volts.

Now let us say you have a powerful electro magnet operating as in Fig. 6. A voltmeter shows 80 volts applied to it, and an ammeter shows 20 amperes flowing. How could you determine the resistance of the magnet coils? The 3rd formula shows exactly how to do this, as it says resistance can be found by dividing the volts by amperes, or

$$R = \frac{E}{I} \text{ or } R = \frac{80}{20} \text{ or 4 ohms}$$

resistance in the coils.

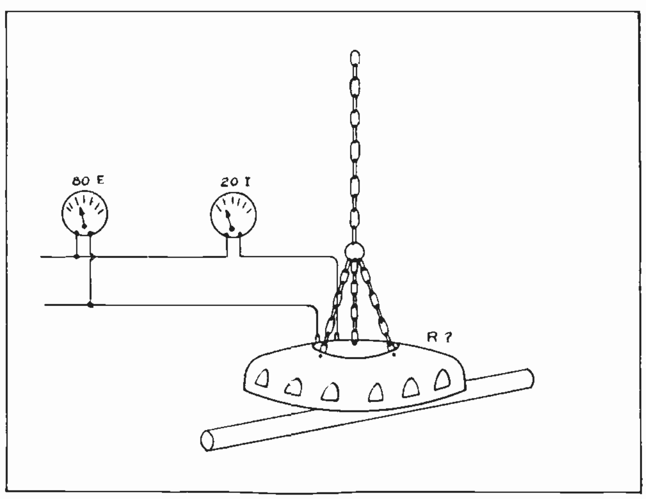


Fig. 6. Electro-magnet and meters, showing voltage and current supplied to operate it.

So we see that whenever we know any two of the three factors of any electrical circuit, we can easily determine the other one, even without instruments, by the use of these simple formulas.

42. SIMPLIFIED OHMS LAW FORMULA

A very simple way to remember all three of these formulas in one is shown by the following figure:

$$\frac{E}{I \times R}$$

All that is necessary is to cover the one you wish to find and the remaining 2 factors show you what to do, if you know their values. For example if you know the current and resistance of a circuit and wish to find the voltage, cover E and the parts still shown indicate to multiply $I \times R$. Or if you know the voltage and resistance and wish to find the current, cover I and do as indicated by the remaining two or divide E by R.

WATTS LAW

43. We also need a law and formula to calculate the amount of power of electrical circuits or devices.

You will recall that the watt is the unit of electrical power.

To produce power we must have current flowing under pressure. **And one ampere flowing under a pressure of one volt, will produce one watt of power.**

From this relationship we get Watts Law or, the **power in watts in any D. C. circuit is equal to the pressure in volts multiplied by the current in amperes.**

And from this law we obtain the very useful formulas:

$$I \times E = W$$
$$W \div E = I$$
$$W \div I = E$$

In which:—

I=current in amperes.
E=pressure in volts.
W=power in watts.

So if we want to determine the amount of power used in a circuit in which we know the current and pressure, we simply use the first formula.

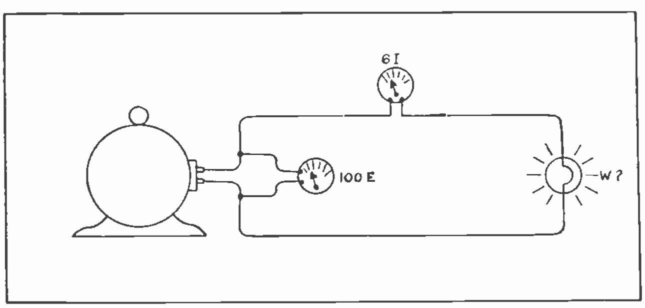


Fig. 7. How many watts does the lamp in this circuit use, according to the simple rule on this page?

In Fig. 7 we have a generator producing 100 E and supplying current to a lamp. An ammeter in the circuit shows a current flow of 6 amperes. Find the power used by the lamp.

$I \times E = W$, or $6 \times 100 = 600$ watts.

Many electrical devices have their rated power in watts and their operating voltage marked on them.

And in such cases if you wish to determine the current such a device will use, apply the second formula.

$$W \div E = I.$$

44. FIELD PROBLEMS

Suppose on some future job you have a case as in Fig. 8. Your generator supplies 200 volts to a 4000 watt machine. How much current will the machine use, or what should an ammeter read, if connected in this circuit?

$W \div E = I$, or $4000 \div 200 = 20$ amperes.

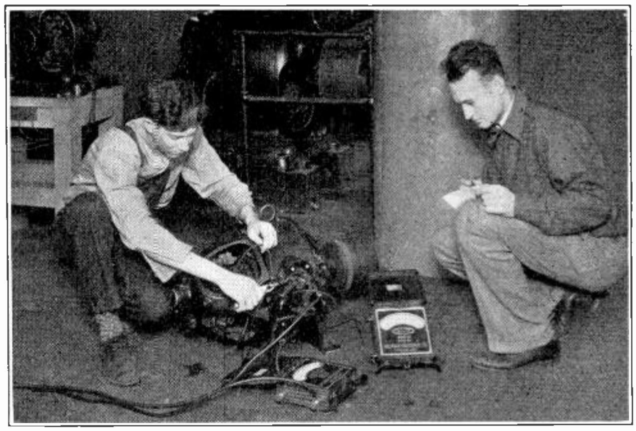


Fig. 8. Using meters right on the job to test a motor. When you know the rating of a machine in volts and amperes, it is easy to determine with meters whether the machine is properly loaded or not.

The next day you have another problem as in Fig. 9. You have a special lamp of 600 watts, and an ammeter in its circuit shows the lamp is using 5 amperes. What is the voltage of the circuit to which the lamp is connected?

Here we use the third formula.

$W \div I = E$, or $600 \div 5 = 120$ volts.

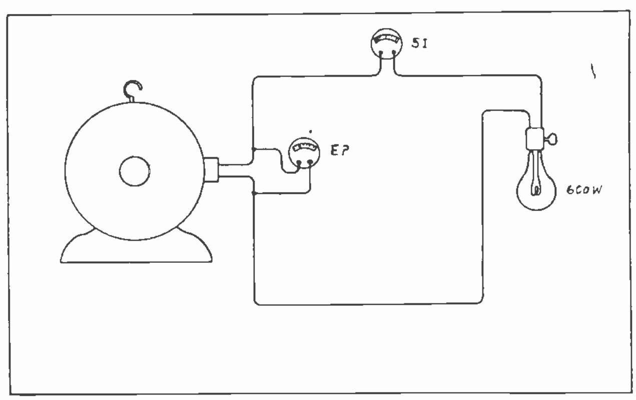


Fig. 9. Generator supplying 5 amps to a 600 watt lamp. What is the generator voltage?

The three watts law formulas can also be simplified for use in the following manner:

$$\frac{W}{I \times E}$$

Then by covering the one you wish to find the value of, the remaining ones indicate what to do.

There are also two other very convenient formulas for finding the power in watts, when we do not know both the amperes and volts, but may know either the amperes and ohms, or the volts and ohms of the circuit or device. They are as follows:

$$I^2 \times R = W$$
$$E^2 \div R = W$$

In which:—

I^2 equals amperes squared, or multiplied by itself.
E^2 equals volts squared, or multiplied by itself.
R equals resistance in ohms.

In the first case if we have a circuit of 5 ohms resistance and in which a current of 10 amperes is flowing, we square the current first and then multiply by resistance, or $10 \times 10 = 100$, and $100 \times 5 = 500$ watts.

Or if in another circuit you found a device of 20 ohms resistance connected to a line of 200 volts. You could very easily find its power in watts by using the formula $E^2 \div R = W$, or $200 \times 200 = 40{,}000$, and $40{,}000 \div 20 = 2000$ W or 2 KW.

To prove that all three of the formulas for finding power in watts are always dependable, try them all on the same circuit, where current pressure and resistance are all known.

In Fig. 10, a generator of 440 volts supplies 22 amperes of current to a device of 20 ohms resistance.

Using the first formula, or $I \times E = W$, we find that $I \times E$ is 22×440 or 9680 watts.

Using the second formula or $I^2 \times R = W$, we find that $I^2 \times R$ is $22 \times 22 \times 20$ or 9680 watts.

Using the third formula or $E^2 \div R = W$, we find that $E^2 \div R = \dfrac{440 \times 440}{20}$ or 9680 watts.

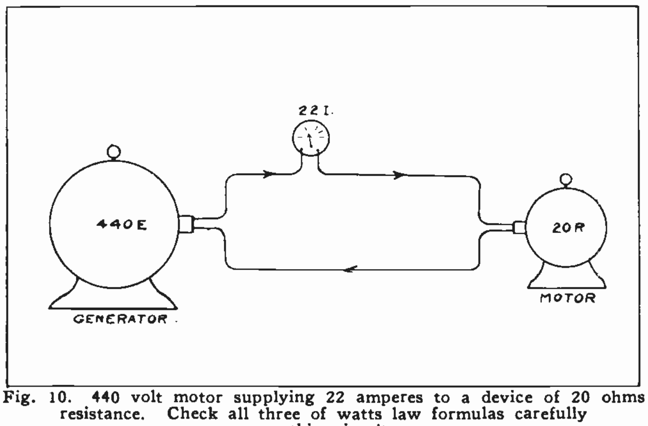


Fig. 10. 440 volt motor supplying 22 amperes to a device of 20 ohms resistance. Check all three of watts law formulas carefully on this circuit.

So we see that we can depend on any one of these formulas that is most convenient to use for any problem.

You are not expected to memorize all these formulas at once. But practice using them frequently, on every practical electrical problem you can find, and soon they will be easy to use and remember.

45. LINE DROP

In electrical work we often hear the term **Line Drop** used. This refers to the voltage used or required, just to force the current load through the line resistance alone. And it becomes a very important item to consider on long transmission lines, or feeders of considerable length to lights and motors. If we have too much voltage drop in the line, we of course will not get enough pressure at the device operating at the end of the line.

The line drop in volts is proportional to the load carried, in amperes, and to the resistance of the wires, or

$$Ed. = I \times R.$$

In which:—

Ed. equals line drop in volts.
I equals current in amperes, flowing through line.
R equals line resistance.

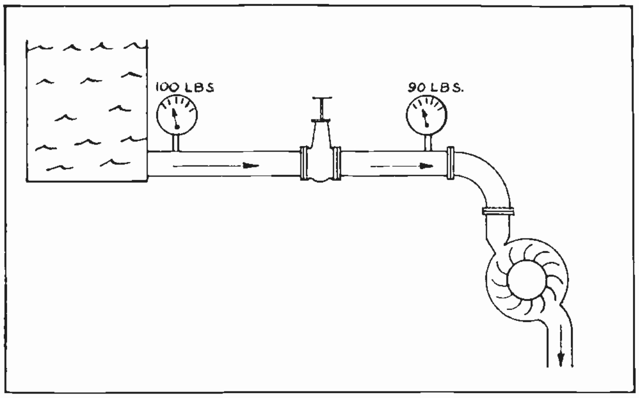


Fig. 11. Water pressure tank and pipe line to water turbine. Note drop in pressure in the pipe line, by readings of the two gauges.

In Fig. 11, we have a water pressure tank, and pipe line. While the water is flowing through the pipe, it creates friction or resistance. Some pressure is required to overcome this resistance in the pipe and maintain a given flow.

The gauge on the pipe near the tank, shows 100 lbs. pressure, but the one at the end of the pipe only shows 90 lbs. pressure. So 10 lbs. pressure was used to force the water through the pipe resistance, and 90 lbs. used to force it through the water wheel.

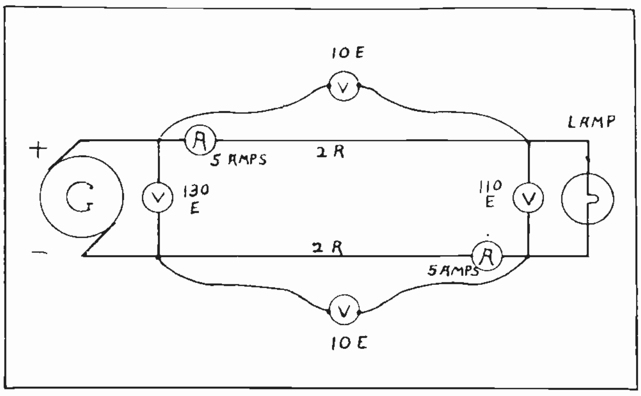


Fig. 12. Generator, lamp and meters connected for testing "voltage drop" and proving Ohms Law Formulas. This is typical of problems encountered by the head electrician in the field.

In Fig. 12, is shown a generator producing 130 volts pressure, and sending current of 5 amperes over a line of 4 ohms total resistance, to a lamp which requires 5 amperes at 110 volts to operate it.

You will note there is a difference of 20 volts between the reading of the voltmeter at the generator and the one at the lamp. This shows a line drop of 20 volts.

An ammeter near the generator shows five amperes flow to the lamp, and one at the lamp shows 5 amperes flow from the lamp back to the generator.

So if there are 5 amperes flowing through each side of the line, and each line wire is 2 ohms resistance, then by using the formula I×R=Ed, we have 5×2 or 10 volts drop in each wire, or 20 volts total line drop.

Voltmeters connected as at (A) and (B) would each show 10 volts drop.

So in this case we have 20 volts used to force the 5 amperes of load current through the line resistance, and 110 volts used to force the current through the lamp resistance. Or a total of 130 volts required at the generator.

46. LINE LOSS

This term refers to the power consumed by the line, and which goes into heat along the line. It is usually expressed in watts.

This is found with our regular Watts Law formulas, but using only the voltage drop in the line itself, to multiply by the current.

In the problem shown in Fig. 12, the line loss is I×Ed=W, or 5×20=100 watts.

Such problems as this are frequently encountered by the practical man when installing or inspecting wires feeding lamps or motors. And the man who knows these simple rules and formulas, is the man who is most valuable to his employer, and bound to advance most rapidly to the better jobs and salaries.

ELEMENTARY ELECTRICITY

SECTION FIVE

SERIES AND PARALLEL CIRCUITS

As we have already learned, in order to use electricity in any device, we must have a complete path or circuit for the current to flow from the generator or source of supply, to the device, through it, and back again to the source.

We call this a complete electrical circuit.

Where two or more devices are connected to the same line or source of supply, there are different methods of connecting them. They can be arranged to form a **Series** circuit or a **Parallel** circuit, or in a combination of series and parallel.

If you understand series and parallel circuits, it will be easy to understand most any combination of circuits.

47. A SERIES CIRCUIT IS ONE IN WHICH THE CURRENT HAS ONLY ONE PATH

(See Fig. 1). Here is shown a generator and 4 lamps connected in series. The devices are conneced one after the other along the wire or line, and the same current must pass through them all. So the current will be the same in all parts of a series circuit. This current is of course governed by the total resistance of all the devices in the circuit, as well as the voltage applied.

Suppose you wish to find the total resistance in a series circuit such as Fig. 1. It is very simple. **To find the total resistance of a series circuit, add the resistances of all the devices in the circuit.**

In the case of Fig. 1, where there are 4 lamps of 40 ohms each, the total is 160 ohms.

So we can easily see that the greater number of lamps or devices we put in a series circuit, the greater the total resistance becomes, and the higher the voltage which will be required to force a given current through it.

Or if we do not increase the voltage, the current will decrease for every additional lamp or device that is added, because each one tends to make the circuit or path longer, and resistance higher.

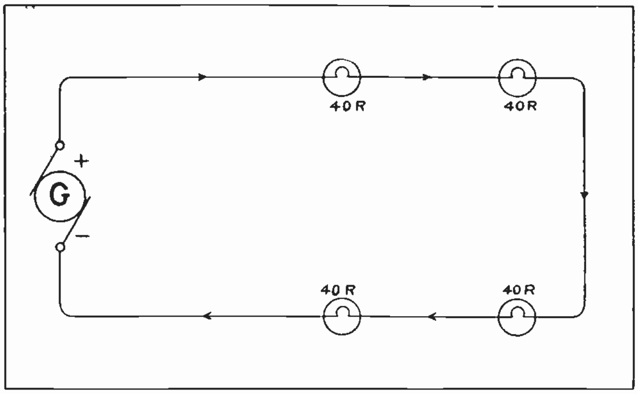


Fig. 1. Four lamps connected in series to a generator. Total resistance of lamp circuit 160 ohms.

48. APPLICATIONS OF SERIES CIRCUITS

Series circuits are often used for street lighting, and such applications where a number of lamps or devices of the same current requirements, are operated a considerable distance apart, and away from the source of supply.

This effects quite a saving in copper and line costs, as the total current flow is only that of any one device. Thus the wires can be kept smaller than with parallel circuits. And only one continuous wire is needed, instead of two to each device, as required with a parallel system. (See Fig. 2A and Fig. 2B.)

One of the disadvantages of series circuits is that we cannot conveniently control the devices separately.

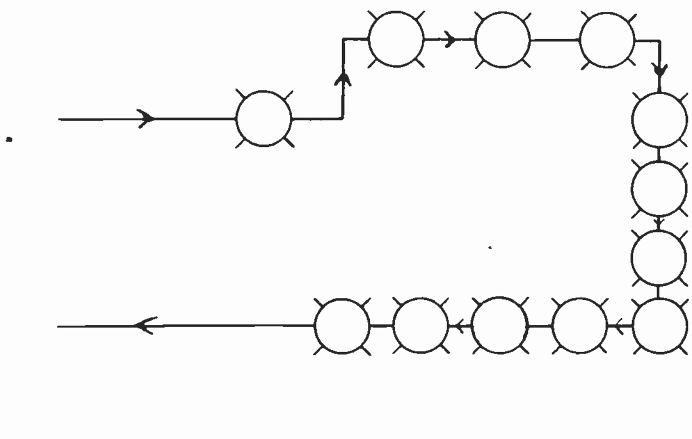


Fig. 2-A. Twelve lamps connected in series. Note that only one main wire is needed.

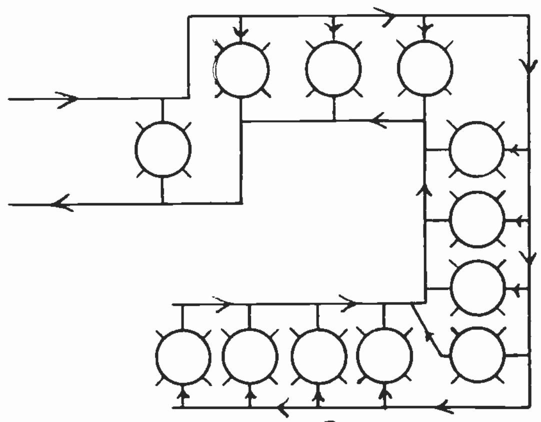


Fig. 2-B. Twelve lamps connected in parallel. Two main wires are needed for this circuit.

In a series circuit the voltage applied to any device, is the same as the voltage drop across this device. And it will be a fraction of the total line voltage, and proportional to the resistance of the device, also the total number of devices in the line. (See Fig. 3.)

A voltmeter connected across the terminals of any one of the lamps in this circuit will show 50 volts drop.

The sum of the voltages of all lamps will be that of the generator. Assuming of course that the line resistance is not enough to be considered.

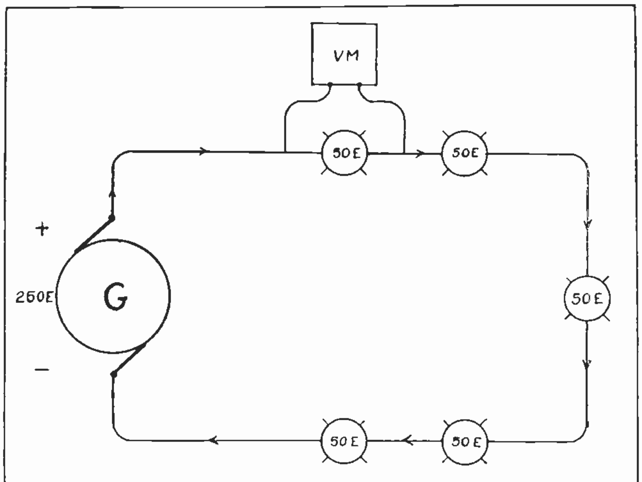


Fig. 3. Five 50 volt lamps in series. Voltmeter will show 50 volts drop through any lamp, or 250 volts total.

49. A PARALLEL CIRCUIT IS ONE IN WHICH THE CURRENT HAS TWO OR MORE PATHS THROUGH WHICH IT CAN FLOW

In such circuits the current from the generator or source divides, and part flows through each of the branches of the circuit according to their resistances. (See Fig. 4.)

Here is shown a generator and four lamps connected in parallel. Sometimes such a circuit is called a multiple circuit.

So if you hear a circuit called multiple or parallel, remember they both mean the same.

In this circuit shown, the resistance of all lamps is equal or 40 ohms each, so the current will divide equally through them. Note how the arrows show by their direction and size, the division and amounts of current in the various parts of this circuit.

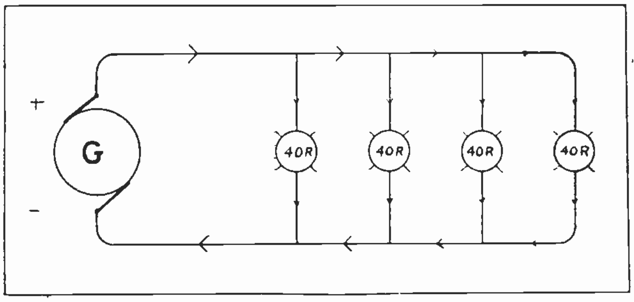


Fig. 4. Four lamps in parallel. Note how the current divides through each path.

The current tends to flow from the positive or top wire to the negative or bottom wire, through every path we give it. It is easy to see that as we connect more devices in a parallel circuit, it makes more paths or a larger total path of lower resistance, for current to flow through. So every device added in parallel causes more current to flow. If we were to connect too many devices on such a circuit, the amount of current required would be an overload on the wires or generator. It is very important therefore that we know how to calculate the total resistance of parallel circuits, so we can properly regulate the current load by having the proper resistance.

50. RESISTANCE OF PARALLEL CIRCUITS

If the total resistance of a parallel connection gets less as we add more paths, then we see we cannot get the correct total resistance of all paths, by adding their separate resistances.

To find the total resistance of a parallel circuit, where all paths are of equal resistance, we divide the resistance of one path by the number of paths.

This is a very simple method but applies only to paths of equal resistance.

To get the total resistance of the circuit in Fig. 4, we divide 40 by 4, and our answer is 10 ohms.

Suppose you have a circuit with 10 lamps of 20 ohms each, connected in parallel. What is the total resistance? The resistance of one path divided by the number of paths, or $\frac{20}{10}$ equals 2 ohms.

Many parallel circuits have devices of unequal resistance, and to find the total resistance of such a circuit we must use a different method, known as the **"Reciprocal"** or conductance method.

This method uses the reciprocal of the resistance values, which is the conductance of the path. You will recall the term conductance and its unit "Mho," explained on earlier pages.

Adding more paths or devices to a parallel circuit decreases the total resistance, but it increases the conductance. So if we find the reciprocal of the resistance, which is the conductane of each path, and add them all to get total conductance, then change this back to its reciprocal, we will have the total resistance.

The important thing to remember is that conductance and resistance are opposite, and the reciprocals of each other. As one increases in any circuit the other decreases.

To find the total resistance of a parallel circuit, with paths of unequal resistance, get the reciprocal of each resistance and add them to get their sum or the total conductance. Then take the reciprocal of this which is the total resistance.

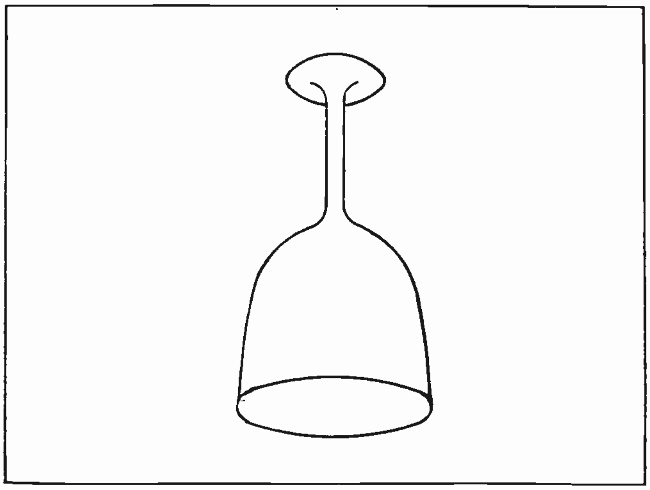


Fig. 5. What is this? Invert or turn it up-side-down and see.
When we invert a fraction we get its reciprocal.
Now it is a tumbler. Before it was a reciprocal of a tumbler, so to speak.

To find the reciprocal of any whole number we place the figure "one" above it with a line between to make a fraction. For example, the reciprocal of 2 is $\frac{1}{2}$ that of 12 is $\frac{1}{12}$ that of 25 is $\frac{1}{25}$ etc.

To find the reciprocal of a fraction, we simply invert it. For example the reciprocal of $\frac{1}{2}$ equals $\frac{2}{1}$ or 2, that of $\frac{1}{5}$ equals $\frac{5}{1}$ or 5, that of $\frac{2}{6}$ equals $\frac{6}{2}$ or 3, that of $\frac{5}{20}$ equals $\frac{20}{5}$ or 4, etc.

51.—FIELD PROBLEMS

Now suppose you have a circuit with 3 lamps in parallel as in Fig. 6.

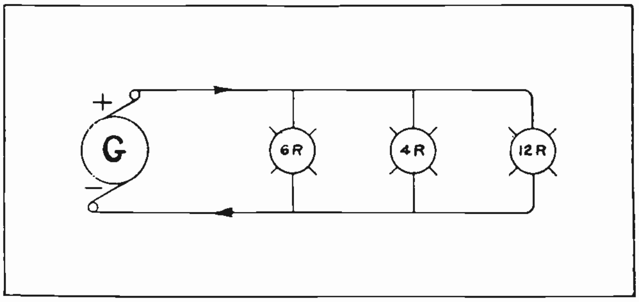


Fig. 6. Three lamps of unequal resistance, in parallel. Use the "reciprocal" method to find total resistance.

One lamp is 6 ohms, one 4 ohms, and one 12 ohms. How will you find the total resistance? According to our rule we first get the reciprocals of each resistance.

The reciprocal of 6 equals $\frac{1}{6}$

The reciprocal of 4 equals $\frac{1}{4}$

The reciprocal of 12 equals $\frac{1}{12}$

Then we add these to get the total conductance in Mhos.

Before we can add $\frac{1}{6}$, $\frac{1}{4}$, and $\frac{1}{12}$ we must get common denominators for them to make them "like fractions."* Twelve is common to all, so

$$\frac{1}{6} \text{ equals } \frac{2}{12}$$

$$\frac{1}{4} \text{ equals } \frac{3}{12}$$

$$\frac{1}{12} \text{ equals } \frac{1}{12}$$

Then $\frac{2}{12}$ plus $\frac{3}{12}$ plus $\frac{1}{12}$ equals $\frac{6}{12}$ Mho.

Then its reciprocal equals $\frac{12}{6}$ or 2 Ohms, which is the total resistance.

*If you wish to brush up on fractions and reciprocals, etc., you will find this covered in the mathematics section on fractions.

An interesting and valuable rule to remember, and with which to check such calculations, is that **the total resistance of any parallel group, is always lower than the lowest resistance in the group.**

Note how this proves out with the problem just finished.

This method of finding the total resistance is important enough to be worth a little practice on any problem you can find or think up, and this is one of the best ways to fix it in your memory.

In a parallel circuit having resistances as in Fig. 7. What is the total resistance?

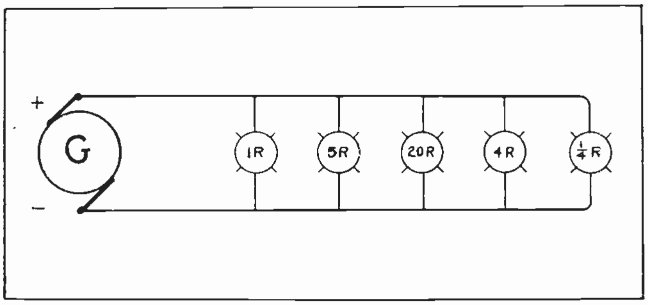


Fig. 7. Could you find the total resistance of a circuit like this, if you were asked to by your employer? See the example given.

Reciprocal of 1 equals $\frac{1}{1}$

Reciprocal of 5 equals $\frac{1}{5}$

Reciprocal of 20 equals $\frac{1}{20}$

Reciprocal of 4 equals $\frac{1}{4}$

Reciprocal of ¼ equals $\frac{4}{1}$

20 is common to all so:—

$\frac{1}{1}$ equals $\frac{20}{20}$

$\frac{1}{5}$ equals $\frac{4}{20}$

$\frac{1}{20}$ equals $\frac{1}{20}$

$\frac{1}{4}$ equals $\frac{5}{20}$

$\frac{4}{1}$ equals $\frac{80}{20}$

Then: $\frac{20}{20}$ plus $\frac{4}{20}$ plus $\frac{1}{20}$ plus $\frac{5}{20}$ plus $\frac{80}{20}$ equals $\frac{110}{20}$ Mho.

And the reciprocal of $\frac{110}{20}$ Mho equals $\frac{20}{110}$ or $\frac{2}{11}$ ohm, total resistance.

52. IMPORTANT FACTS ABOUT SERIES AND PARALLEL CIRCUITS

Advantages of parallel circuits are, that all devices receive equal voltage, or the voltage of the main wires, and any device can be controlled separately, without affecting the others. If the wires and generator are large enough, we can connect any desired number of devices in such a circuit. Lamps, motors and most electrical devices are usually connected in parallel.

The important things to remember about series and parallel circuits are the effects they produce on resistance, current, and pressure, when different devices are connected one way or the other.

We have seen that a series connection of lamps or current consuming devices, increases the resistance to the sum of all their resistances. This tends to reduce the current flow, or requires higher voltage to maintain a certain current. Series circuits also effect economy of copper or wire size in certain systems.

We have also shown how current consuming devices connected in parallel, reduce the total resistance by making the path larger in effect, and increasing the current required. Parallel circuits provide independent control and give all devices full line voltage.

53. SERIES AND PARALLEL CONNECTIONS OF GENERATORS AND BATTERIES

We have so far only considered the effects of series and parallel connections on current consuming devices. It is also very important to know the results that can be obtained by use of series and parallel connections on sources of electrical supply, such as batteries or generators.

Suppose you have a device which you want to operate with dry cells, and one cell will not furnish high enough pressure to force the required current through the resistance of the device.

By connecting cells together in series, that is positive of one to the negative of the next as in Fig. 8, the voltage may be increased to almost any desired amount.

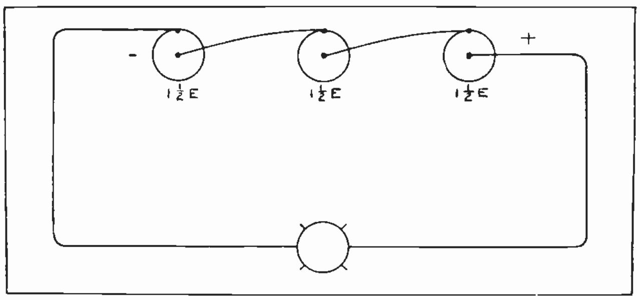


Fig. 8. Connecting dry cells in series will give the sum of their voltages at the lamp.

In Fig. 8, 3 dry cells are shown connected in series to increase the voltage they can supply. If each cell has 1½ volts, this connection will give 4½ volts.

The current that flows through the lamp must also flow through each cell because it has only one path. Therefore the current flow will not be increased, but will be just that of one cell.

Such series connections of cells are commonly used. A good example is in radio "B" batteries, where a number of very small cells are connected in series, to get up to 45 volts from one battery.

The current required from these batteries is very small, so a straight series connection can be used.

54. EFFECT OF SERIES CONNECTION ON GENERATOR VOLTAGE

Electric generators can also be connected in series to obtain higher voltages than one machine alone can produce. (See Fig 9.)

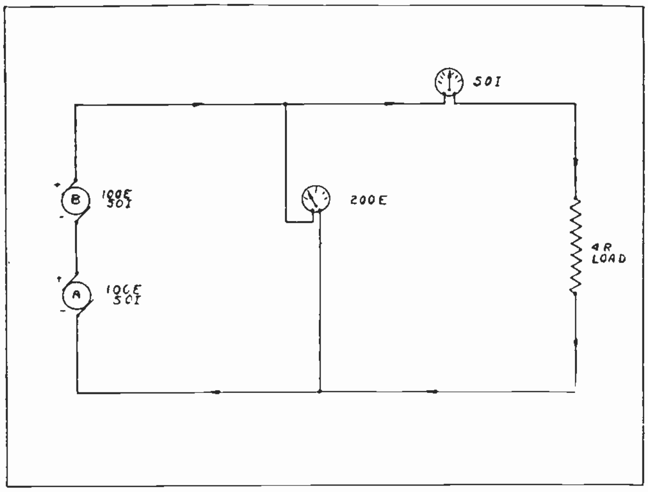


Fig.9. Two 110 volt generators connected in series. Compare carefully the readings of the voltmeter and ammeter with the generator ratings.

Here are two generators properly connected positive to negative, so their voltages add together. But the current that can be supplied by these two machines in this connection, is only the same as the capacity of one.

This circuit is easily compared and illustrated with a water system in Fig. 10.

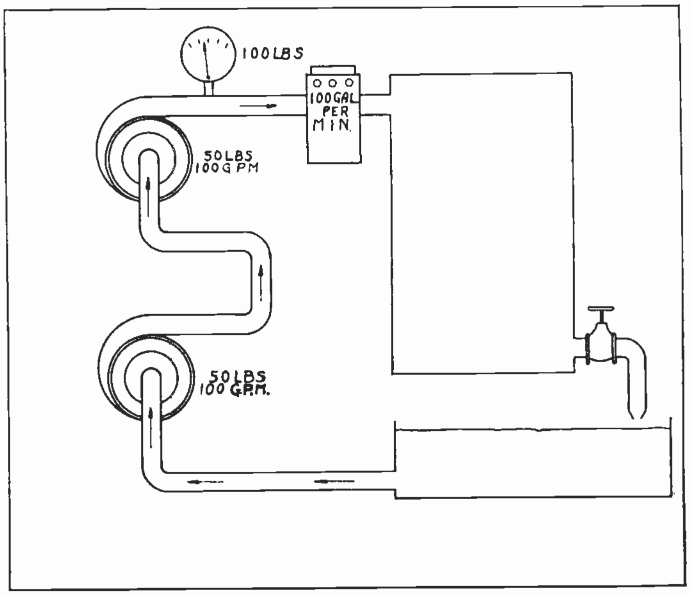


Fig. 10. Two water pumps in series, each producing 50 pounds pressure, and pumping 100 gallons per minute. The total pressure will be 100 pounds, and total flow 100 gallons per minute.

Here we have two water pumps also connected in series. They can supply double the pressure produced by one pump, as their pressures add together. But the current they supply is only the same as passes through one pump.

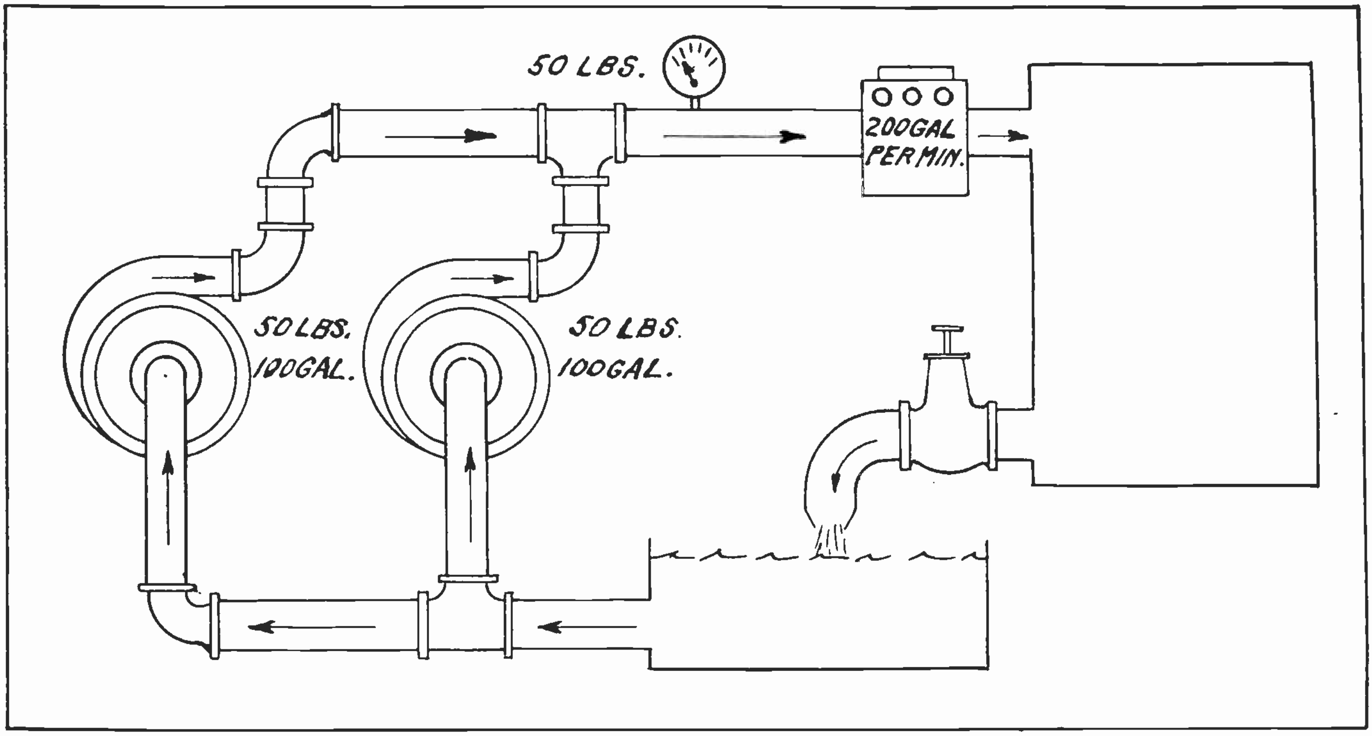


Fig. 11. Two 50 lb., 100 gal. per minute pumps operating in parallel. They develop 50 lbs. total pressure and pump 200 gallons per minute.

Now if we wish to get a greater current or volume of water at lower pressure, we can arrange the pumps as in Fig. 11. Here the pressure on the mains will be the same as that of one pump, but their current flow will add together, and be twice that of one pump.

Similarly in Fig. 12, we have two generators connected in parallel. The voltage across the main wires is only equal to that of one machine, but their currents will add, and the total current flowing will be twice that of one machine.

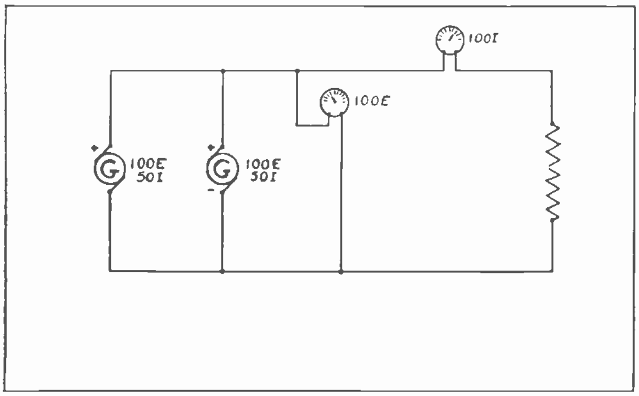


Fig. 12. Two 100 volt, 50 amp generators in parallel. The line pressure is 100 volts, and full load current is 100 amperes.

In large power plants, generators are commonly connected in this way, and we often find from 2 to 10 or more, all operating in parallel, and each supplying its share of the total load current. (See Fig. 13.)

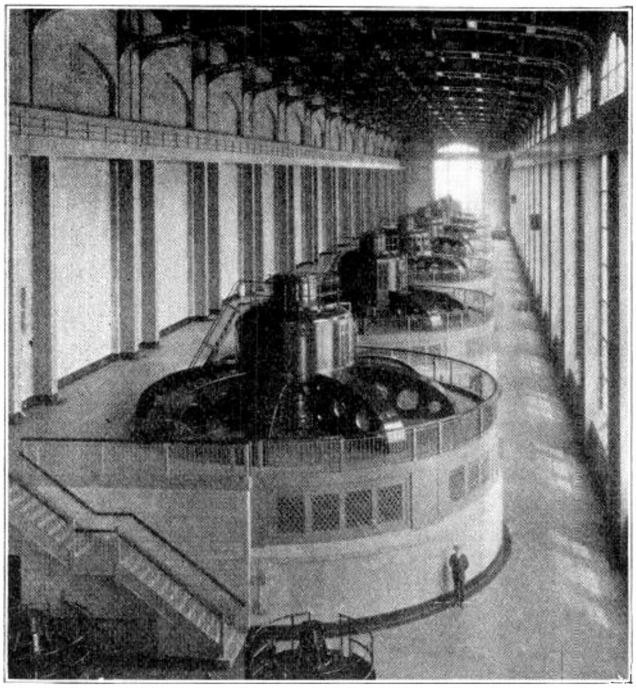


Fig. 13. Row of generators in a modern power plant. These machines are operated in parallel, each one supplying its share of the total load.

On small requirements where batteries or cells are used we can connect them in parallel to increase the current supply. (See Fig. 14.)

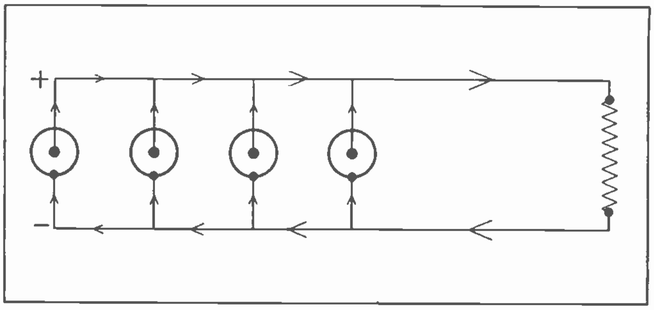


Fig. 14. Four dry cells connected parallel to obtain more current than one could supply.

Here are 4 dry cells connected in parallel, or all positives to one wire, and all negatives to the other. The voltage on the main wires will only be 1½ or the same as one cell. But the current will be the sum of that of all 4 cells.

55. COMBINATION OF SERIES AND PARALLEL CIRCUITS

If we wish to obtain both higher voltage and more current than one cell can produce, we can combine the series and parallel connections, in a **series-parallel** system as in Fig. 15.

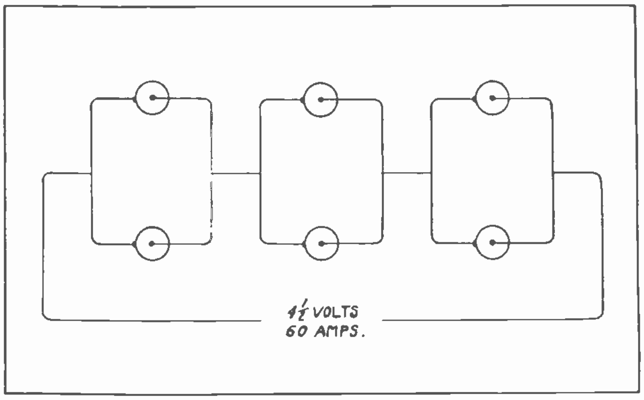


Fig. 15. Six cells connected series-parallel. Note voltage and amperage obtained by this connection.

Here are 3 groups of 2 cells each. The two cells in each group are connected in parallel to add or double their current. Then all 3 groups are connected in series to add their voltages. So at the main wires we can obtain 3 times the voltage of one cell, and twice the current.

The same effect would be obtained if they were connected **parallel-series** as in Fig. 16.

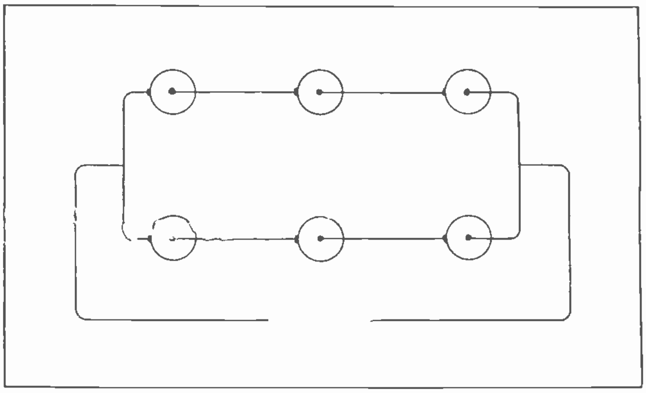


Fig. 16. Parallel-series connection of six cells.

So it makes no difference in the voltage obtained, whether we connect cells in **series-parallel or parallel-series,** as long as we keep the same number in series and the same number in parallel.

There is often some argument as to whether a certain circuit should be called **series-parallel,** or **parallel-series.**

This is easy to determine if you just call the name of the external or main wires first, or note what kind of a connection is made **Of** the groups. Note the emphasis on the word **Of.**

Thus in Fig. 15 we say we have a series connection **Of** parallel groups, or series-parallel. In Fig. 16 we have a parallel connection **Of** series groups, or parallel-series.

In connecting such combination circuits we should see that all groups are equal. Do not connect a group of 2 cells in series with a group of 4. And do not connect a series group of 3 cells in parallel with a group of 6. Their voltages would be unequal, and the group of six would discharge through the 3, even with no load attached to the main wires. (See Fig. 17.)

A general rule is, when we wish to obtain high pressures and moderate current, we connect batteries or generators in series. And when we need large amounts of current at moderate voltage, we connect them in parallel.

This is one of the most important rules to remember about series and parallel connections.

As you progress into the later sections on electric systems and machines you will more fully appreciate the importance of this knowledge of series and parallel circuits. You will also find it much easier to make certain installations, and locate troubles in your future work in the field, now that you know these principles.

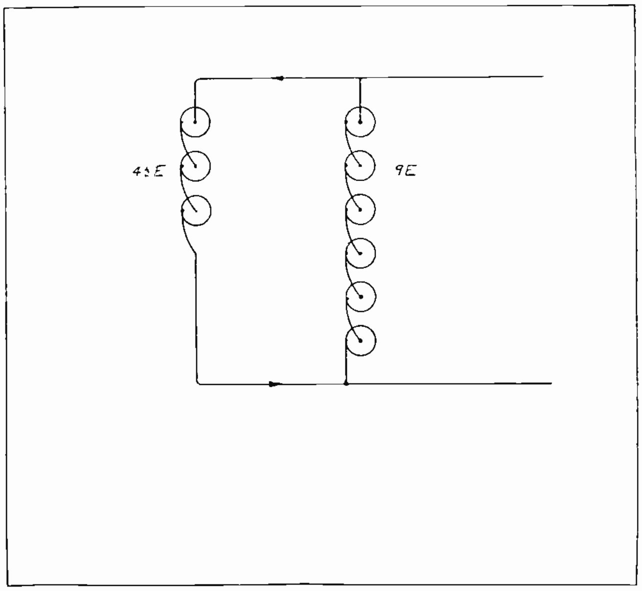


Fig. 17. Wrong connection of unequal numbers of cells in parallel-series. This connection would discharge the cells, even without any load connected.

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SECTION SIX

ELECTRIC CELLS AND BATTERIES

56. **Electric batteries** are commonly used to supply current in small amounts, and particularly to portable equipment.

It is cheaper to produce electricity from large generators in power plants than from batteries. But where no generators or power lines are available, and where only very small amounts of power are needed for small or portable devices, the convenience of electric batteries offsets their higher cost of current.

There are many millions of them in use in automobiles, electric trucks, radios, airplanes, electric lanterns, flashlights, and in telephone, burglar alarm and signal systems. In some power plants big groups of large batteries are used for emergency service, in case of shut down of the generators, and in such cases they may supply thousands of amperes for short periods.

The term **"Battery"** applies to 2 or more cells grouped together in series or parallel. As you have already learned such a group will supply more voltage or current than one cell, according to the way they are connected. But where only very small amounts of current are needed, at low voltage, one cell may be used alone, as in small flashlights or door bell systems, etc. Fig. 1 shows a large battery for telephone operation.

As we said in a previous section, batteries are devices to convert chemical energy into electrical energy, or they use the chemical method of producing dynamic electricity.

All batteries consist of some chemical solution or paste, and metal elements to be acted upon or consumed by the acid or solution.

57. PRIMARY AND SECONDARY CELLS

Batteries or cells are divided into two classes, called **"Primary"** and **"Secondary."** The **Primary**

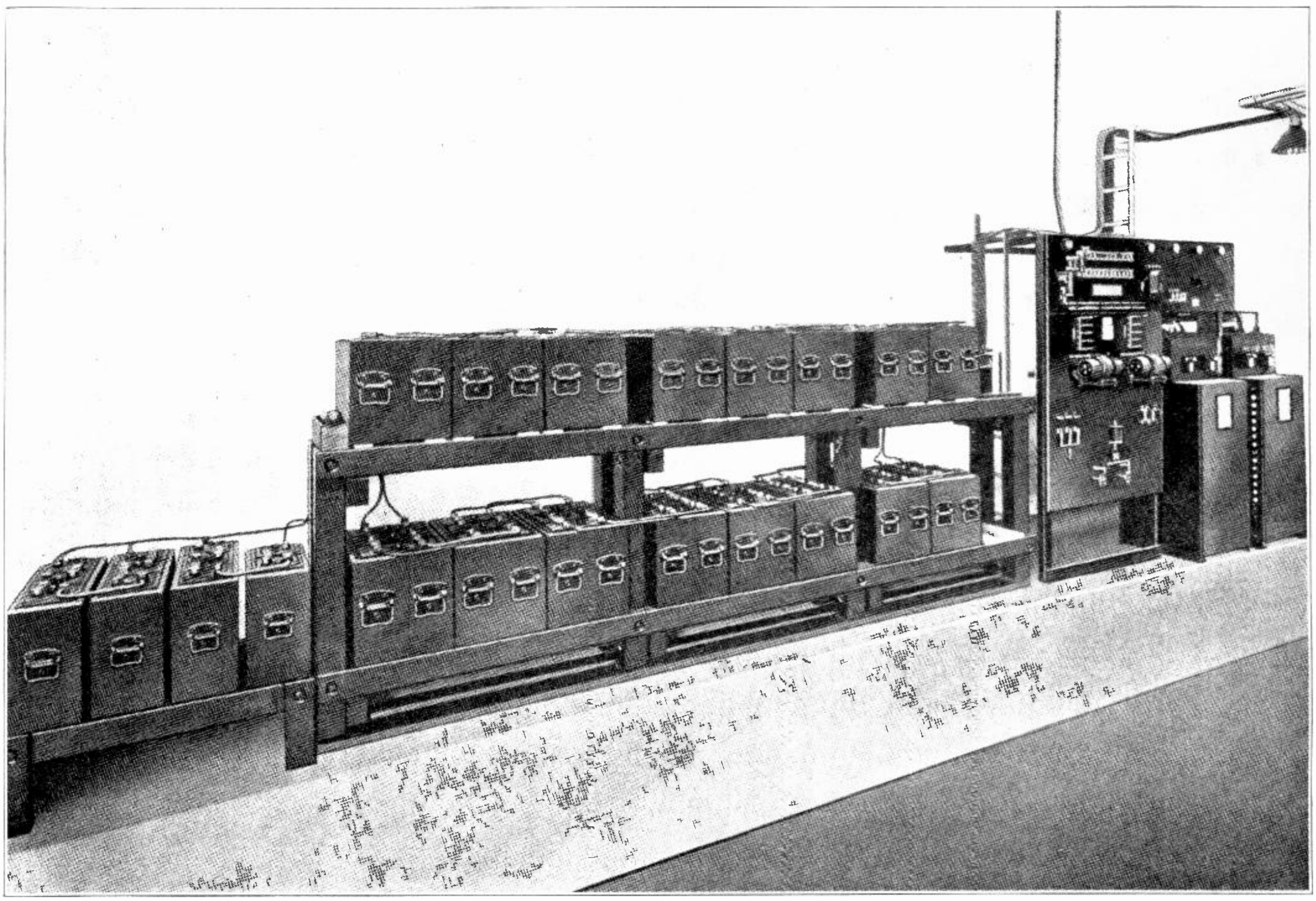


Fig. 1. Photo of group of storage batteries used for telephone work.

Cell is one that is made of such materials that it will supply electric pressure as soon as it is assembled, without first receiving any electrical charge. In these cells part of the unlike metal elements are consumed by the chemical action during their use and when the materials are used up or destroyed, they must be renewed before the cell can deliver current again.

A Secondary Cell is one that uses metal elements of similar nature when first constructed, and will not deliver current, until it has first been charged by passing electric current through it.

This charging or flow of current through the cell sets up one form of chemical action, and changes the nature of the material in the metal plates. Then when the cell is being used or discharged, a reverse chemical action is taking place.

When such a secondary cell is discharged the metal elements are not destroyed, and it can be again charged by passing current from a generator or other source, through it in the opposite direction to its flow during use. These cells can be charged and discharged many times before their metal elements need renewing. So they are often called **storage** cells or batteries. But remember they do not store electricity, instead they simply store a form of chemical energy, set up by the charging current flow.

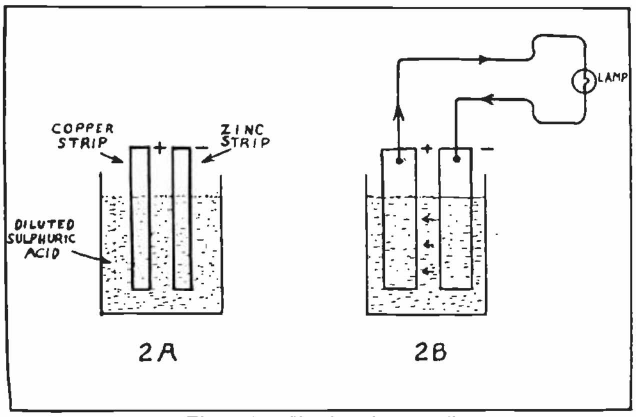


Fig. 2-A. Simple primary cell.
Fig. 2-B. Primary cell connected to a lamp. This cell has larger metal strips than the one in Fig. 2-A.

58. CONSTRUCTION OF PRIMARY CELLS

Primary cells are made of positive and negative elements of different kinds of material, immersed in the acid or chemical solution, and all in some suitable container.

The acid solution is called the **"Electrolyte."**

Cells which have the electrolyte in liquid form are called "Wet cells." Those having the electrolyte in a moist paste form are called "dry cells." These are not really dry, but because there is no loose liquid to spill, and the manner in which they are sealed, they can be placed in any position and treated as a dry cell.

A simple form of wet primary cell is shown in Fig. 2A. This is known as a "Voltaic cell."

Here we have a strip of copper and one of zinc, immersed in an electrolyte of sulphuric acid that has been diluted or weakened with water.

59. CELL VOLTAGE

The action of the acid on the zinc causes a difference of potential between it and the copper. So if we connect a voltmeter to the top ends of the copper and zinc elements, it will show a pressure of about one volt.

The amount of voltage we can obtain from a cell depends on the kind of materials used, and not on their size. Thus copper and zinc used with sulphuric acid electrolyte give about 1 volt, while carbon and zinc used with an electrolyte of ammonium chloride will give about 1.5 volts. Or carbon and zinc with sulphuric acid and a little bichromate of potassium will give about 2 volts.

If we connect a lamp to the terminals of this simple cell as in Fig. 2B, a current will flow from the positive terminal on the copper, through the lamp to the negative terminal on the zinc, and also inside the cell from the zinc through the electrolyte to the copper. This shows the complete circuit or path of current in both the external and internal parts of the circuit.

As long as the external circuit is closed and current allowed to flow, the chemical action decomposes and consumes the zinc plate. The copper, however, is not destroyed. When the zinc element is practically all destroyed, the cell will not furnish any more current and is said to be dead.

By replacing the zinc with a new piece it will again deliver the current.

In referring to the terminals and external circuit of a battery the element at which the current leaves the cell is commonly called the **positive element** or **pole,** and the one at which current enters the cell is called the **negative element** or **pole.**

Inside the cell however, the current flows from zinc to copper, so in the internal circuit the element at which current enters the electrolyte is the positive or **anode,** while the one at which current leaves the electrolyte is the negative or **cathode.**

60. CELL CURRENT AND LIFE

From the above we can see that the amount of current we can obtain from such a cell, as well as the life of the cell, will depend on the size of the elements.

The cell in Fig. 2B, having elements twice as large as in Fig, 2A, will furnish current twice as long at the same rate, or would deliver more current on a low resistance circuit than the smaller cell.

A cell such as in Fig. 2A, or 2B, is sometimes called a one fluid cell, as the electrolyte is just diluted sulphuric acid.

61. POLARIZATION

Such one fluid cells are not used much except for experimental purposes, because if we leave some device connected in the circuit to operate continuously, we find that the current flow will very rapidly decrease to almost nothing.

This is caused by what is called **Polarization.** As the acid attacks the zinc element hydrogen gas is created and has a tendency to collect on the copper plate in the form of little bubbles. If the current continues to flow at a very heavy rate, the copper plate soon becomes so coated with a layer of these bubbles that they shut off the current flow, as the gas is an insulator of very high resistance, and reduces the active area of copper in contact with the electrolyte.

When the copper is thus coated with bubbles, if it is taken out and wiped off or dried, then put back, the cell again delivers current a short time until it becomes polarized once more.

Such a cell can only be used for short periods, or on circuits that are normally open, and just closed intermittently. So they are called open circuit cells.

In primary cells we sometimes have **"Local Action"** at the zinc element, caused by impurities in its surface. The action of the acid on these particles of other metals is different than on zinc, and sets up a difference of potential, and little short circuited local currents at these spots. This consumes the zinc even when the cell is not in use. To prevent it, we sometimes amalgamate or coat the zinc with mercury.

62. CLOSED CIRCUIT CELLS, AND PREVENTION OF POLARIZATION

For many uses we need cells that will furnish current continually or at least for reasonable periods, without polarizing.

There are several ways of constructing such cells to prevent polarization. In Fig. 3, is shown a cell using two solutions for the electrolyte, copper sulphate in the bottom, and sulphuric acid and zinc sulphate in the top. These two liquids stay separate because the copper sulphate is heavier than sulphuric acid or zinc sulphate. The lighter liquid floats on the copper sulphate, as oil will float on water.

In the bottom of the jar, and immersed in the copper sulphate solution, we place the copper element which is usually several strips of thin copper fastened together in the center, and the ends spread out fanwise. From this a rubber insulated wire leads up through the solution to the top of the jar.

In the top of the jar and in the sulphuric acid solution we place a zinc element, that consists of several heavy bars cast together to a vertical stem, in the shape of a **"Crowfoot".**

The stem has a hook shaped extension at the top to hang it on the rim of the glass jar and hold it up in place, also a terminal nut for connecting wires to it.

When this cell is in operation, the acid acts on the zinc the same as in our first simple cell, and hydrogen gas is again set free. But before it can reach the copper element it must pass through the copper sulphate solution in the bottom of the jar.

When the gas reaches this solution it combines with part of the copper sulphate, forming sulphuric acid which stays in the top, and metallic copper collects on the copper element, instead of hydrogen bubbles.

Thus polarization is prevented. The copper deposited on the copper element of course does no harm as it is a conductor, instead of high resistance like the gas bubbles.

This type of cell is called a **Closed Circuit Cell** because it can be used to supply small currents continually, to closed circuit electrical systems.

They are also called **"Gravity Cells"** because of the manner in which the two solutions are kept separated by their different gravities. They are one form of **Daniel Cell** and often called by this name. Fig. 4 shows two such cells connected to telegraph instruments.

They are used for telegraph and telephone work, and in some types of signal and alarm systems.

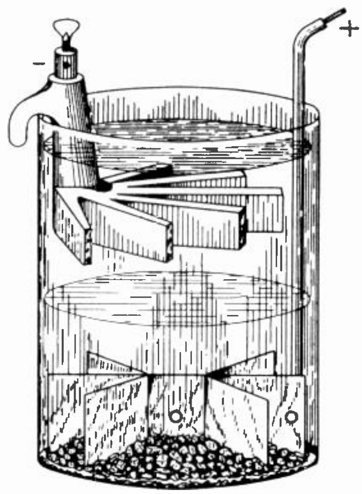


Fig. 3. "Two Fluid" Gravity Cell. These cells do not polarize as the one fluid type do.

63. ASSEMBLY AND PREPARATION OF GRAVITY CELLS

In preparing such a cell for use we place the copper element in the bottom of the jar, with its "lead in" wire brought to the top, then sprinkle the bottom of the glass jar evenly and about ½

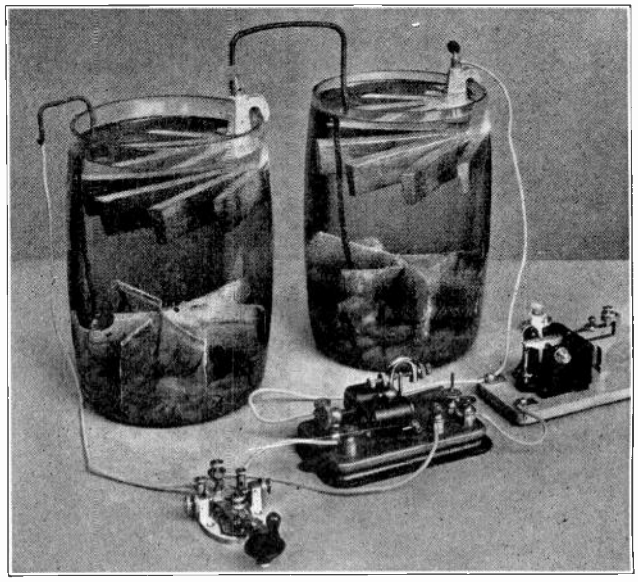


Fig.4. Photo of two gravity cells, showing their parts and construction.

inch thick with copper sulphate crystals. Then hang the zinc element in the top and fill the jar with water (preferably distilled) to within about 2 inches of the top, or well over the zinc.

If the cell is to be used at once it may be necessary to add about a tablespoon full of sulphuric acid. But if it can be allowed to stand a little while on short circuit, a chemical action takes place which soon forms enough zinc sulphate to start operation.

After quite a period of use the zinc element becomes practically destroyed and must be renewed. The electrolyte and copper sulphate crystals must also be renewed occasionally to keep the cell up to good strength.

The copper element becomes heavily coated with metallic copper from the solution, after long periods of operation.

It is well to cover the top of the electrolyte in these cells with a thin film of oil to prevent evaporation.

64. CARE OF CELLS

They should not be left on open circuit long, as they will deteriorate if no current is flowing. The acids tend to mix when the cell is idle. When standing idle and not in use in a regular circuit, it is best to connect a wire or coil of about 30 or 40 ohms resistance across them.

There is a noticeable difference in the color of the two solutions. The lower solution or copper sulphate should show a blue color when in good condition. When it shows a brown color it indicates that the zinc is deteriorating.

The line of separation of the two liquids should be about half way between the copper and zinc elements. If too low, it can be raised by adding a little copper sulphate crystals and water. If too high, a little can be siphoned out with a small rubber tube. Then short circuit the cell awhile to create more zinc sulphate.

65. PORUS CUP CELLS

Another form of primary cell, also one of the Daniel type, uses a **porous cup** or cylinder between the positive and negative elements to separate the solutions. (See Fig. 5).

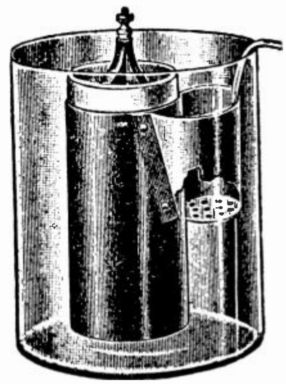


Fig. 5. Daniel Cell, in which the liquids are kept separated by a porous cup.

This cell has a porous cup to keep the two liquids separated. Inside this cup is placed a saturate solution of zinc sulphate, and the zinc electrode. Outside the cup the jar is filled with copper sulphate solution or dilute sulphuric acid, in which the copper electrode in the form of a cylinder is placed. The copper sulphate solution is kept renewed by the dissolving of copper sulphate crystals in a little perforated copper container shown in Fig. 5.

In this cell the porous cup keeps the liquids separate, and thereby prevents polarization, but does not prevent the proper chemical action, or prevent the current flow in the cell. They are better for portable use than the gravity type, as their solutions cannot mix so easily by motion or jarring.

66. EDISON PRIMARY CELL

The Edison cell is very extensively used in railway signal work, and many other places. These cells use an alkaline solution such as caustic soda or caustic potash, and a positive element of copper oxide, and negative of zinc. (See Fig. 6.) They supply a low voltage of about .7 volt, but their internal resistance is very low, and they will deliver from 1.5 to 7.5 amperes according to the size of the cell. If short circuited their current will range from 7 amperes with the small cells to 33 amperes for the largest, but this rate of course cannot be maintained long.

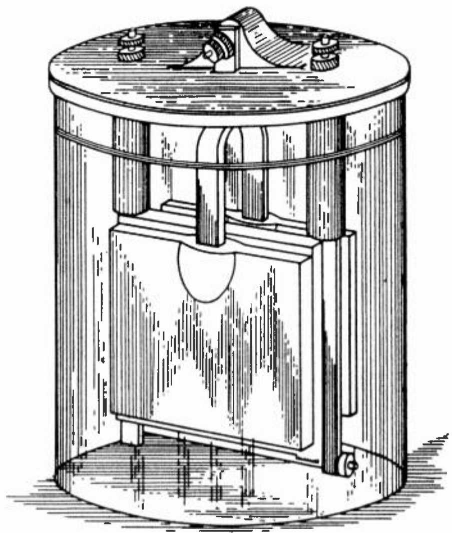


Fig. 6. Edison Primary Cell.

The negative zinc element is amalgamated throughout by adding mercury to it while it is being cast. The positive element consists of a mass of copper oxide mixed with metallic particles coated with copper, to decrease its resistance.

After considerable use the hydrogen bubbles reduce the copper oxide to metallic copper, and it must then be replaced like the zinc.

These cells are very rugged in construction and will stand quite cold weather without freezing, so they are often used for railway signal batteries, and other outdoor work.

The electrolyte should be covered with a thin layer of paraffin oil to prevent evaporation, and to stop the salts from "creeping" over the sides of the jar.

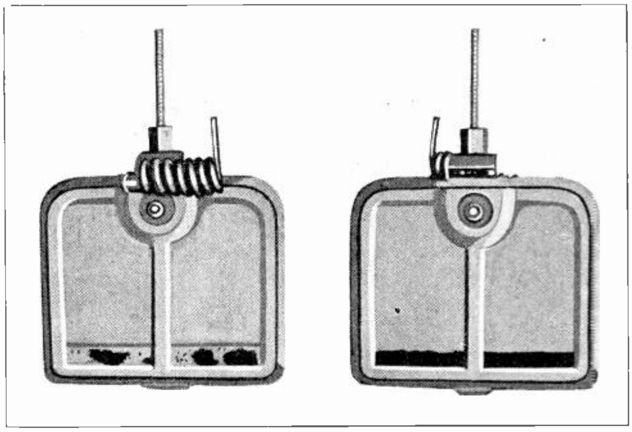


Fig. 7. Zinc elements of an Edison Primary cell. with "indicator panels" which show their condition.

The zinc plates of these cells are made with special sections or panels at the bottom edges, which become eaten away first, as the cell is used and exhausted.

This is called an **indicator panel,** and is very useful in determining when the cells should be renewed.

Fig. 7 shows two plates at different stages of exhaustion. The one at the left with the panel partly eaten away is about 85% exhausted, and the one at the right with the panels eaten out entirely is almost completely exhausted. They should be replaced at once when this condition is noted.

Fig. 8 shows the renewal parts for one of these cells. This consists of the new zinc element, a can of caustic soda, and the bottle of oil to cover the electrolyte surface. The soda and oil supplied are in just the right amounts for the one cell, and the entire contents should be used when renewing a cell.

In maintaining these cells and making renewals, clean water should be used, and the soda should be poured slowly into the water while it is being stirred constantly, with a clean wood stick or glass rod.

This caustic soda should be handled very carefully, as it will burn the flesh and destroy clothing if spilled on them.

The element should hang vertically when immersed in the solution. If the cell is to be used on open circuit work the element should be short circuited with a piece of wire before inserting it in the hot solution, and the "short" left on a couple of minutes after the element is immersed, and then remove the wire.

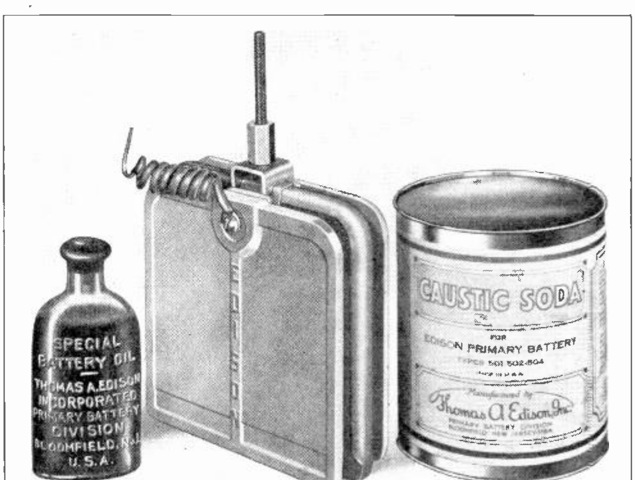


Fig. 8. Renewal parts for Edison Primary cell, consisting of zincs, caustic soda and oil.

The electrolyte should be kept up to within ¾" of the top of the jar at all times, and should always be stirred after adding water.

Fig. 9 shows a group of this type of primary cells in use in a railway signal tower.

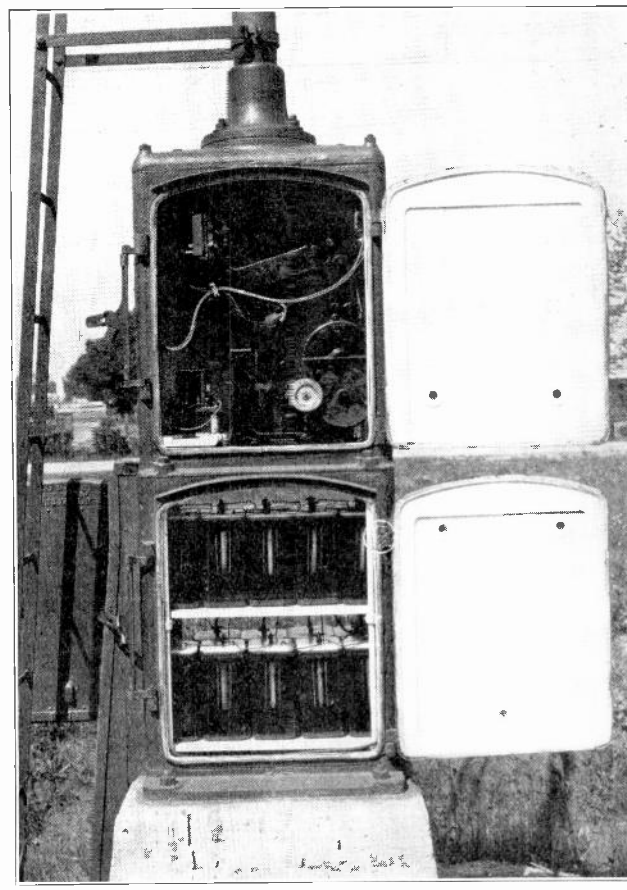


Fig. 9. Edison cells in railway signal tower.

They are located in a weather proof iron box in the lower section of the tower. Many times they are located in concrete pits or "battery wells" along the tracks.

67. DRY CELLS

Dry Cells are probably the most universally used of any type, because of their great convenience and portability.

Practically every one has seen and used them in some device or other, such as flashlights, lanterns, door bells, electric clocks, electric toys, gas engine ignition systems, rural telephones, radios, etc.

Their construction is shown in Fig. 10.

The zinc element is in the form of a cylinder and serves as the container for the rest. The other element is a carbon rod in the center, and around it is packed a pasty mass of granulated carbon and manganese dioxide, saturated with ammonium chloride (Salammoniac) as the electrolyte.

The manganese dioxide acts as a depolarizer and helps prevent the formation of hydrogen gas bubbles. Other ingredients are added by various manufacturers in their patented processes.

Between the wet mass and the zinc container there is a porous paper separator which allows the chemical action to take place, but prevents a short circuit between the carbon and zinc.

The tops of these cells are sealed with compound that makes it possible to handle or place them in any position. This compound will melt if the cell is over heated.

The whole cell is placed in a paper container to prevent the zinc from coming in contact with other metal objects, and to serve as a protector and insulator.

68. USE AND CARE OF DRY CELLS

Dry cells are designed to operate on open circuit systems, where current is only used occasionally for short periods. But they are sometimes used on

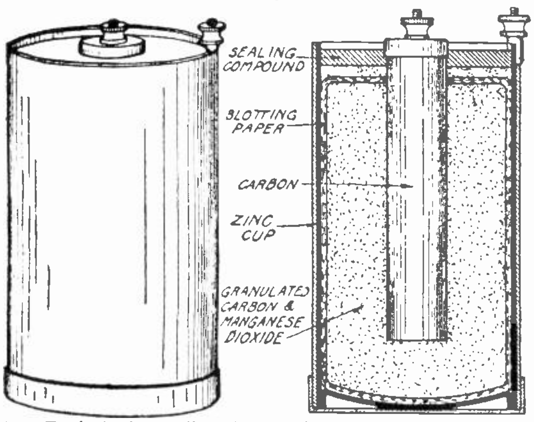


Fig. 10. Typical dry cell, with sectional view showing parts and construction.

closed circuit systems where only very small amounts of current are required.

If used on a circuit or device requiring heavy current, or if short circuited, the rate of current flow at first may be 30 amperes or more, but will fall off very rapidly. This is because their depolarizing material is not strong enough to prevent the formation of hydrogen gas at higher rates of current flow.

If a cell which has been shorted briefly or used on a heavy load, is allowed to stand a while, it will often recuperate or supply nearly normal current again, as it has been given time to break up the gas formation with its depolarizer chemical.

The life of a dry cell will be much greater if used as intended, to supply small currents for short periods with intervals of rest between.

Dry cells are made in different sizes, but perhaps the most commonly used is the number 6 size, about 2½ inches in diameter and 6 inches high. This cell when new should test 1½ volts with a battery voltameter, and 30 to 35 amperes on short circuit with a battery ammeter.

Then there are the very small sizes used in pocket flashlights, etc. As before mentioned, radio "B" batteries are a group of these little cells connected in series and sealed in a paper box.

Some dry batteries for radio and test work requiring high voltages, are built of little flat cells stacked together. These use flat plates, of zinc and carbon with a layer of the acid paste in between, for each cell. When a number of these are stacked they are more compact and eliminate a lot of connecting wires. See Fig. 11, which shows a comparison of the old type, and the new type "layer built" B batteries.

Dry cells should not be stored or located in damp places, or they will quickly deteriorate or lose their strength.

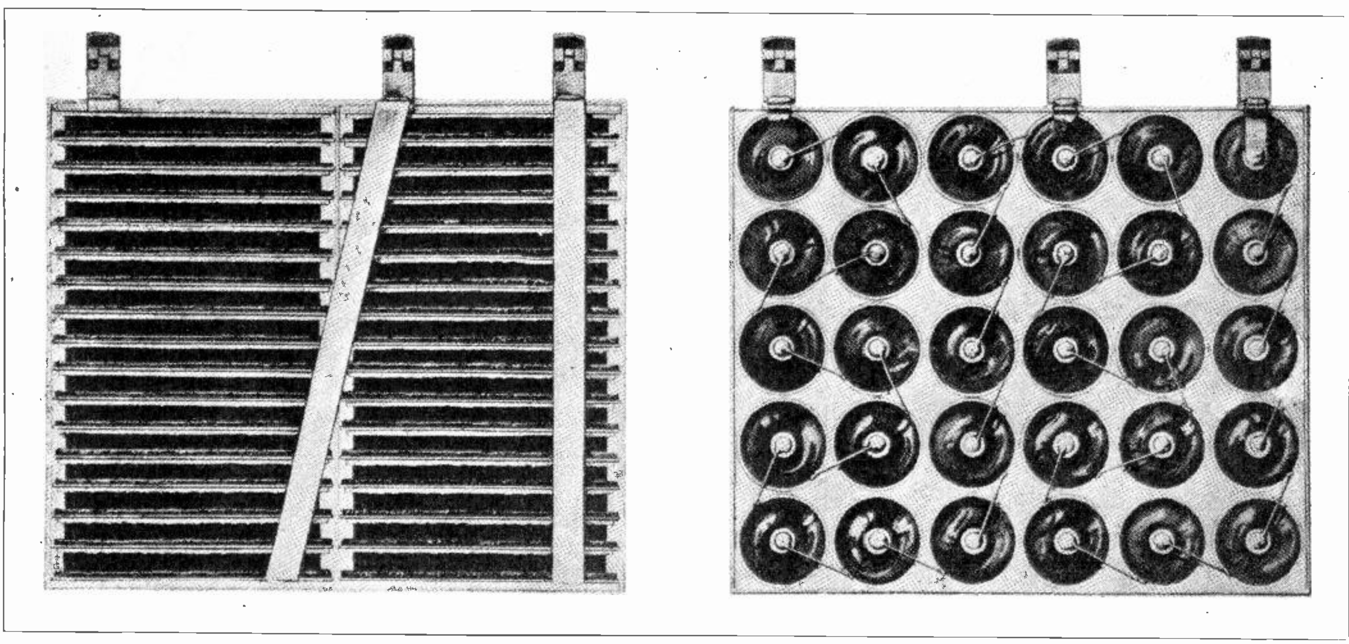


Fig. 11. Views showing inside construction of radio "B" batteries. Compare the new "layer built" type on the left, with the series grouped cells on the right.

Their tops and terminals should be kept clean of dirt and dampness, and terminals also kept tight.

The terminal nuts provided for easy connection of wires are very convenient, and are sometimes called binding posts.

69. POLARITY

The center terminal on the carbon electrode is always positive and the one on the zinc shell is negative. Current flows from positive to negative outside the cell, and from zinc or negative through the paste to carbon or positive, in the internal circuit.

These cells will often decrease in strength if stored too long in shelves before being sold, and therefore should be tested when buying.

When the paper covering of a dry cell shows damp or greasy appearing spots, or if when the paper is removed, the zinc shows bulges and holes eaten through it, this shows the cell is dead or used up, and should be replaced.

It is not practical to try to recharge dry cells, except in rare emergencies.

Dry cells can be adapted to many uses, and made to supply a wide variety of voltages or current capacity, by proper connection in series or parallel as covered in the previous section on series and parallel circuits. Fig. 12 shows a group of six dry cells connected parallel-series, and ready for use in a burglar alarm system.

In dealing with any cells it is well to remember that the copper or carbon electrode at which current leaves the cell is called the **Cathode**, and has the positive terminal attached to its top or pole. The zinc electrode at which current enters the cell from

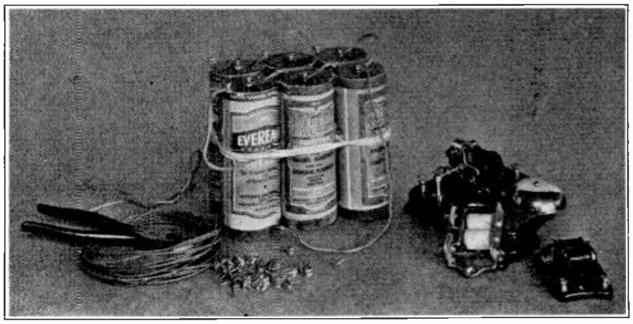


Fig. 12. Six dry cells connected parallel-series, for use in an alarm system.

the external circuit, is called the **Anode**, and has the negative terminal attached to its top.

The **Internal** circuit of a cell includes the electrodes and electrolyte. The **External** circuit refers to the wires and devices connected to its terminals.

The practical man will often have many uses for various types of batteries in his work, and this general knowledge of their operation and care should be of great value to him.

When you have carefully studied this material you should feel confident of your ability to install, care for, test and renew any of the common primary cells.

Remember you are not expected to memorize all of the material or data, but should use this set for reference any time necessary, when you have such problems or work ahead to do, and until practice fixes them in your mind.

This section has dealt only with various types of primary cells, as storage batteries of the lead plate and acid type, and also the nickle-iron alkaline type, will be covered thoroughly in a later section.

ELEMENTARY ELECTRICITY

SECTION SEVEN

MAGNETISM

70. **MAGNETS AND MAGNETISM** play such an important part in the operation of many electrical devices and machines, that every electrical man should have a good understanding of them.

Magnetism is also an extremely interesting subject, and you will really enjoy the following practical material.

You have probably seen magnets in use in some form or other, such as magnetic tack hammers or toy horseshoe magnets, with their mysterious power to attract tacks, nails, and other iron and steel objects.

Then there are the common magnetic compass, magnetized pocket knives and screw drivers, as well as magnets of another type in bells, buzzers, etc. But most people without electrical training do not realize that magnets form a large part of every electric motor and generator, and thousands of other devices such as telephone and radio receivers, telegraph instruments, power and telephone relays, magnetic tools, etc.

71. **NATURAL MAGNETS** were first found in Magnesia, a country in Asia Minor, about 600 B. C., and for this reason were called magnetite or magnets. (See Fig. 1.)

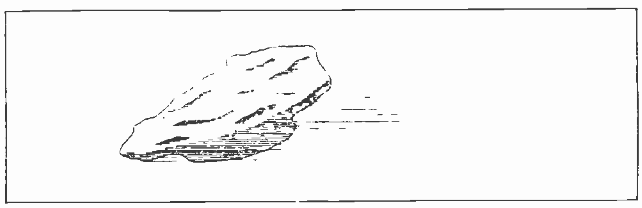


Fig. 1. Sketch of natural magnet or lodestone.

These first magnets were just lumps of iron ore or oxide, which were found to have the power of attracting small pieces of iron. Later it was also discovered that if an oblong piece of this material was suspended by a thread, it would always turn to a position with its length north and south. If moved or turned, the same end would always go back to point north. So its end which pointed north was called the North seeking or North end, and the other end the south seeking or south end. It was used in this manner as a crude compass and often called **"Lodestone,"** meaning leading stone.

Our compasses today are simply small steel needles that have been permanently and strongly magnetized, and mounted on jeweled pivots so they are free to turn easily. They are made by the thousands in many styles and sizes from the pocket variety used by hunters and explorers to keep their directions, to the big elaborate ones used to guide our steamships and airplanes.

72. EARTH'S MAGNETISM

The earth is also a natural magnet on a huge scale, with centers of magnetic force or attraction on its north and south sides. (See Fig. 2.)

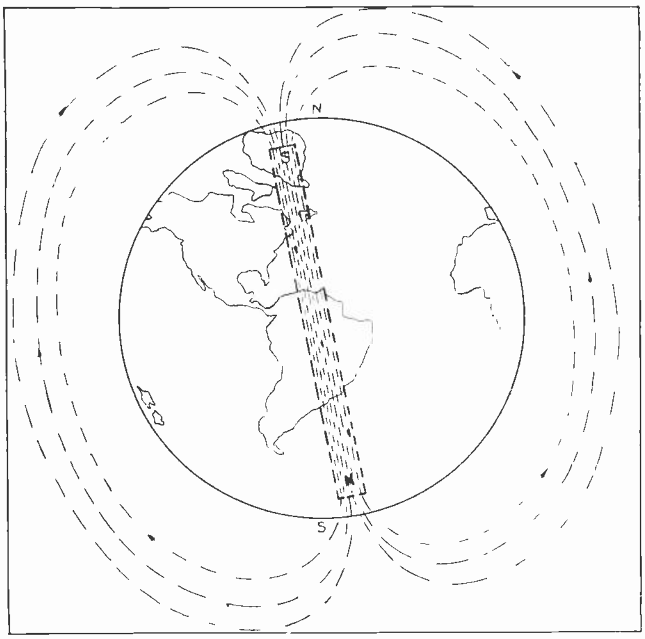


Fig. 2. Sketch showing earth's magnetic field and poles. Note that the magnetic poles do not exactly align with the geographical poles.

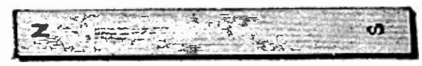
This is the reason for the attraction of the ends of the compass needle to a north and south position. But a compass does not point exactly true north, because the earth's magnetic centers are not exactly at its true north and south geographical poles, or ends of its axis.

In using a compass for accurate work, mariners, aviators, and surveyors allow a certain number of degrees for correction of this error, at various places on the earth.

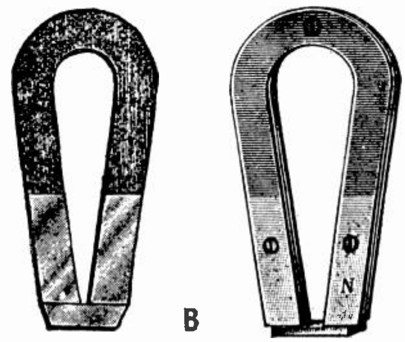
You will note in Fig. 2, the earth's magnetic poles are opposite to its geographical poles. This will be explained later.

73. ARTIFICIAL MAGNETS are made of steel and iron, in various forms. Common types are the straight bar and horseshoe forms. (See Fig. 3A and 3B.) These are usually much more powerful than the natural magnets or lodestones.

Artificial magnets can be made by properly stroking a bar of steel with a lodestone or some other magnet, or by passing electric current through a coil around the bar. In fact we find that a piece of iron often becomes magnetized, just lying near a strong magnet. This last method is called **Induced Magnetism.**



A



B

Fig. 3-A. Common bar magnet.
Fig. 3-B. Horseshoe magnets with "keepers" across poles.

If a small bar of soft iron is held near to, but not touching a strong magnet, as in Fig. 4, the small bar will be found to have magnetism also, and attract nails or other iron objects. But as soon as it is taken away from the permanent magnet, it will lose its charge. This is an example of induced magnetism.

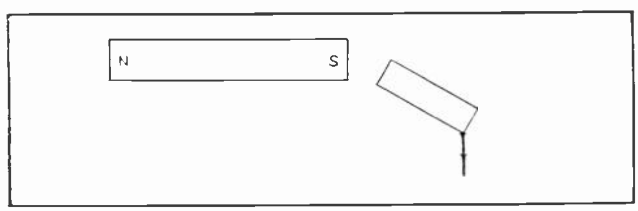


Fig. 4. The small bar of iron attracting the nails, obtains its magnetism by induction from being near the large magnet.

74. MAGNET POLES

All magnets whether natural or artificial, usually have their strongest pull or effects at their ends. These ends or points of stronger attraction are called **Poles.**

Ordinary magnets usually have at least two poles, called **north** and **south,** because of their attraction for the north and south poles of the earth.

If we dip a bar magnet in a pile of iron filings or tacks, we find it will attract them most at its ends, and not much in the middle. (See Fig. 5.)

75. ATTRACTION AND REPULSION

If we take two magnets and suspend them so they can turn freely until they come to rest with their north poles pointing north, and south poles pointing south, then we know that their ends which point north are alike, as well as the two which point south.

Now if we mark these magnets and bring the two north poles together, we find they will try to push apart, or repel each other. The two south poles will do the same if we bring them near each other. But if we bring a north pole of one magnet near the south pole of the other they will try to draw together or attract each other.

This proves one of the most important principles or rules of magnetism often called the first law of magnetism, as follows: **Like Poles Always Repel and Unlike Poles Attract Each Other.** This law should be remembered as it is the basis of operation of many electrical machines and devices.

Prove it for yourself with magnets, at your first opportunity, so you will remember it better.

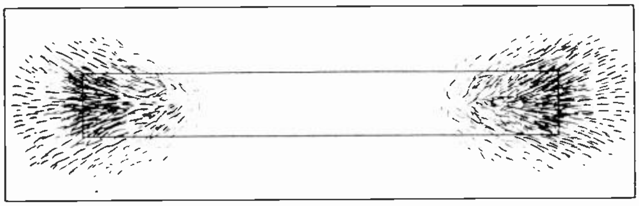


Fig. 5. Sketch of bar magnet showing how iron filings are attracted almost entirely at its ends or poles.

Refer back to Fig. 2, showing the earth's magnetic poles and you will now understand how we know that the magnetic pole in the north must be unlike the north pole of our compass, and why we assume that the earth's magnetic poles are opposite to its geographical poles.

76. LINES OF FORCE

Magnets do not have to be touching each other, but will exert their force of attraction or repulsion through a distance of several inches of air in many experiments.

If we place a magnet under a piece of glass or paper which is covered with iron filings, and tap or jar it, the filings will arrange themselves as shown in Fig. 6A and 6B.

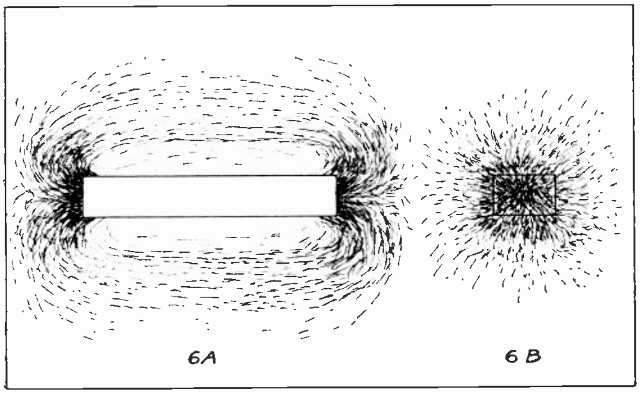


Fig. 6-A. Iron filings on a paper over a bar magnet, show shape of lines of force around the magnet.
Fig. 6-B. Filings over end of magnet.

This gives us some idea of the shape and direction of the lines of force acting around a magnet.

For practical purposes it is assumed that all magnets have what are called **Lines of Force** acting around and through them, and in the direction indicated in Fig. 7.

These magnetic lines are of course invisible to the eye, and cannot be felt, but we can easily prove that the force is there by its effect on a compass needle. By moving a small compass around a large magnet we can determine the direction of the lines of force at various points. **They always travel through the compass needle from its south to north pole, so it will always turn to such a position that its north pole indicates the direction the lines are traveling.** It is well to remember this, as a compass can often be used to determine the direction of magnetic lines of force in testing various electrical machines.

77. MAGNETIC FIELD AND CIRCUIT

The lines of force around a magnet are called **Magnetic Flux,** and the area they occupy is called the **Field** of the magnet.

The strong, useful field of an ordinary magnet may extend from a few inches to several feet around it, but with sensitive instruments we find this field extends great distances, almost indefinitely, but becomes rapidly weaker as we go farther from the magnet.

In Fig. 7, note that the lines of force through the bar or **Internal** path, are from the south to north pole, and outside the magnet through the **External** path, are from the north to south pole. This is a very important fact to remember.

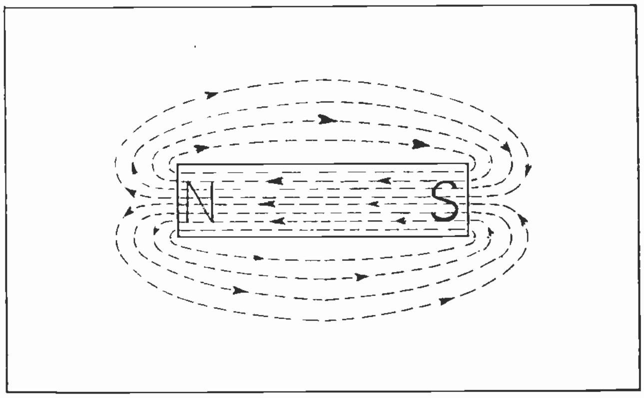


Fig. 7. Sketch of magnetic field, showing direction of lines, inside and outside the magnet.

We can also get further proof of the shape of this magnetic field by floating a magnetized needle in a cork, over a bar magnet as in Fig. 8.

If started at various points in the field the needle will travel the lines as indicated.

The path of lines of force around and through a magnet is often called the **Magnetic Circuit.**

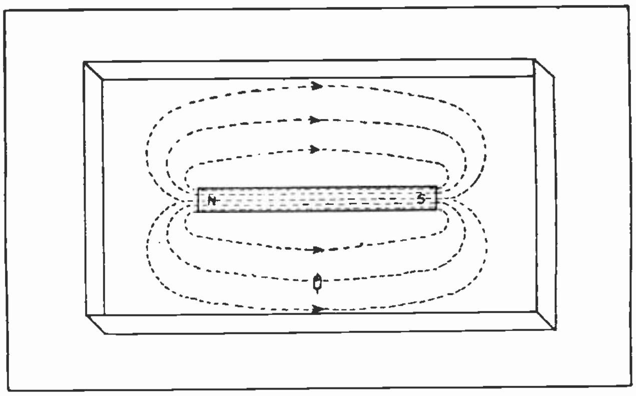


Fig. 8. Floating a needle in a cork, in water over a magnet, to show shape of lines of force.

78. ACTION OF MAGNETIC FIELDS

When two magnets are placed with unlike poles near each other as in Fig. 9, we find that their lines of force combine in one common path through them both as shown by the dotted lines.

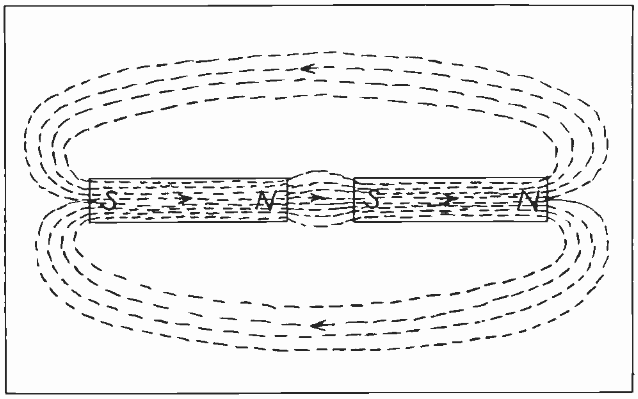


Fig. 9. Two bar magnets with unlike poles near each other, and attracting. Note how their fields join.

These lines then seem to try to shorten their path still more by drawing the magnets together, thus their attraction for each other.

It may be well to consider magnetic lines of force as similar in some ways to stretched rubber bands, revolving like endless belts, and continually trying to contract or shorten themselves.

This will help to get a practical understanding of many important effects and principles of magnetism, without going into lengthy and detailed theory.

If we place two magnets with their like poles near each other as in Fig. 10, we find their fields will not join, as the lines of force are coming in opposite directions. Therefore they crowd apart in separate paths between the ends of the poles, and the magnets push apart or repel each other to avoid this conflict or crowding of the opposing fields.

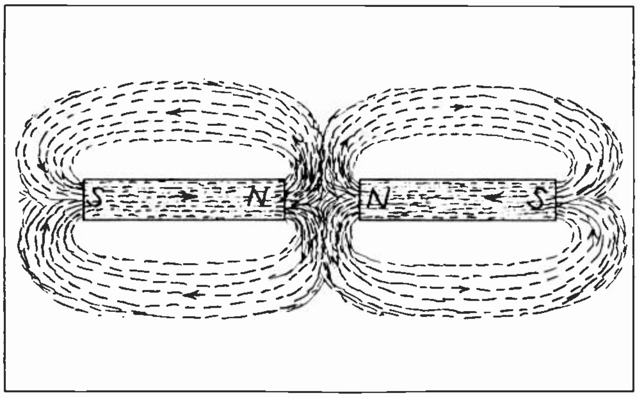


Fig. 10. Two bar magnets with like poles near each other and repelling. Note how their fields oppose.

79. MAGNETIC AND NON-MAGNETIC MATERIALS

In our experiments with magnets we find that only certain materials can be magnetized or attracted by magnets, while others cannot.

Those that can be magnetized we call **Magnetic Materials,** and those that cannot be magnetized we call **Non-Magnetic Materials.**

Iron and steel are good magnetic materials, and most magnets are made from them. Nickel and cobalt are somewhat magnetic. Brass, copper, gold, silver, lead, wood, glass, air, etc., are all non-magnetic materials.

80. PROPERTIES OF MAGNETIC MATERIALS

Soft iron is very easily magnetized, but does not hold its charge long. In fact it loses most of its magnetism as soon as the magnetizing force is removed.

Hard steel is much more difficult to magnetize, but when once charged it holds its magnetism much longer.

A good steel magnet may hold a strong charge for many years. Such magnets are called **Permanent Magnets.**

Materials that hold a charge well are said to have high **Retentivity,** meaning retaining power.

Therefore steel has high retentivity and soft iron is low in retentivity. In order to understand how magnets become charged, and why some will hold a charge better than others, let us briefly consider the molecular theory of magnetism. We know that all matter is made up of very small particles called molecules, and these molecules consist of atoms and electrons.

Each molecule has a polarity of its own, or might be considered as a tiny magnet. In a bar of iron or steel that is not magnetized, it seems that these molecules arrange themselves in little groups with their unlike poles together, forming little closed magnetic circuits as in Fig. 11.

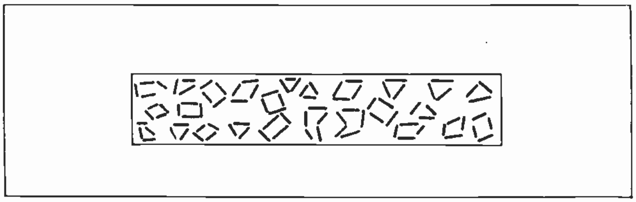


Fig. 11. Simple sketch showing the supposed arrangement of molecules in an unmagnetized bar of iron.

This view, of course, shows the molecules many times larger in proportion to the bar, than they really are.

Now when lines of force are passed through the bar, from some other strong magnet, causing it to become magnetized, the little molecules seem to line up with this flux, so their north poles all point one way and all south poles the other way. (See Fig. 12.)

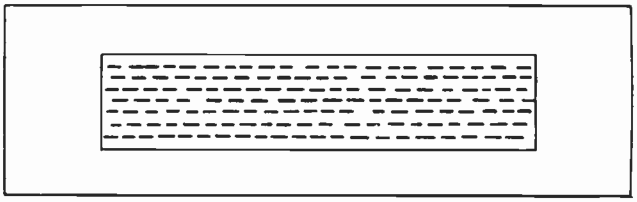


Fig. 12. Molecules lined up, in a fully magnetized bar.

In soft iron this change is effected very easily, and as we have already said it can be easily magnetized. But the molecules of iron also shift back to their natural position easily, so it quickly loses its magnetism.

With hard steel the molecules do not shift so easily, so it is harder to magnetize, but once charged the molecules do not shift back to their normal position so easily, and it holds its magnetism much better, as stated before.

When charging or making permanent steel magnets, tapping or vibrating the bar slightly seems to help speed the process. On the other hand if a permanent magnet that has been charged, is struck or bumped about roughly it will lose a lot of its strength, as the jarring seems to shift the molecules. Therefore, permanent magnets should be handled carefully.

The magnetism of a bar can also be destroyed by heating it to a cherry red. This is called **De-Magnetizing.**

If a magnet is placed in a reversing flux or field from some source, so its charge or polarity is rapidly reversed, the rapid shifting of the molecules sets up heat. This is called **Hysteresis** loss. Naturally this effect is much less noticeable in soft iron than in hard steel, as the molecules shift easier and with less friction and heat, in the soft iron.

81. PERMEABILITY AND RELUCTANCE

Experiments prove that magnetic lines of force will pass through iron and steel, or magnetic materials much easier than through air, wood and brass, or non-magnetic materials of any kind. So iron and steel form a good path for magnetic flux, and are said to have high **Permeability,** and low **Reluctance.** The term reluctance means the same to magnetic flux as resistance means to electric current.

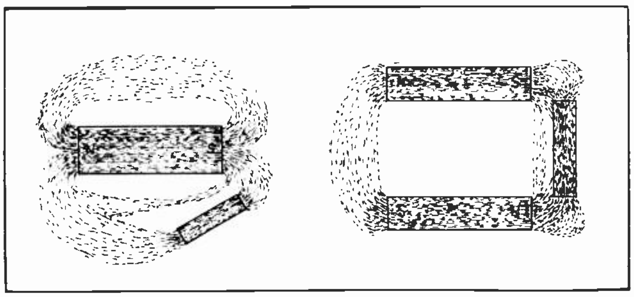


Fig. 13-A. & B. Sketches showing how lines of force can be distorted and made to follow the easier path through the small iron bars.

If we place a small bar of soft iron in the field of a larger magnet as in Fig. 13A or near the ends of two magnets as in Fig. 13B, in both cases the lines of force will largely choose the easier path through the iron as shown. This can be proven by sprinkling iron filings on a glass over such a group of magnets and iron. This not only proves that iron is of lower reluctance than air, but also that magnetic flux will choose the easiest path available.

Good soft iron is only about 1/2000th part as high reluctance as air. For this reason we construct many magnets in the form of a horseshoe, which brings the poles closer together, greatly reducing the air gap reluctance and increasing the strength and life of the magnet. (See Fig. 14A and 14B.)

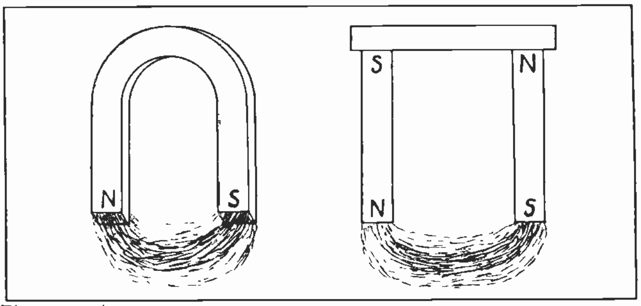


Fig. 14-A. Horseshoe magnets have a much shorter flux path through air from pole to pole.
Fig. 14-B. Double magnet constructed in horseshoe shape, also to shorten its air gap.

In Fig. 14B, the bar joining the two magnets together is called a **yoke.** We often place a soft iron "keeper" across the ends of horseshoe magnets as in Fig. 15, when they are not in use, to provide a complete closed circuit of magnetic material and eliminate the air gap reluctance. This will greatly increase the life of the magnet.

82. PULLING STRENGTH

Horse shoe shaped magnets having unlike poles near each other, have a much greater lifting power when in contact with an iron surface, than the one end of a bar magnet does. This is because the horseshoe type has so much better complete path of low reluctance for its lines of force, and the field will be much more dense, and stronger. (Compare Fig. 15 and 16.)

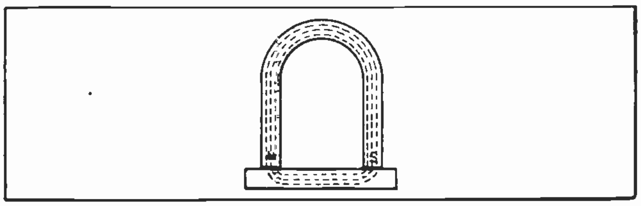


Fig. 15. Horseshoe magnet with keeper bar across its poles to decrease air gap when not in use.

In Fig. 16, the lines must pass a considerable distance through air, which greatly weakens them. In Fig. 15, the lines can travel entirely within a closed iron path or circuit of much lower reluctance, and give a much stronger pull.

A good horseshoe magnet weighing one pound, should lift about 25 pounds of soft iron.

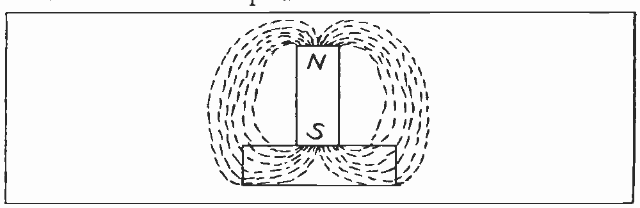


Fig. 16. Bar magnet attracting a piece of iron. Note the long path through air, which the lines of force must take.

83. EFFECT OF AIR GAPS

As air is of such high reluctance it is very important to reduce the air gaps as much as possible in all magnetic circuits where we wish to obtain the greatest possible strength of flux or pull.

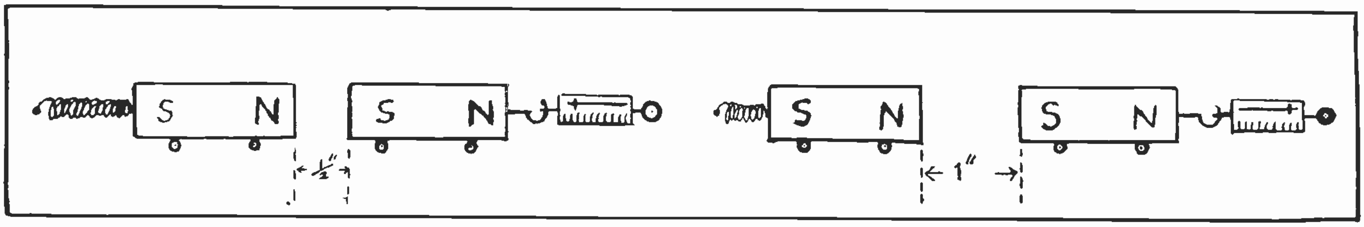


Fig. 17-A. & B. Doubling the distance between two magnets, decreases their pull to ¼ of what it was.

If two magnets are placed as in Fig. 17A, and their pull measured, and then they are moved farther apart as in Fig. 17B, we find that the small increase in the distance or air gap makes a great reduction in their pull. If the distance is doubled, the pull is decreased to about ¼ of what it was.

If the distance is tripled, the pull decreases to about 1/9 of what it was.

If on the other hand we reduce the distance to ½ its original amount, the pull will increase to 4 times the original pull.

So we get another very important law of magnetism as follows:

The force exerted between two magnets varies inversely with the square of the distance between them.

If we change the strength of the magnets we find their combined pull will vary with the **Product of Their Separate Strengths.**

84. MAGNETIC SHIELDS

While iron is a good conductor of magnetic flux, and air is a very poor one, we do not have any known material that will insulate or stop magnetic lines of force. They will pass through any material. But we can shield magnetic flux from certain spaces or objects, by leading it around through an easier path. As before mentioned the lines of force will largely choose the easiest path. So if we arrange a shield of iron around a device as in Fig. 18, we can distort the flux around, and prevent most of it from entering the shielded area.

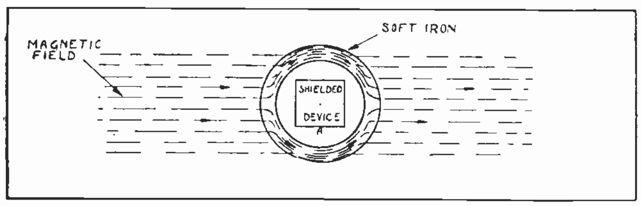


Fig. 18. Iron shield to deflect lines of force away from instrument or device (A).

Quite often the magnetic field of some large generator or electric machine may affect the operation of a meter or some delicate device located near it. So you should remember how to shield such instruments. Many meters are equipped with iron cases to shield their working parts in this manner.

Sometimes in our work with magnets we find evidence of more than two poles, or points of attraction at other places along the magnet besides at its main poles. Such poles are called **Consequent Poles,** and are formed by adjoining sections being oppositely magnetized so the fluxes oppose. Very weak magnets may sometimes develop consequent poles. (See Fig. 19.)

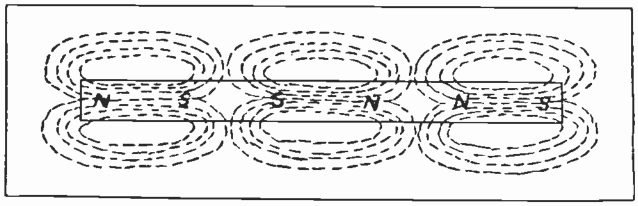


Fig. 19. Consequent poles in a bar magnet.

If a long magnetized bar is broken into several pieces, each piece will take on separate north and south poles. (See Fig. 20.)

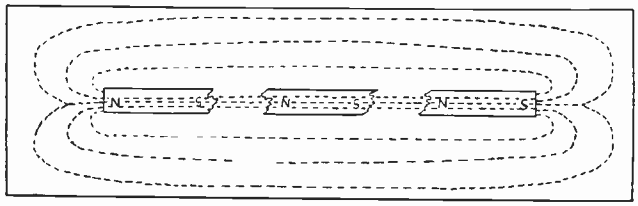


Fig. 20. Bar magnet broken into several pieces. Note each piece takes on separate poles in this case.

Two or more separate magnets with their like poles grouped together will in many cases give more strength than a single magnet the size of the group. Such a magnet is called a **Compound Magnet.** (See Fig. 21A and 21B.)

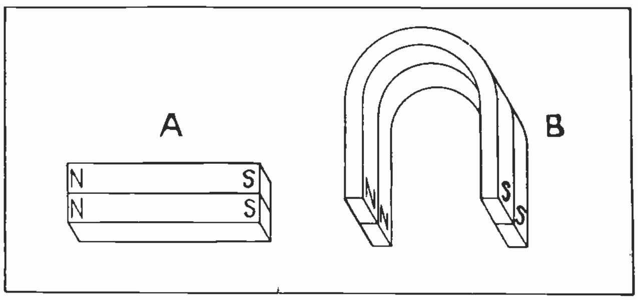


Fig.21-A. Compound bar magnet.
Fig. 21-B. Compound horseshoe magnet.

85. COMPASS TEST

When using a compass to test the polarity of magnets, or the direction of flux on motors or generators, it is well to first test the compass by letting it come to rest in the earth's magnetism, away from the device to be tested. Compass needles sometimes have their polarity reversed by the influence of strong magnets around which they are used. **But the end of the needle that points north is always the north pole, and the one which will point in the direction of flux travel.**

This may seem confusing because we know unlike poles attract, and might wonder how the north pole of the compass would point to the north pole of the earth. But remember that the magnetic pole of the earth which is near its north geographical pole, is in reality a south magnetic pole. This was illustrated in Fig. 2, and explained in Articles 72 and 75.

86. SPECIAL MAGNETIC ALLOYS

There are certain patented alloys of iron and steel mixed with other metals, which have very good magnetic properties. Some of these have higher permeability than soft iron, and others have higher retentivity than hard steel.

Cobalt Steel is one of these improved alloys, especially good for strong, permanent magnets.

Permalloy is another, of very low reluctance, used in thin ribbon form for wrapping telephone and telegraph cables.

We find a few materials that show slight properties of repulsion to either pole of a magnet. These are called **Diamagnetic.**

Some of the uses of permanent magnets were mentioned in the first part of this subject. They are also used for fields of magnetos, in electric meters, for surgical instruments, and many other things.

Before proceeding farther, be sure you have a good understanding of these important principles of magnets and magnetism, as it will be of great value to you in all electrical work. It will also make it easy for you to understand the very interesting section on **Electro-Magnetism** which follows.

ELEMENTARY ELECTRICITY

SECTION EIGHT

ELECTRO-MAGNETISM

You will recall that in an earlier section we found that one of the very important effects of dynamic electricity, was its magnetic effect.

We learned that whenever a current is passed through a wire, it sets up whirling lines of force around the wire. This is called **Electro-Magnetism.**

87. MAGNETIC FIELD AROUND WIRES CARRYING CURRENT

The **strength** of this magnetic field around a wire depends on the **amount** of current flowing, and can be varied at will by controlling the current flow.

The **direction of the line's rotation** depends on the **direction of current through the wire**; reversing if we reverse the current.

If we pass a stiff wire which is carrying current, vertically through a piece of paper, as in Fig. 1, and sprinkle iron filings on the paper, they will arrange themselves in a pattern as shown.

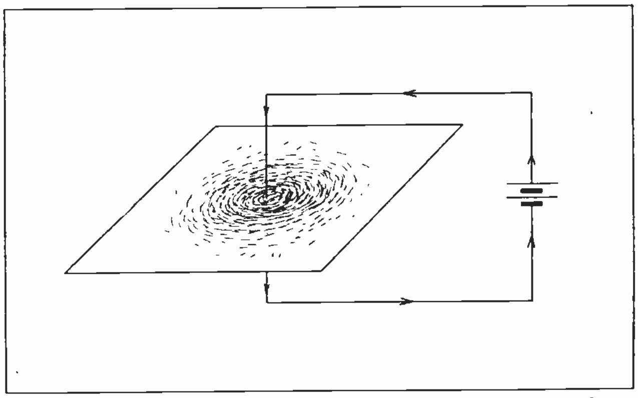


Fig. 1. Electro-magnetic lines shown by iron filings around a conductor.

If we remove the filings and place several small compass needles on a cardboard around the wire, they will point in a circle as shown in Fig. 2. These experiments prove the existence of this invisible magnetic force, and also show the circular shape of the field around the wire. The north poles (black ends) of the compass needles also show the direction the lines of force travel. If the current flow is stopped, the needles will all point north, but as soon as current is again started they will point in a circle once more.

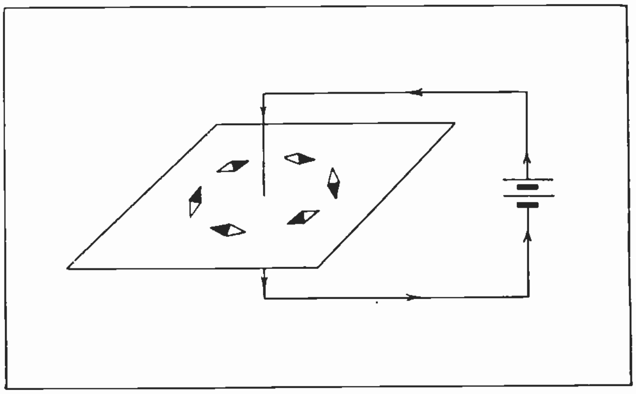


Fig. 2. Small compass needles showing shape and direction of lines around a conductor.

88. DIRECTION OF LINES AROUND CONDUCTORS

Note the direction of current in the wire in Fig. 2, and the direction the needles point. If we change the leads at the battery, and thereby reverse the direction of current through the wire, the needles will at once reverse their direction also. This proves that the field reverses with the current.

We can see from this that if we know the direction of current in any wire, we can determine the direction of the lines of force around it. Or if we know the direction of flux, we can find the direction of current.

A single compass needle is all that is required to tell the direction of flux. See Fig. 3.

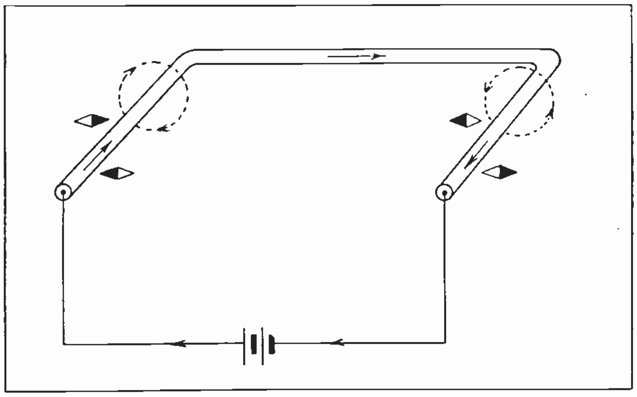


Fig. 3. Convenient compass test for direction of flux around conductors. Note carefully the direction of current and flux of each end of the wire.

Here we have a bent piece of stiff wire connected to a battery by other wires. The current in the left end is flowing away from us, and if we place a compass under the wire it points to the left. If we move the compass above the wire it points to the right.

This proves that **when current is flowing away from you** in a wire, the lines of force are revolving **Clockwise**, as the hands of a clock turn.

When we try the compass on the right end of the loop where the current flows toward us, we find it points opposite to what it did on the left end.

This proves that **when current flows toward you in a wire,** the lines of force revolve **counter clockwise.** See the lines of force indicated by the dotted lines. Study this rule over carefully and start practising it at every opportunity on actual electric circuits, because it will be very useful later in your work on power machines and circuits.

89. RIGHT HAND RULE FOR DIRECTION OF FLUX

Another simple rule by which you can determine the direction of current, or flux of wires, is called the "Right hand rule". **Grasp the wire with the right hand, with thumb pointing in the direction of current flow, and your fingers will point in direction of flux around the wire.** (See Fig. 4-A and 4-B.)

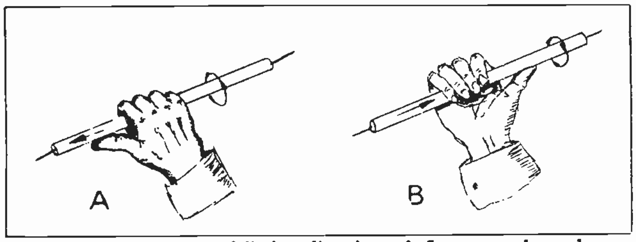


Fig. 4. "Right hand rule" for direction of flux around conductors.

This rule should be memorized by practice.

Of course in the case of a bare, uninsulated wire it is not necessary to touch or actually grasp it to use this rule. After a little practice you can use it very well by just holding your hand near the wire in a position to grasp it, and with thumb in direction of current, your finger tips will indicate the direction of flux.

90. MAGNETIC FORCES BETWEEN PARALLEL WIRES

If we run two wires parallel to each other, close together, and both carrying current in opposite directions, we find their lines of force being in opposite directions tend to crowd apart, and actually make the wires repel each other. See Fig. 5-A.

In Fig. 5-B, are shown two flexible wires suspended close together, yet loosely and free to move. When a rather heavy current is passed through them in the direction shown by the arrows, they will crowd apart quite noticeably. The dotted lines show where they would hang normally when no current is flowing.

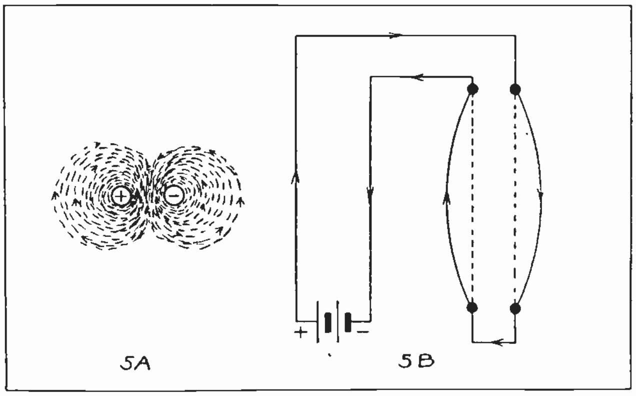


Fig. 5. This sketch shows the repulsion of parallel wires, carrying current in opposite directions.

If we run two wires parallel to each other, close together, and both carrying current in the same direction, we find that their lines of force tend to join together in one common field around both wires, as in Fig. 6-A and 6-B.

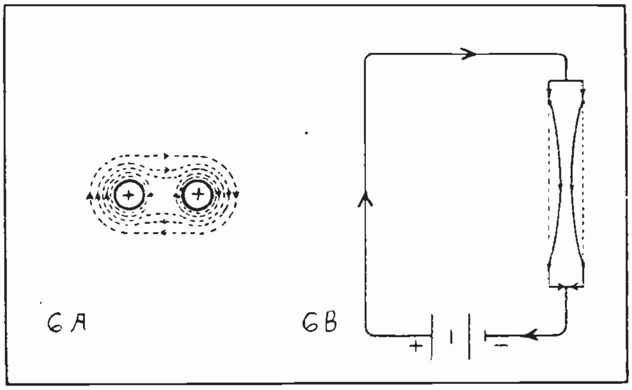


Fig. 6. When parallel wires carry current in the same direction, their flux tends to draw them together.

When wires are close together in this manner, the combined path around the two is shorter than the two separate paths around each. Then by joining each other, the lines avoid going in opposite directions in the small space between the wires. This flux around the two wires tends to pull them together, as the lines of force are always trying to shorten their path, as we learned before.

In Fig. 6-B, we again have the two suspended parallel wires, this time carrying current in the same direction, and we find they now draw toward each other.

This magnetic force exerted between wires often becomes very great in the heavy windings of large power machinery, especially in case of excessive currents during overloads or short circuits. So we find their coils are often specially braced to prevent them moving due to this stress.

91. STRONG FIELDS AROUND COILS

We can make excellent use of this tendency of magnetic flux, to join in a stronger common field around two or more wires, to create some very powerful electro-magnetic fields.

One of the best ways to do this is to wind a coil of insulated wire as shown in Fig. 7-A.

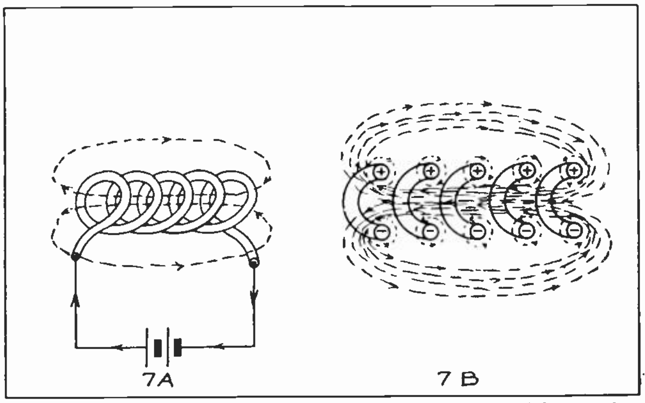


Fig. 7-A. The lines of force around the turns of a coil join together, in one very strong field.
Fig. 7-B. Sectional view, note how the lines join around all turns, and the dense flux set up in the center of the coil.

We can easily see that all turns of such a coil are carrying current in the same direction on all sides of the coil. If we split such a coil from end to end, as shown in Fig. 7-B, we can then see how the flux of all the turns will unite in a common field through the center of the coil and back around the outside.

92. SOLENOIDS

Such a coil of a single layer is called a **Helix.** Coils for creating strong electro-magnetic fields, are often wound with many layers of insulated wire on a spool of brass or fibre, or some other non-magnetic material. Such coils are called **Solenoids.** See Fig. 8.

By referring to both Figs. 7 and 8, we see that all the lines of force travel one way through the center of the coils in a very dense field, and back the other way outside the coil. Thus a solenoid has north and south poles just as a bar magnet does.

Now if we place an iron core inside of a solenoid the field will at once become much stronger, as the iron offers a much better path for the lines of force than air does. When we start to insert the core in a solenoid that has current flowing in it, we find it exerts a strong pull on the core, tending to draw it into the coil. This seems to be an effort of the lines of force to draw the iron into the most dense flux, which is inside the coil.

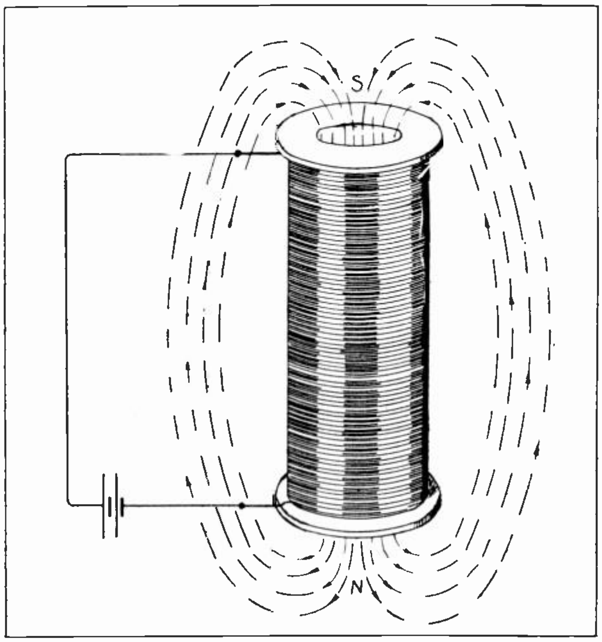


Fig. 8. Solenoid, or coil wound on a non-magnetic tube. Note the direction of the lines, and polarity of this solenoid.

A solenoid will give a strong and fairly uniform pull for about half its own length. This is the most effective distance. Solenoids with movable cores attached to levers, or handles of switches and controllers, are used considerably on electrical equipment.

93. ELECTRO-MAGNETS

While an iron core is inside a coil and current is flowing, we find the iron becomes strongly magnetized due to the very dense field in which it is located. But if the core is soft it loses practically all its magnetism as soon as the current is turned off.

Such a coil and core are called an **Electro-Magnet.** Or in other words an **Electro-Magnet** is a core of soft iron, wound with a coil of insulated wire.

Electro-magnets are the ones used in bells, buzzers, relays, lifting magnets, and electric motors and generators. They can be made extremely powerful, and have the advantage of being magnetized or demagnetized at will, by turning the coil current on or off.

The lifting magnet in Fig. 9, is an example of a huge electro-magnet. With the current turned on it is lowered to the iron it is to lift, often raising many tons at a time. Then when we want it to drop the iron the current is simply turned off.

94. CONSTRUCTION OF SIMPLE ELECTRO-MAGNETS. RESIDUAL MAGNETISM.

Electro-magnets for various tests or handy uses, can be easily made by winding a few turns of insulated wire around any soft iron core, and connecting the coil ends to a dry cell or storage battery. Even a nail or small bolt will do, and will prove quite a strong magnet when wound with 50 to 100 turns of No. 24 to 30 wire, and used with a dry cell. But you will note that as soon as the coil is disconnected, or the battery current turned off, the core will lose practically all its noticeable magnetic strength, as

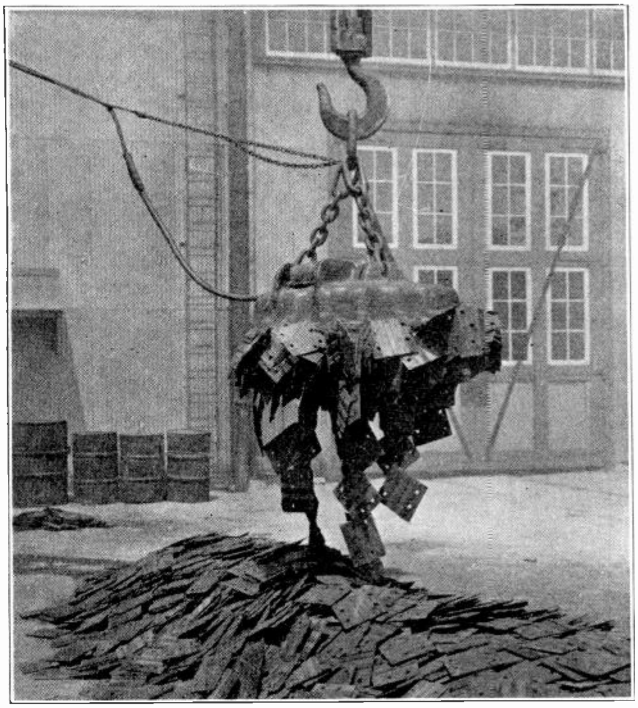


Fig. 9. Electro-magnet used for handling iron and steel. This magnet has a number of coils inside its frame or cover.

far as any attraction is concerned. However, in reality there is almost always a very feeble charge left in the core for a while after the current stops flowing. This charge remaining or residing in the core is called **Residual Magnetism.** The softer iron the core is made of, the less residual magnetism it will retain. Residual magnetism plays a very important part in the operation of many electric generators, as will be found later.

Permanent magnets can be made by placing a piece of hard steel in a coil for a time, with the current turned on. Then when the current is turned off, the hard steel being of higher retentivity than iron, retains considerable of its charge as residual magnetism.

Powerful electro-magnets are often used to charge permanent magnets, by holding or rubbing the magnet to be charged on the poles of the electro-magnet. See Fig. 10.

A good charging magnet of this type for charging magneto magnets, can be made of two round cores of soft iron about 3x6 inches, wound with 500 turns of No. 14 wire on each. They should have a soft iron bar 1x3x8 inches bolted to their bottom ends, and square pieces 1x3x3 inches on their top ends. Such a magnet can be used on a 6-volt storage battery, and is often very handy in a garage or electrical repair shop.

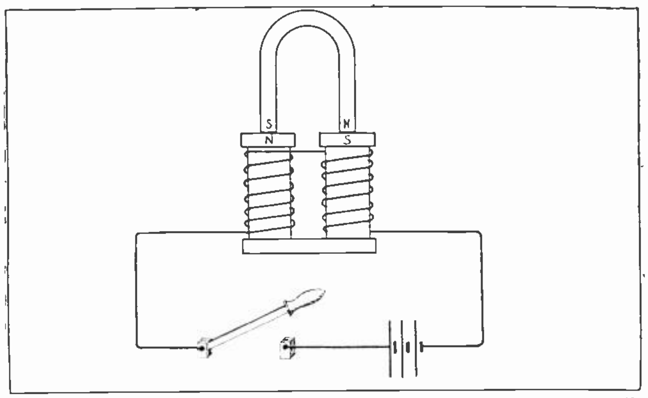


Fig. 10. Powerful electro-magnet for charging permanent magnets. The horseshoe magnet is in position to be charged and its poles will be as shown.

95. POLARITY OF ELECTRO-MAGNETS

It is very important to be able to determine the polarity of solenoids and electro-magnets. A compass will, of course, show the north pole by the attraction of its tail or south pole. But if we know the direction of winding of a coil, and the direction current passes through it, we can quickly find the correct polarity with a simple rule. This rule is called the **Right Hand Rule for Electro-Magnets.**

Grasp the coil with your right hand, with the fingers pointing around the coil in the same direction current is flowing in the wire, and your thumb will point to the north pole of the magnet. See Fig. 11.

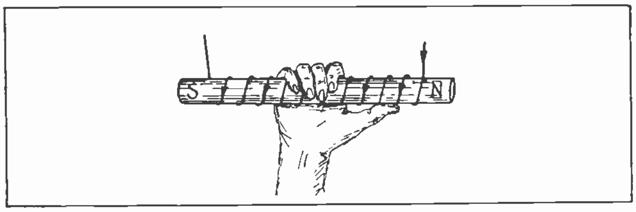


Fig. 11. Right hand rule for determining polarity of electro-magnet.

Every electrical man should know this rule, as there are many uses for it in practical work. Practice it until you can use it easily.

It can also be used to find the direction of current flow if you know the polarity of the magnet. In such a case we again grasp the coil with the right hand, thumb pointing to north pole, and the fingers will point in direction of current flow around the coil.

We already know that the flux around a wire will reverse if we reverse the current flow. This is equally true then of the flux around a coil or group of wires. So we can reverse the polarity of a solenoid or electro-magnet at will, merely by reversing the current supply wires to it.

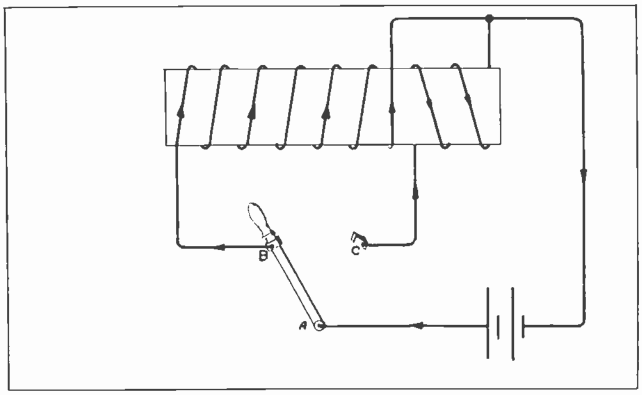


Fig. 12. Electro-magnet with demagnetizing coil for destroying residual magnetism.

Some special electro-magnets are wound with a separate demagnetizing coil, in addition to the main coil.

This may be a smaller coil, wound in the reverse direction to the main coil, so if connected just for an instant, after main coil is turned off, it will just destroy the residual magnetism that might otherwise remain. See Fig. 12.

If when switch (A) opens the main circuit at (B), it is momentarily closed to (C), it will create a reverse flux to more quickly demagnetize the core.

It is also possible to wind a coil on a core so it will create no magnetism in the core. See Fig. 13.

Here the coil has been wound with two wires, and their ends connected together. The current flows through an equal number of turns in each direction, so practically no magnetism will be set up in the core. Non-magnetic coils of this type are often used in meter construction.

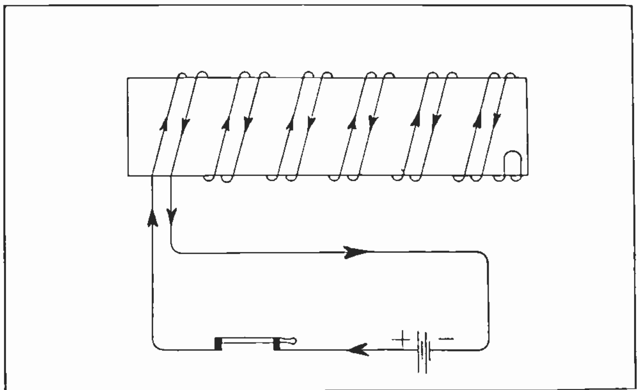


Fig. 13. Non-magnetic winding. One half of the turns oppose the other half, so the core does not become magnetized.

96. UNITS, SATURATION AND STRENGTH OF ELECTRO-MAGNETS

The strength of an electro-magnet depends on the number of turns in its coil, and the amperes or amount of current flowing through them, or as we say the **Ampere-Turns.**

The **Ampere-Turns** are the product obtained, when the amperes are multiplied by the number of turns.

A coil of 100 turns, carrying 2 amperes, has 200 ampere-turns. (Abbreviated I.N.)

Another coil of 400 turns carrying ½ ampere, has 200 ampere-turns.

We say therefore that the number of ampere turns, determines the **Magneto-Motive-Force.** (Abbreviated M.M.F.) and meaning magnetizing force.

The greater the M.M.F. or number of ampere-turns we apply to a given core, the stronger magnet it becomes, up to certain limits.

As we go on increasing the ampere-turns and strength of a magnet, the lines of force in its core become more and more dense and numerous. After we reach a certain point in flux density, we find a further considerable increase of ampere turns of the coil, does not cause much increase of flux in the core, as we have apparently reached its practical limit in the number of lines it can carry. This is called the **Saturation-Point.**

Good magnetic iron or steel can carry about 100,000 lines per square inch, before reaching the practical saturation point. Therefore, if we wish to make electro-magnets requiring more than 100,000 lines of force, we should use a core larger than 1 square inch cross sectional area. **Fifteen ampere-turns per inch of core length, on a closed core of 1 square inch area, will produce approximately 100,000 lines of force.**

The chart in Fig. 14, showing the lines of force per square inch, produced in soft iron by various numbers of ampere-turns, may often be very useful to you.

To read the chart select any number of ampere turns at the bottom line and run up the vertical lines to the curve, then to the left edge, and read number of lines. Thus 5 ampere turns gives about 67,000 lines per square inch. 10 ampere turns gives 90,000 lines. 12 ampere turns about 95,000 lines, etc.

It is interesting to note how the factors in a magnetic circuit can be closely compared to those of an electric circuit. In the electric circuit, we have pressure or **Electro-Motive-Force, Current and Resistance.** In the magnetic circuit we have **Magneto-Motive-Force, Flux and Reluctance.** And in the electric circuit we have the units volt, ampere and ohm, while in the magnetic circuit we have the **Ampere-Turn, Lines of Force, and Rel.**

The **Rel** is a name often used for the unit of reluctance. Its symbol is R.

One rel is the amount of reluctance offered by a prism of air or non-magnetic material, 1 inch square and 3.19 inches long. We know that iron is much lower reluctance than air, and it takes a bar of mild steel or wrought iron 1 inch square and 460 feet long to have a reluctance of 1 rel. Cast iron is somewhat higher reluctance, and a bar 1 inch square and 50.7 feet long has 1 rel reluctance.

One ampere turn can set up one line of force in a reluctance of 1 rel.

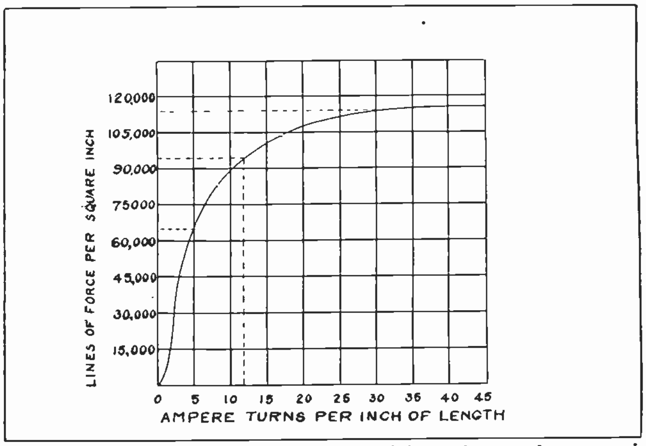


Fig. 14. Curve showing number of lines of force that can be set up in soft sheet iron, with various numbers of ampere turns.

97. PRACTICAL ELECTRO-MAGNET CALCULATIONS

To calculate the total flux or lines of force in a magnetic circuit we can use the following formulas:

$$\phi = \frac{M}{R}$$

In which:

ϕ equals flux in lines of force.
M equals MMF in ampere turns.
R equals reluctance in rels.

For example, if we have 1200 ampere turns M.M.F., on a magnetic circuit of .03 rel, what would be the total flux?

$$\phi = \frac{M}{R}, \text{ or Flux} = \frac{1200}{.03} \text{ or } 40{,}000 \text{ lines.}$$

In order to be able to calculate the reluctance of a magnetic circuit, we must know the **Reluctivities** of common magnetic and non-magnetic materials. **Non-magnetic materials all have a reluctivity of about .313 rel, per inch cube.**

Mild steel or wrought iron usually has a reluctivity of about .00018 rel, per inch cube, and cast iron .00164 rel per inch cube, under favorable conditions. But of course, the values vary somewhat with the density of the flux used in the metals.

Knowing these values, the reluctance of a core can be found as follows:—

$$R = \frac{\nu \times L}{A}$$

In which:

R equals rels.
ν equals reluctivity of core per inch cube.
L equals length of core in inches.
A equals cross sectional area of core in square inches.

If you wish to make a magnet using a wrought iron core 2x2x8 inches, what would the core reluctance be?

$$R = \frac{\nu \times L}{A}, \text{ or } R = \frac{.00018 \times 8}{4} \text{ or } .00036 \text{ rel.}$$

If the same magnet has an air gap of about 2x2x1 inches, what would the total reluctance of the circuit be, including the core and air?

$$R = \frac{\nu \times L}{A}, \text{ or } R = \frac{.313 \times 1''}{4} = .07825 \text{ rel.}$$

reluctance of air core.

Then .00036 plus .07825 = .07861 rel reluctance of total circuit.

If you wind 1000 turns of wire on this core, and pass 5 amperes of current through the coil, how much flux will be set up?

5 amps × 1000 turns equals 5000 ampere turns or I.N., and I.N. also equals M or MMF.

Then from our formula for determining flux:

$$\phi = \frac{M}{R}, \text{ or flux} = \frac{5000}{.07861} \text{ or } 63{,}605 \text{ lines.}$$

98. LIFTING POWER

The pulling or lifting power of a magnet depends on the flux density in lines per square inch, and the area of the poles in square inches. Then to determine the actual lift in pounds we use the figure 72,134,000, which is a "constant," determined by test of the ratio of lines to lbs.

From this we get the very useful formula:

$$\text{Pounds Pull} = \frac{\text{Area} \times (\text{Flux Density})^2}{72{,}134{,}000}$$

(Note the flux density is to be squared or multiplied by itself.)

If a magnet has a pole area of 4 square inches and a flux density of 100,000 lines per square inch, what would be its lifting power?

$$\text{Lbs.} = \frac{4 \times 100{,}000^2}{72{,}134{,}000} \text{ or } 554.5 + \text{ pounds.}$$

So we find that a good magnet should lift over 138 pounds per square inch of pole surface.

We can usually depend on a lift of over 100 pounds per square inch even though the magnet is only working at a density of 90,000 lines per square inch. This, of course, means the lift obtainable when both poles of the magnet are actually in good contact with the iron to be lifted.

You have now learned how to use the units Ampere-turn, lines of force, and rel, to calculate flux and pull of magnets by simplified formulas.

99. C. G. S. UNITS

It may be well to mention here another set of units used in some cases instead of those above mentioned.

These are the **Gilbert, Maxwell, and Oersted.**

The **Gilbert** is a unit of M.M.F., similar to the ampere-turn, but one ampere-turn is larger, and equal to 1.257 Gilbert.

The **Maxwell** is a unit of flux, or the same as one line of force.

The **Oersted** is a unit of reluctance, and is the reluctance of 1 cubic centimeter of air or non-magnetic material.

This second set of magnetic units are from the C.G.S. (Centimeter, gram, second) system of units, and can be used for practically the same purpose as the ampere-turn, line of force, and rel. They merely differ slightly in size, the same as the centimeter and the inch are both units of measurement, only of different sizes.

The practical man will probably find the ampere-turn, lines of force, and rel, much easier units to use, because they deal with square inches instead of centimeters, and the ampere-turn is so easily understood, as a unit of M.M.F. The other units are merely mentioned and explained here, so if you see or hear them used from time to time you will understand their meaning.

Direct current is best for operation of Electro-magnets, as its steady flow gives a much stronger pull per ampere-turn, than alternating current.

However, many A. C. magnets are used on motor controllers, relays, circuit breakers, etc.

100. MAGNET WINDING AND REPAIRS

In making electro-magnets the core should be of good soft iron, and covered with one or more layers of oiled paper or varnished cloth insulation.

This will prevent the wires of the first layer of winding from becoming grounded or shorted to the core, if their insulation should become damaged.

Some sort of end rings should be provided to hold the ends of the winding layers in place. Hard fibre is commonly used for this purpose. See Fig. 15, which shows a sectional view of an electro-magnet.

Some magnet coils are wound with thin insulation between each layer of wire, and some are wound without it. It is not absolutely necessary to have the turns of each layer perfectly flat and even, as they are in machine wound coils, to make a good magnet. But they should be wound as smooth and compact as possible.

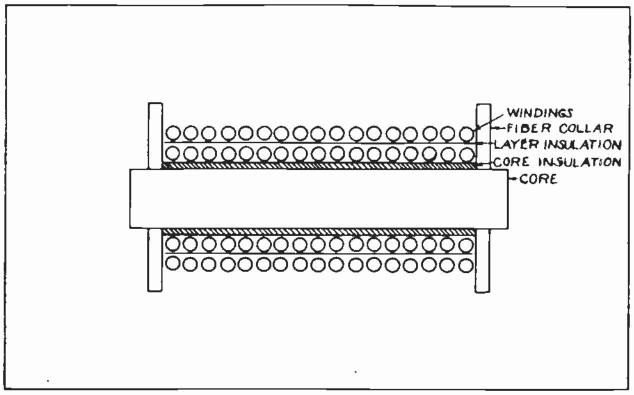


Fig. 15. Sectional view of electro-magnet, showing core, insulation and winding.

Magnet wires, with insulation of cotton, silk, enamel, or combinations of cotton-enamel or silk-enamel, are used for winding electro-magnets. Enamel is excellent electrical insulation, takes up the least space in the coil, and carries heat to the outside of coil very well. Therefore it is ideal for many forms of compact coils, of fine wires. But the cotton or silk covered wires are easier to handle and wind, as they stand the mechanical abuse better.

When winding a magnet coil with very fine wires which are easily broken, it is well to splice a piece of heavy flexible wire to the fine wire, for both starting and finishing leads of the coil. The piece of heavier wire used in starting the coil should be long enough to make several turns around the core, to take all strain off the fine wire in case of a pull on this end wire. Then wind the fine wire over the "lead in" wire, and when the coil is finished attach another piece of heavy wire, and wrap it several times around the coil, to take any possible strain on this outer "lead" wire. Any splices made in the coil should be carefully done, well cleaned, and soldered, so they will not heat up, arc or burn open, after the coil is finished and in service. A layer of tape or varnished cloth should be put over the outside of the coil to protect the wires from damage.

When repairing and rewinding magnet coils from motors, controllers, relays, or any electrical equipment, be careful to replace the same number of turns and same size of wire as you remove. Otherwise the repaired coil may overheat or not have the proper strength.

If the wire removed is coarse, the turns can usually be carefully counted. If it is very fine and perhaps many thousands of turns, it can be accurately weighed, and the same amount by weight, replaced.

The size of the wire used for the repair should be carefully compared with that removed, by use of a wire gauge or micrometer.

The same grade of insulation should be used also, because if thicker insulation is used it may be difficult to get the full number of turns back on the coil, or it may overheat, due to the different heat carrying ability of the changed insulation.

101. TESTING COILS FOR FAULTS

It is very simple to test any ordinary magnet coil for "open circuits," "grounded circuits" or "short circuits," commonly referred to as opens, shorts, and grounds.

A test lamp or battery and buzzer can be used for most of these tests.

See Figs. 16-A, B and C.

In Fig. 16-A, the coil has a break or "open," and a battery and test lamp or buzzer connected to its ends, will not operate, as current cannot pass through. If the coil was good and not of too high resistance, the lamp or buzzer should operate. In testing coils of very high resistance, a high voltage magneto and bell are often used instead of the battery and lamp.

In Fig. 16-B, the insulation of one turn of the coil has become damaged, and allows the wire to touch the core. This is called a "ground."

With one wire of the lamp and battery circuit connected to the core, and the other connected to either coil wire, the lamp will light, showing that some part of the coil touches the core and completes the circuit. If there were no grounds and the insulation of the entire coil was good, no light could be obtained with this connection, to one coil lead and the core.

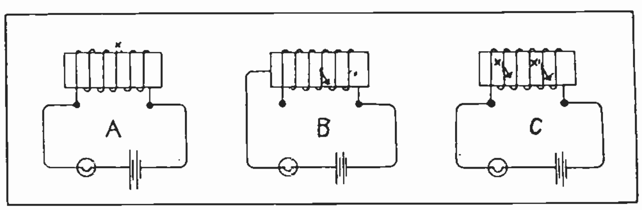


Fig. 16. Methods of testing coils for faults.

In Fig. 16-C, the coil has developed two grounds at different places, thus "shorting" out part of the turns, as the current will flow from X to X1 through the core, instead of around the turns of wire. With the battery and lamp connected as shown this would usually cause the lamp to burn a little brighter than when connected to a good coil. If a good coil of the same type and size is available, a comparative test should be made.

Some of the turns being cut out by the "short" reduces the coils resistance, and more current will flow through the lamp. In some cases a low reading ammeter is used instead of the lamp, to make a more accurate test.

Short circuits may also occur by defective insulation between two or more layers of winding, allowing the turns to come together and possibly shorting out two or more layers, thus greatly weakening the coil and causing overheating.

Figs. 17, 18, 19 and 20, show several types of electro-magnets.

Note carefully the windings and direction of current flow in each of these magnets, and check the polarity of each with your right hand rule. This will be excellent practice and help you to remember this valuable rule.

The two coils on the double magnet in Fig. 17, are wound in opposite directions to create unlike poles together at the lifting ends. This is very important and necessary, or otherwise the magnet would have like poles, and not nearly as strong attraction or pull. The coils of the telephone receiver and bell, in Fig. 19, are also wound oppositely for the same reason.

Those in the motors in Fig. 20 are wound opposite to create unlike poles adjacent, to allow a complete magnetic circuit from one to the other. Note carefully the path of the flux in each case.

If you have carefully studied this section on magnetism and electro-magnetism, you have gained some very valuable knowledge of one of the most important subjects of electricity.

You will undoubtedly find many definite uses for this knowledge from now on, and it will be a great help in understanding electrical machines of practically all kinds.

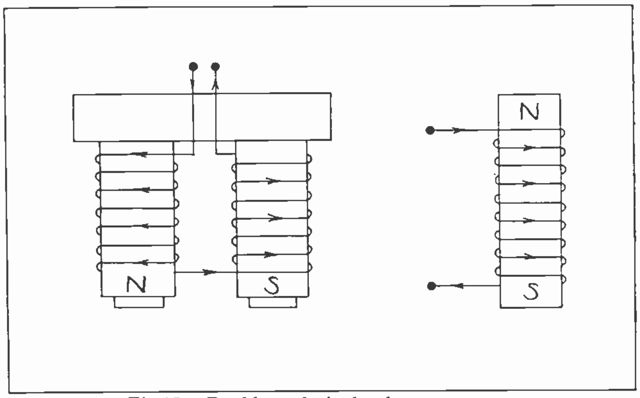


Fig.17. Double and single electro-magnets.

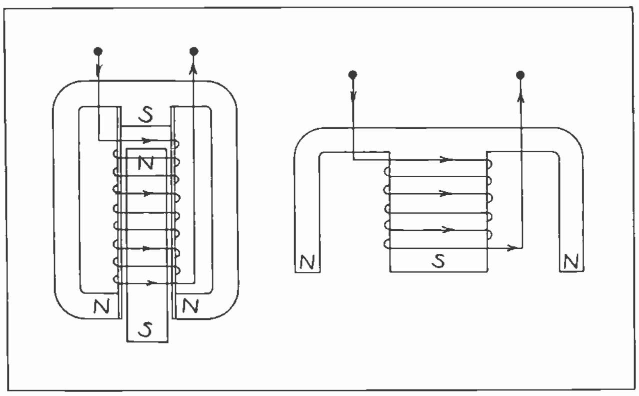


Fig. 18. Plunger type magnet at left. Shell type magnet at right.

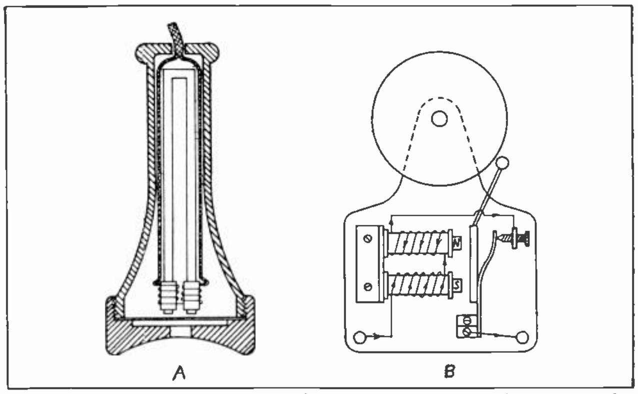


Fig. 19. Sketches showing use of electro-magnets in telephone receiver and door bell.

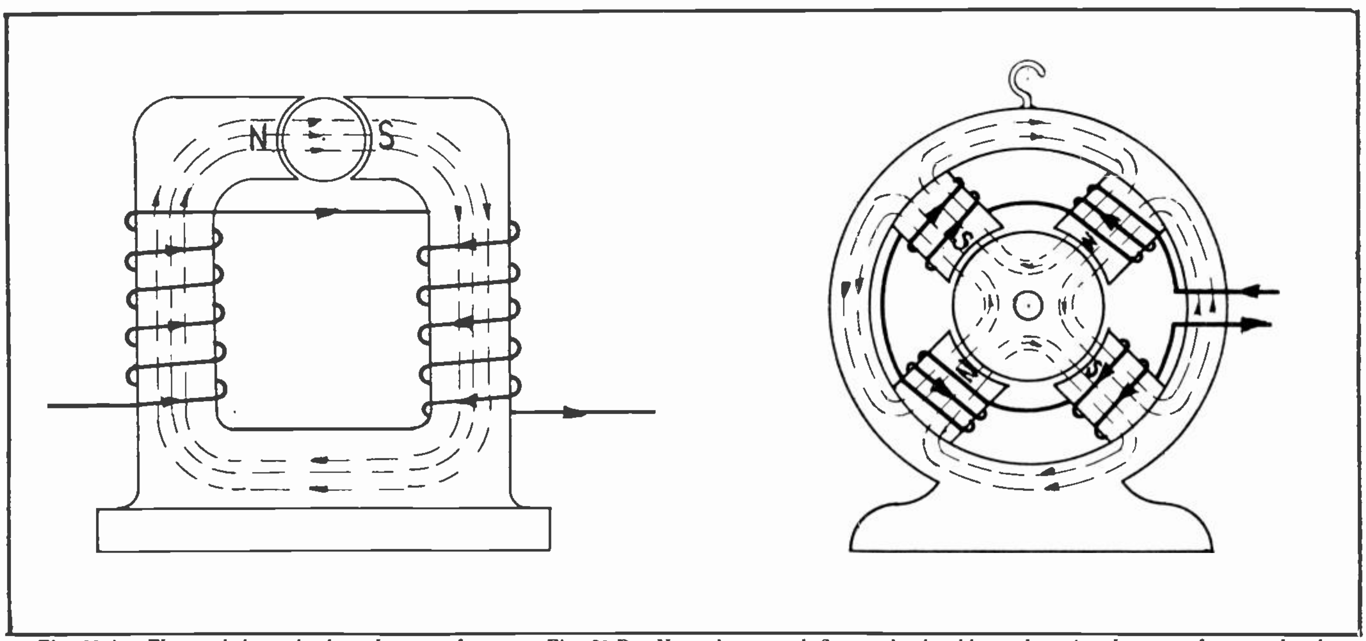


Fig. 20-A. Flux path in a simple early type of motor. Fig. 20-B. Note the several flux paths in this modern 4 pole motor frame and poles.

ELEMENTARY ELECTRICITY

SECTION NINE

ELECTRO-MAGNETIC INDUCTION

Electro-magnetic induction is another very interesting and important subject. This is the principle used in all of our power plant generators, motors, transformers and many other electrical machines.

102. GENERATING ELECTRIC PRESSURE BY INDUCTION

If we move a piece of wire through magnetic lines of force as in Fig. 1, so the wire cuts **across** the path of the flux, a voltage will be induced in this wire. Faraday first made this discovery in 1831.

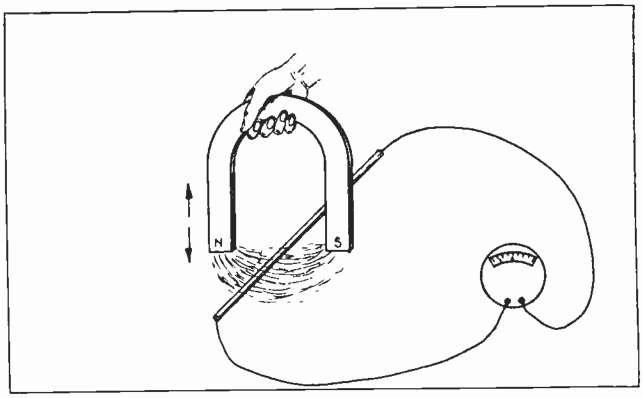


Fig. 1. When a wire is moved through magnetic flux, voltage is generated in the wire.

If we connect a sensitive voltmeter to this wire, thus completing the circuit, the needle will indicate a flow of current every time the wire is moved across the lines of force. This induction, of course, only generates electrical pressure or voltage in the wire, and no current will flow unless the circuit is complete as shown in Fig. 1. So it is possible to generate voltage in a wire, without producing any current, if the circuit is open.

In fact we never do generate current, but instead we generate or set up the pressure, and the pressure causes current flow if the circuit is completed. But it is quite common to use either the term induced voltage, or induced current. This is all right and sometimes simpler to state, if we simply remember that current always results from the production of pressure first, and only when the circuit is closed.

103. DIRECTION OF INDUCED PRESSURE AND CURRENT

Referring again to our experiment in Fig. 1, if we move the wire up through the flux the meter needle reads to the left of zero, which is in the center of the scale. If we move the wire down through the flux, the needle reads to the right. If we move the wire rapidly up and down, the needle will swing back and forth, to left and right of the zero mark. This proves that the direction of the induced pressure and resulting current flow, depends on the direction of movement through the magnetic field, and that we can reverse the voltage and current, merely by reversing the direction of movement of the wire.

A simple rule to determine the direction of the voltage induced, when the direction of the lines of force and movement of the conductor are known, is as follows:

Consider the lines of force as similar to moving rubber belts, and the wire as a pulley free to revolve when it is pushed against the belts. (See Fig. 2.)

Assume (A) and (B) to be the ends of wires to be moved. (A) is moving upwards against lines of force traveling to the right. Then its imaginary rotation would be clockwise as indicated by the arrows around it, and this will be the direction the lines of force will revolve around the conductor from its own induced current. Then remembering our rule from the section on electro-magnetism, we know that clockwise flux indicates current flowing away from us.

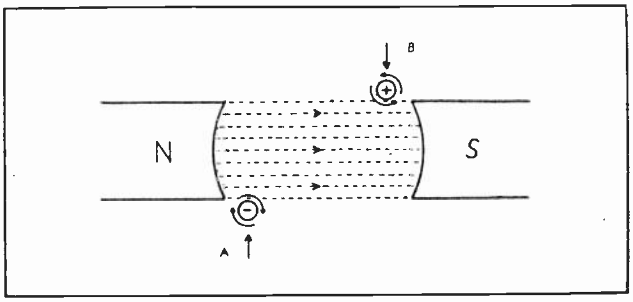


Fig. 2. Sketch of conductors moving through flux, as in a simple generator. Note direction of induced pressure.

Wire (B) is moving down against the lines of force, so if it were to be revolved by them it would turn counter clockwise. As this would be the direction of flux around the wire from its induced current, it indicates current would flow toward us.

Another rule that is very convenient, is the **right hand rule for induced voltage,** as follows:

Hold the thumb, forefinger and remaining fingers of the right hand, at right angles to each other. Then let the forefinger point in the direction of flux travel, the thumb in direction of movement of the wire, and remaining fingers will point in the direction of the induced pressure. (See Fig. 3.)

In the illustration the flux moves to the left, the wire moves up, and the current in the wire would be flowing toward you, as indicated by the three remaining fingers.

Practice this rule, as you will find a great deal of use for it on the job, in working with motors, generators, etc.

104. AMOUNT OF PRESSURE GENERATED DEPENDS ON SPEED AT WHICH LINES ARE CUT

Referring back again to Fig. 1, if we hold the

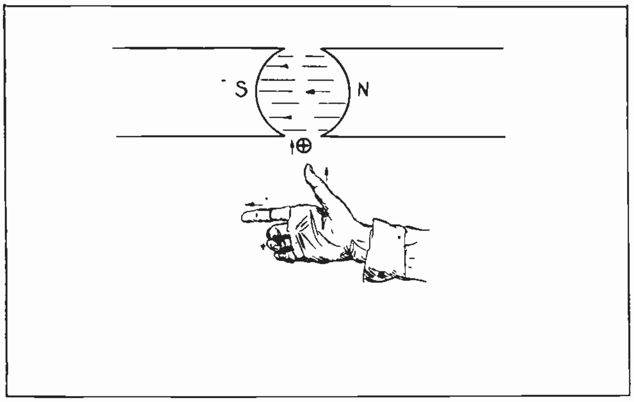


Fig. 3. Right hand rule for direction of induced voltage. Compare position of fingers with direction of flux and wire movement.

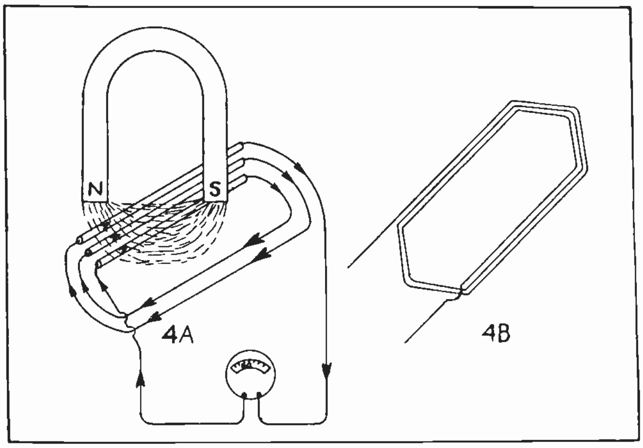


Fig. 4-A. Using several wires connected in series to obtain higher induced voltage.
Fig. 4-B. Coil of several turns, as used in generators.

wire still, even though in the magnetic field, no pressure will be generated. Or if we move the wire to right or left, parallel to the path of the flux, no pressure will be produced. So we find that the wire must cut **across** the flux path to generate voltage, or as we often say it must be "Cutting" the lines of force.

The faster we move the wire through the magnetic field, or the stronger the field and greater the number of lines of force, the farther the meter needle moves.

So the **amount of pressure or voltage produced** by electro-magnetic induction, **depends on the speed with which lines of force are cut,** or the number of lines cut per second.

A very important rule to remember is that **one conductor cutting 100,000,000 lines of force per second will produce 1 volt pressure.**

This probably seems to be an enormous number of lines to cut to produce one volt, but we do not actually have to use one magnet with that many lines of force, as we can speed up the movement of the conductor in an actual generator, so fast that it will pass many magnet poles per second.

We can also add the voltage of several wires together by connecting them in series in the form of coils. (See Fig. 4A and 4B.)

Here we have three separate wires all of which are moved upwards through the flux at once, and we find an equal amount of pressure is induced in each, all in the same direction. Then when we connect them all in series as shown, so their voltages will all add up in the same direction in the circuit, our meter reads three times as much voltage as it did with one wire. Generator coils are often made with many hundreds of turns so connected, thus obtaining very high voltage.

105. SIMPLE GENERATOR PRINCIPLES

In Fig. 5A and Fig. 5B, are shown single turn coils A, B, C, D, arranged to be revolved in the field of permanent magnets. The ends of the coils are attached to metal **slip rings** which are fastened to the shaft, and revolving with it. This gives a connection from the moving coils to the lamp circuits by means of metal or carbon brushes rubbing on the slip rings.

Assume that the coil A, B, C, D in Fig. 5A, revolves to the right, or clockwise. The wire A. B, will be moving upward through the flux, and the induced pressure will be in the direction indicated by the arrow on it.

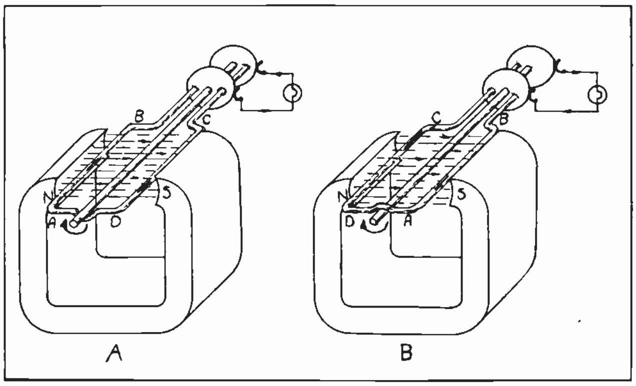


Fig. 5-A. Simple electric generator of one single wire loop, in the flux of a strong permanent magnet.
Fig. 5-B. Here the coil has revolved one-half turn farther than in (A).

Wire C, D, is moving downward, and its induced pressure will be in the reverse direction, but will join with, and add to that of wire A, B, as they are connected in series in the loop. Note that the current flows to the nearest collector ring, and out along the lower wire to the lamp, returning on the upper wire to the farthest collector ring and the coil.

In Fig. 5B, is shown the same coil after it has turned one-half revolution farther, and now wire A, B, is moving downward instead of up as before. Therefore, its pressure and current are reversed. The wire C, D, is now in position where A, B was before, and its pressure is also reversed. This time we find that the current flows out to the farthest collector ring, and over the top wire to the lamp, returning on the lower wire.

106. ALTERNATING CURRENT AND DIRECT CURRENT

So we see that as the conductors of such a simple generator revolve, passing first a north pole and then a south, their current is rapidly reversed. Therefore we call the current it produces **alternating current,** abbreviated A. C.

If we wish to obtain **direct current** (D. C.), we must use a **commutator** or sort of rotary switch, to reverse the coil leads to the brushes as the coil moves around. All common generators produce A. C. in their windings, so we must convert it in this manner if we wish to have D. C. in the external circuit. (See Fig. 6A and 6B.)

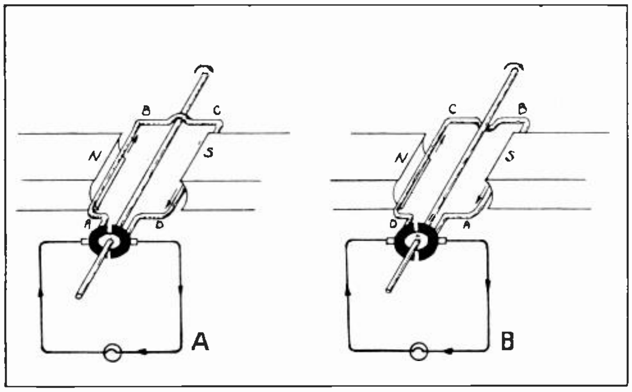


Fig. 6-A and B. Single loop generators with simple commutators, for producing direct current. Note how current continues in same direction through the lamp, at both positions of the coil.

Here again we have a revolving loop. In Fig. 6A, the wire A, B is moving up, and its current is flowing away from us, and that of C. D. toward us. The coil ends are connected to two bars or segments of a simple commutator, each wire to its own separate bar. With the coil in this position, the current flows out at the right hand brush, through the lamp to the left, and re-enters the coil at the left brush.

In Fig. 6B, the coil has moved one-half turn to the right, and wire A, B is now moving down, and its current is reversed. However, the commutator bar to which it is connected has also moved around with the wire, so we find the current still flows in the same direction in the external circuit through the lamp.

107. INDUCTION COILS

Now did you think of this?

If moving a wire through lines of force will induce pressure in the wire, why wouldn't it also generate pressure if the wire was stationary, and the flux moved back and forth across it?

That is exactly what will happen. (See Fig. 7.)

Here we move the magnet up and down, causing the lines of force to cut across the wire which is stationary, and again we find that the meter needle swings back and forth. This proves that pressure is generated whenever lines of force are cut by a wire, no matter which one it is that moves.

You also know that every wire carrying current has flux around it.

Now if we place one wire which is carrying current, parallel and near to another wire, its flux will encircle the wire that has no current. (See Fig. 8A and 8B.)

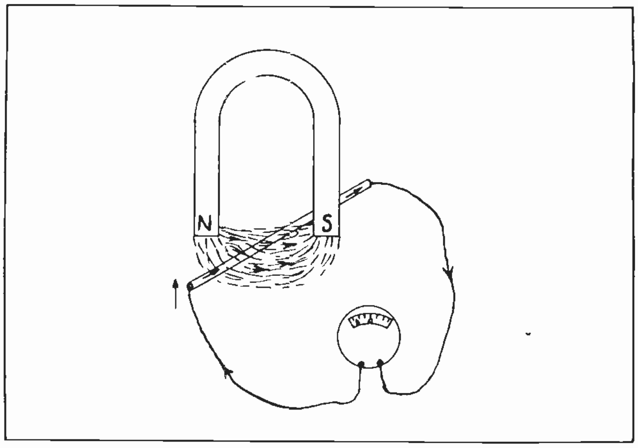


Fig. 7. Induction experiment, moving the magnet and its field instead of the wire.

When we close the switch the current starts to flow in wire "B," building up its magnetic field around it. In building up, these lines seem to expand outward from the wire, cutting across wire "C," and the meter will show a momentary deflection when the switch is closed.

After the flux has been established the meter needle drops back to zero, and remains there as long as the current in wire "B" does not change. This shows that no induction takes place unless the current is changing, causing the flux to expand or contract and cut across the wire.

When we open the switch interrupting the current flow, and allowing the flux to collapse around wire "B," the meter needle reads in the opposite direction to what it did before. Then it drops back to zero once more after the flux has died down.

If we open and close the switch rapidly, causing a continual variation in current and flux of wire "B," the meter needle will swing back and forth, showing that we are inducing alternating current in wire "C." This is the principle on which induction coils and power transformers operate.

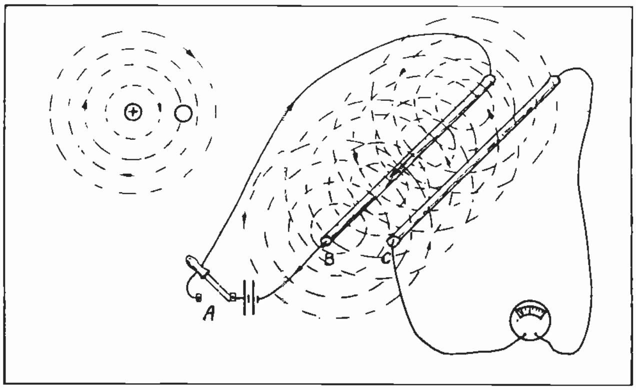


Fig. 8-A and B. Sketch showing how induction takes place between two wires, when current and flux are varied.

If we arrange two coils as in Fig. 9, we find the induction between them much greater than with the single straight wires, because of the stronger field set up around coil A, and the greater number of turns in coil "B" which are cut by the flux. The meter will now give a much stronger reading when the switch is opened and closed.

In Fig. 9, coil A, which is said to be excited or energized by the battery, is called the **"Primary."** Coil "B," in which the voltage is induced by the flux of the primary, is called the **"Secondary.**

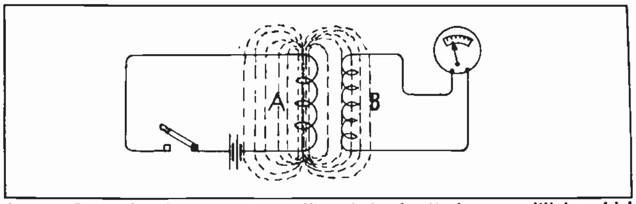


Fig. 9. Induction between two coils. A is the "primary coil" in which exciting current flows. B is the "secondary coil" in which current is being induced.

108. HIGH VOLTAGE SPARK COILS

The greater number of turns we use in the secondary coil, the higher will be the induced voltage. This is due to the fact that all the turns are affected by the flux, and all are in series, so the voltages induced in each turn are added, giving a pressure equal to their sum at the coil ends.

In this manner we can get very high voltages by winding the primaries and secondaries of induction coils or transformers with proper ratios, or numbers of turns. This is called stepping up the voltage. Of course when we increase the voltage in this manner, the current in the secondary decreases proportionately, or by the same proportion as the voltage is increased. Thus the watts remain the same except for slight losses in the coils.

In Fig. 10, is shown the construction of a simple type of spark coil. The iron core (A) is made of soft iron strips called **Laminations,** or sometimes of iron wires bundled **tightly. The** primary coi' which is a few turns of rather heavy wire, is wound over the insulated core. Then after a layer of good insulation is placed over the primary, the secondary coil is wound over it all. This secondary usually consists of several thousand turns of very fine wire, and may have a pressure of several thousand volts induced in it.

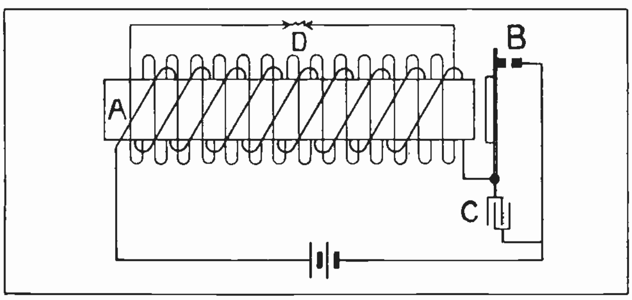


Fig. 10. Diagram of a spark coil, showing primary and secondary coils and make and break contacts.

Such high voltages will cause a hot spark through an air gap, as at "D."

An interrupter to make and break the circuit rapidly, is shown at "B." This interrupter is operated or kept vibrating by the magnetism set up in the iron core. It serves to keep the current and flux of the primary continually changing, to accomplish induction.

A condenser is shown at "C." Its purpose is to reduce sparking at the interrupter contacts, and cause a quicker collapse of primary flux when the current is interrupted. The action of such condensers will be more fully explained later.

109. TRANSFORMERS, also operate on this principle of electro-magnetic induction. Transformers are used to increase or decrease the pressure or voltage of electric circuits, for many purposes. They range in size from the little bell ringing type, to those of several kilowatts capacity, located on the poles and supplying power and light current to our homes; and on up to those of many thousands of kilowatts, for the high voltages of our great power transmission lines.

In Fig. 11, is shown a simple transformer illustrating in general the construction and principle of all common types. Here the primary and secondary coils are wound on opposite legs of **a** closed iron core. This core serves to carry the flux of the primary, over to the secondary coil. Such transformers operate on alternating current, so they do not need an interrupter, as alternating current is continually reversing in direction, and varying in amount. As the current in the primary coil reverses, and increases and decreases, its flux whips back and forth across the turns of the secondary, inducing alternating current in them.

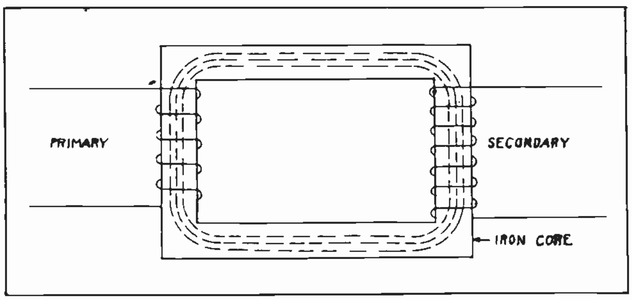


Fig. 11. Core and windings of a simple transformer.

Transformers of various types will be covered thoroughly in a later section, but be sure to obtain a good knowledge of this principle of electro-magnetic induction, as you will use it in many ways in your work from now on.

Now if you have studied carefully and thoroughly each part of this elementary section, you can feel that your time has been very well spent. Nothing is so essential to the practical man as a good general knowledge of the fundamental and important principles of electricity, covered in this section.

With a good understanding of these things you can proceed into the following sections and easily understand them. You will also find that some of these same simple principles will clear up many trouble shooting and operating problems in the field, that would otherwise be very mysterious and difficult. This is where the trained man has the advantage, and is well repaid for all his efforts and study, by being able to solve the problems that stick many an "old timer."