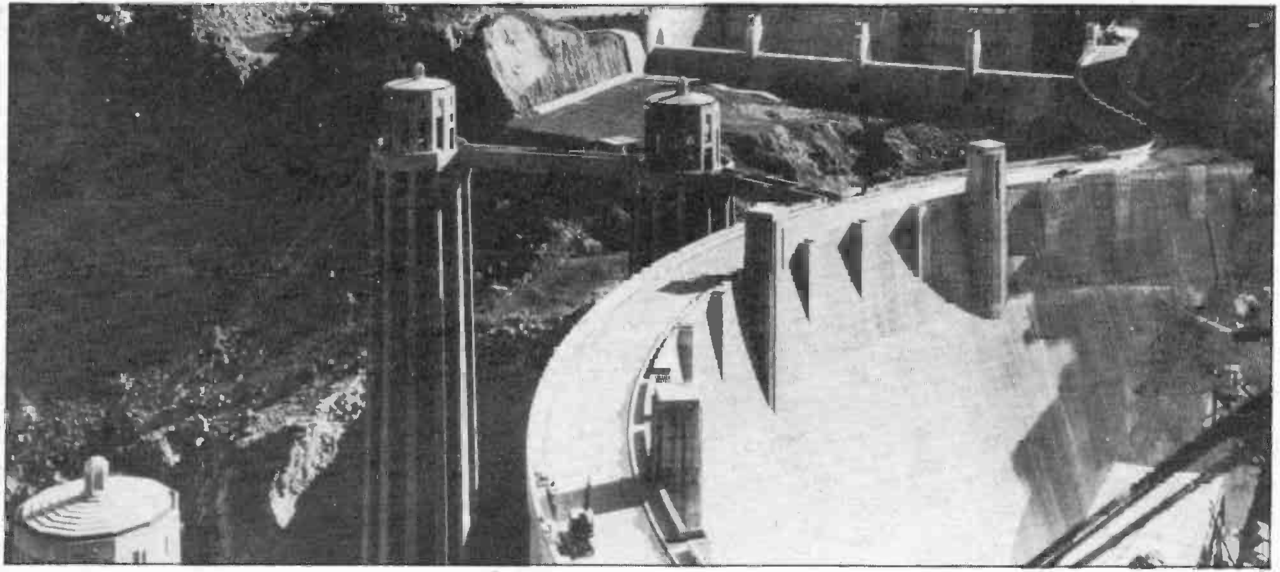

COYNE
PRACTICAL
Electrical and Rad
Books
for
PRACTICAL MEN
APPLIED
PRACTICAL
ELECTRICITY

COYNE
PRACTICAL APPLIED ELECTRICITY



ARIZONA BOULDER DAM

General view over the crest of Dam showing four lane highway that leads from Las Vegas, Nevada, to Kingman, Arizona. The highway winds down Black Canyon.

COYNE PRACTICAL APPLIED ELECTRICITY

A Set of Complete Practical Books

For Home Study

and

Field Reference

On

Electrical principles, telephones, wiring, meters, D.C. and A.C. motors, controls, and equipment, household appliance repair, Rural Electrification, Armature winding, Generators, Diesel Electric Plants, Automotive Electricity, Batteries, Electrical Refrigeration and Air Conditioning, Industrial Electronics, Radio Electric Welding — laws, rules, etc. — Over 3,000 subjects, 5,000 Electrical facts, thousands of photos and diagrams.

By

THE TECHNICAL STAFF

of the

COYNE ELECTRICAL SCHOOL

Printed in United States of America

FOREWORD

ELECTRICITY is the greatest force known to **mankind.**

ELECTRICITY is leaping ahead at an unbelievable rate. It is moving into practically every part of the world and has become **the most important factor in modern civilization.** Practically every month the Kilowatt hour demand sets a new high—it has been doing this for the past 25 years. ELECTRICITY, even though it is one of America's youngest industries, already employs directly and indirectly over 3 million people.

All of our marvelous developments in Radio, Television, Electronics, Radar, etc., employ **electrical** power and the principles of **Electricity.** It is truly **one of the world's greatest industries.**

Because of the tremendous opportunity in the field of **Electricity,** there have been many books written on the subject. Most treat with **one** specific phase of **Electricity.** This set of books — Coyne Practical Applied Electricity (of which this volume you now read is an integral part)—covers the entire field.

This set is NEW. It includes the very latest methods and explanations of Electrical installation, operation and maintenance.

COYNE PRACTICAL APPLIED ELECTRICITY WRITTEN BY A STAFF OF EXPERTS

Most Electrical publications are written by **one man** and can therefore **only** cover **his** own specific knowledge of a subject. COYNE PRACTICAL APPLIED ELECTRICITY, however, represents the combined efforts of the **entire Coyne Electrical School Teaching Staff and the assistance of other authorities on the subject.** These men have a wide field and teaching experience and practical knowledge in **electricity** and its allied branches.

HOW THIS SET WAS DEVELOPED

In submitting any material for these books these experts kept two things in mind — 1. MAKE IT SIMPLE ENOUGH FOR THE "BEGINNER"— 2. MAKE IT COMPLETE, PRACTICAL and VALUABLE FOR THE "OLD TIMER". All material that was submitted for these books by any individual was then rewritten by an editorial group so that added explanations for the benefit of clarity and easier understanding could be included.

You will note that in some places in this set we have explained and shown illustrations of the earlier types of Electrical equipment. We had a definite purpose in doing this, namely, that many of the earlier types of equipment are easier to understand. The basic principles of these earlier machines are the same as the modern equipment of today. Modern equipment has not materially changed in principle—it is merely refined and modernized. We have found that it is to these early beginnings we find it advisable to turn to get a more complete understanding of the present advanced types of electrical apparatus.

Coyne Practical Applied Electricity can pay you big dividends every day "on the job". However, if you only use the set occasionally when you MUST BE SURE before going ahead on a job—the set **will pay for itself many times over.**

Coyne Practical Applied Electricity is to an electrician what a set of complete law books is to a lawyer or a set of medical books is to a doctor. Regardless of whether a lawyer or a doctor is "just starting out" or is an "old timer" and has been practicing his profession for many years **he has**

many occasions to refer to his reference books. Many doctors and lawyers spend thousands of dollars on complete sets of reference books—they find it a very wise investment.

In ELECTRICITY the need for good reference books is just as great. So, when you make a purchase of this set you are not just buying a set of books—you are making an investment in your future that can pay dividends all your life.

H C Lewis

PRESIDENT
COYNE ELECTRICAL SCHOOL

ACKNOWLEDGMENTS

We wish to acknowledge and express our appreciation for the assistance and co-operation given by the following companies, in supplying data and illustrations for the preparation of this Electrical Set.

GENERAL ELECTRIC COMPANY
WESTINGHOUSE ELECTRIC & MFG. CO.
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AMERICAN BROWN BOVERI CO.
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WELSH SCIENTIFIC CO.
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TABLE OF CONTENTS

HOW TO USE THIS SET OF BOOKS

Coyne Practical Applied Electricity will be of use and value to you in exact proportion to the time and energy you spend in studying and using it.

A Reference Set of this kind is used in two distinct ways.

FIRST, it is used by the fellow who wishes to make Electricity his future work and uses this Reference Set as a home training course.

SECOND, it is especially valuable to the man who wishes to use it strictly as a Reference Set. This includes electricians, mechanics or anyone working at any trade who wishes to have a set of books so that he can refer to them for information in Electrical problems at any time.

You, of course, know into which group you fall and this article will outline how to properly use this Set to get the most value for your own personal benefit.

How To Use This Set As A Home Training Course In Electricity

The most important advice I can give the fellow who wishes to study our set as a home training course in Electricity is to start from the beginning in Volume 1, and continue in order through the other 6 volumes. Don't make the mistake of jumping from one subject to another or taking a portion of one volume and then reverting back to another. Study the set as it has been written and you'll get the most out of it.

Volume 1 is one of the most important of the entire Set. Every good course of training must have a good foundation. Our first volume is the foundation of our course and is designed to explain in simple language terms and expressions, laws and rules of Electricity, upon which any of the big installations, maintenance and service jobs are based. So, become thoroughly familiar with the subjects covered in the first volume and you will be able to master each additional subject as you proceed.

One of the improvements we made in this set was to add "review" questions throughout the books. You will find these questions in most cases at the end of a chapter. They are provided so "beginners" or "old timers" can check their progress and knowledge of particular subjects. Our main purpose in including the "review" questions is to provide the reader with a "yardstick" by which he can check his knowledge of each subject. This feature is a decided improvement in home study material.

Improved Method of Indexing

One of the features desired in any good electrical set is a good indexing system. Without it, any set doesn't mean much because a fellow cannot find out what he wants to know without spending a lot of time. When we planned this set of books we made sure it had the most modern system of indexing. Here is how these books are indexed. First, you will note at the front of all books that we have a TABLE OF CONTENTS. This outlines in a **general way what the book covers.** Then, at the back of each individual volume we have an INDEX of each specific subject covered in **that volume.**

In addition, we have a MASTER REFERENCE INDEX at the back of this volume. This is an index that lists ALL of the specific electrical & radio subjects in ALL of the volumes. This MASTER REFERENCE INDEX tells you the name of the electrical subject, the volume it is to be found in and where it can be found in that volume. This modern 3 way method of indexing gives you the opportunity to locate any subject covered in these books quickly and accurately.

For the special benefit of the fellow desiring to learn Electricity at home, we have prepared a great number of diagrams and illustrations. Refer to these pictures and diagrams in our books regularly.

How To Use This Set of Books

How To Use Coyne Practical Applied Electricity Strictly As A Reference Set

The man who is interested in using these books mainly for reference purposes will use it in a little different way than the fellow who is trying to learn Electricity as a trade. Some of the types of fellows who use this set strictly for reference purposes are: home owners, electricians or mechanics, garage owners or workers, hardware store owners, farmers or anyone who has an occasional use for electrical knowledge. Those types of fellows should use this set in the following manner.

Use The Master Index To Locate Electrical Subjects

If some particular type of electrical problem presents itself, **refer immediately to the Master Reference Index in this volume** — it will give you the section and volume of this set in which the subject is covered.

Then, turn to that section and carefully read the instructions outlined. Also read any other sections of the set mentioned in the article. As an example, in checking over some information on electric motors, some reference might be made to an electrical law of principles contained in Volume 1 of the Set. In order to thoroughly understand the procedure to follow in working out the electrical problem, you should refer to Volume 1 and get a better understanding of the electrical law on principles involved.

Thousands of men use this Set in their daily problems, both on the job and around the home as well. If you follow the instructions outlined you will be able to locate any information you may want at any time on your own electrical problems.

And here's a very important point. Although this set of books starts in Volume 1 and proceeds through the other 6 volumes in order, it makes an ideal home study course—nevertheless, **any individual book in the series is independent of the others and**

can be studied separately. As an example, Volume 3 covers D.C. motors and equipment. If a man wanted to get some information on D.C. machines **only** he could find it **completely covered in this volume** and it would not be essential to refer to any other volume of the set unless he wanted some additional information on some other electrical principle that would have a bearing on his problem.

This feature is especially beneficial to the "old timer" who plans to use the set mainly for field reference purposes.

We believe, however, that the entire set of 7 volumes should be read completely by both the "beginner" or the expert. In this way you get the greatest benefit from the set. In doing so the experienced Electrician will be able to get very valuable information on subjects that he may have thought he was familiar with, but in reality he was not thoroughly posted on a particular subject.

ELECTRICITY, AND HOW IT BEHAVES

Among all the ideas about what electricity is and how it acts there is one theory that will help us a great deal in understanding all electrical devices, even those of radio and electrochemistry. To explain this theory we may start by considering a **molecule.** A molecule is the smallest particle of any given substance. For example, a molecule of salt is the smalest particle of salt which may exist and still remain salt. If we further divide a molecule of salt we no longer have salt, but have one **atom** of the element sodium and one atom of the element chlorine.

Of the elements there are ninety-two in all, among them being sodium and chlorine along with such familiar things as iron and such unfamiliar ones as protoactinium. These elements combine in various ways to make up all known substances. Water, as you probably know, consists of two atoms of the element hydrogen and one atom of the element oxygen.

Every atom is believed to include in its makeup a central part, often called the proton, and around this central part one or more **electrons.** The central part of the atom remains fixed in its position, but under certain conditions some electrons may become separated from the atoms and wander loose or become associated with other atoms.

The electrons are considered to be particles of electricity itself. When electrons move through the body of a substance, as through a copper wire, we have moving electricity or the **electric current.** Application of sufficient electrical force will cause electrons to leave the substance and travel through the surrounding space. This is what happens in radio tubes, in television tubes, in X-ray tubes, and in fluorescent lamps.

No one has yet seen an electron. It has been said that an electron in an atom would be compar able in size to a fly in a cathedral. The atom, in turn, is far smaller than a molecule. And a molecule may be of such size that eighty million of them side by side would extend for one inch, and of such weight that ten million, million of them would weigh about five millionths of a millionth of an ounce. From this you see that an electron is almost unbelievably small.

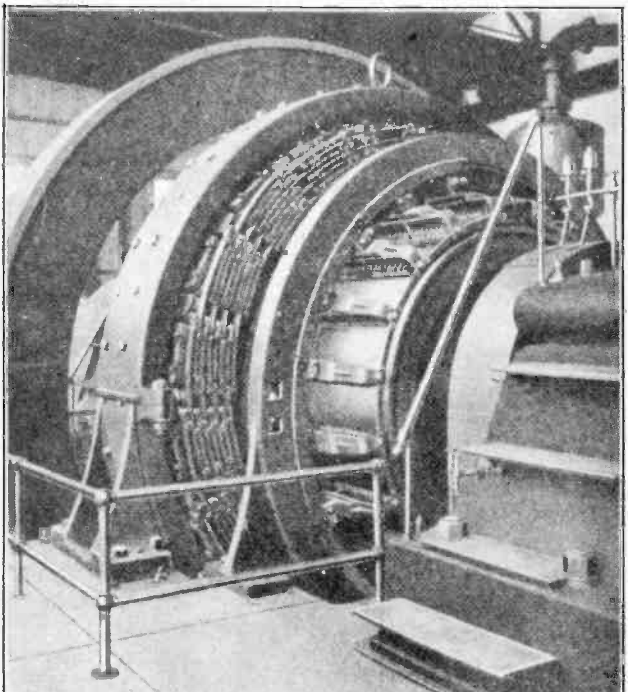


Fig. 5. Large D. C. generator. It is rated as follows, 2000 Kw., 250 V., 8000 I. After carefully reading the pages on units and symbols, you should easily understand this rating.

Even more important than knowing what electricity really is, is to know how it can be controlled, how to select, install and maintain electrical equipment, and what to do when things go wrong. Then you can handle machinery as big as the generator of Fig. 5. It is important to learn enough about the rules and laws governing the behavior of electricity so that you may think for yourself in any emergency. This does not mean that you need study electrical engineering, for that involves higher mathematics and other sciences, but it does mean that you should be thoroughly conversant with practical electricity or applied electricity.

WHAT ELECTRICITY WILL DO

Before getting on with our classification of electrical apparatus and devices there are two facts about electricity that should be understood.

To begin with, energy may exist in many different forms such as mechanical energy, chemical energy, electrical energy, heat energy, light energy, physical energy, etc. According to a basic law, these different types of energy cannot be created, nor can they be destroyed; however, they may be readily converted from one form to another.

First: at least ninety-nine per cent of all useful applications of electricity require that the electricity be in motion. Electricity standing still is no more useful, so far as doing work is concerned, than is a stationary belt between a steam engine and a machine which is to be driven. Electricity in motion is called the electric current. If you knew all there is to know about the behavior of moving electricity you could stop right here and get a job at fifty or a hundred or more thousands of dollars a year—for you would know more than anyone else who ever has lived.

Second: electricity in motion, or the electric current, provides the most effective means ever discovered for carrying energy from one place to another, and of changing one form of energy to another form of energy. To make this statement clearer we should know the meaning of energy.

Energy enables you to shovel coal. Energy is the ability to do work. The physical energy you put to use when shoveling coal is converted to energy of motion. The whirling fly-wheel of a steam engine or a gasoline engine contains energy of motion, which we may call mechanical energy. Any and every moving object contains this kind of energy.

The stone thrown by a small boy contains energy of motion, which will do the work of breaking a window.

Heat is another form of energy. As you well know, heat will do many kinds of work. In Fig. 6 heat from burning coal does the work of changing water into steam, and expansion of the steam runs the steam engine to produce energy of motion. This energy of motion is carried by the belt to the

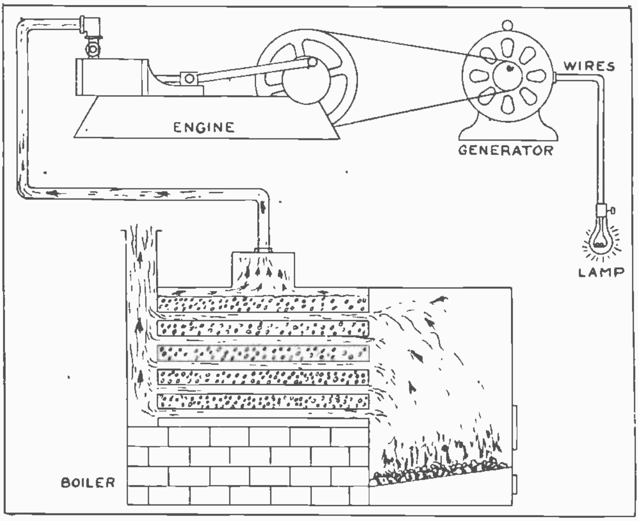


Fig. 6. Sketch showing how heat energy of coal is changed into mechanical energy by the engine, then to electrical energy by the generator, and into heat and light again by the lamp.

electric generator, which converts this mechanical energy into electrical energy. The energy which is in the moving electricity is changed in the lamp to a great deal of heat energy and also to quite a bit of the energy which is light.

Light is a form of energy because it will produce electric current in a photo-voltaic cell, will regulate flow of electricity through a phototube, will change the rate at which electricity may flow through a piece of selenium, and will do the work of producing a latent image on the photographic film in your camera.

Electricity, and How It Behaves

The dry cell in your flash lamp and the storage battery in your automobile contain chemical energy. When chemical changes take place in the flash lamp cell or the automobile battery these changes produce the energy which is electric current. This moving electricity will produce heat and light in the flash lamp or in an automobile headlamp, will produce motion in an automobile starting motor, will produce sparks at the spark plugs in the automobile engine, and will produce sound from the auto horn.

Sound is a form of energy, because sound waves really are vibratory movements of air or other substances through which sound travels. Any motion requires energy.

One of the most important and interesting kinds of energy is radiant energy which travels through a complete vacuum even better than through air, and which will travel through other gases, liquids, and even through solids. It is radiant energy, or radiation, which is responsible for the transmission of radio signals, for X-rays, for the radiant heat that comes to the earth from the sun through 93 million miles of empty space.

By the use of suitable apparatus any form of energy may be converted to electrical energy. Mechanical motion, heat, light, chemical energy, sound, and radiation—all are capable of producing an electric current.

The energy of the electric current, or of electricity in motion, may be converted to any other form of energy—mechanical motion, heat, light, chemical energy, sound, or radiation. It is just a matter of using appropriate apparatus.

Now we are commencing to get at the reasons why electricity in motion is the greatest and most important force in the world. It is the universal means for changing one kind of energy into other kinds. It is the only means by which we may transmit power in large quantities from where it is cheaply or conveniently produced to somewhere else, hundreds of miles away, where the power may be used to advantage.

ELECTRICAL CONDUCTORS

Many of the electrons in a piece of copper are easily separated from the atoms. That is, the application of a relatively small amount of electrical force will cause great quantities of electrons to separate from the atoms and move through the copper. Since movement of electrons means that we have an electric current, we are saying that it takes but little electrical force to produce a large electric current in copper. The same electrical force applied to silver will cause slightly greater quantities of electrons to break away from atoms and move through the silver. The same force applied to hard steel will cause movement of only about one twenty-fifth as many electrons as would be moved in copper, or would produce a current only one twenty-fifth as great.

Here is a list showing the relative numbers of electrons which will be moved by a given electrical force in a number of metals and in graphite. Of course, this list shows also the relative rates of current flow in these substances.

Silver	1,058
Copper	1,000
Gold	706
Aluminum	610
Zinc	295
Nickel	172
Platinum	157
Steel, soft	108
Lead	84
Nickel silver	52
Steel, hard	38
Cast iron	20
Mercury	17
Nichrome	17
Graphite	2¼

As you quite likely know, the electrical force about which we are talking is measured in a unit called the **volt**. It takes an electrical force or pressure of 100 to 120 volts to drive electricity through an ordinary household incandescent lamp at a rate which causes the lamp to light with normal brilliancy. Each small dry cell in an electric flash lamp is capable of delivering a force or difference in pressure of 1½ volts. Each cell of an automobile storage battery is capable of delivering a force of 2 volts, and in the usual three-cell battery there is available a total force of 6 volts.

Any substance in which an electrical force or electrical difference in pressure will separate relatively large quantities of electrons from the atoms, and cause the electrons to move in a steady flow through the substances, is called an **electrical conductor.** Not only all the metals in our list, but all other metals are conductors. Some, like copper and aluminum, are good conductors—meaning that they permit flow of many electrons or of a large current with relatively little force. Others, like soft steel, are fair conductors. Still others, like Nichrome, are very poor conductors and are used where we wish deliberately to hinder or resist the flow of electric current.

Copper is by far the most important electrical conductor, both because of the ease with which it permits flow of current and because of its abundance and low cost. Next in industrial importance comes aluminum, and third is steel. Steel frequently is used not only in electric wires, but also where it already forms part of a structure or framework in which it is desired to carry the electric current. Some liquids are excellent conductors, notably water in which has been mixed any kind of salt or any acid.

INSULATORS

If two copper wires or other conductors should touch each other while carrying electric currents, electricity from one conductor would pass into the other and thus would escape from the path which we desire to have it follow through the first conductor.

To prevent the escape of electric current from conductors into other conductors or into human bodies, all current-carrying conductors should be surrounded and isolated or supported by materials which are not conductors. **Any material which is not a conductor is called a non-conductor or an insulator.**

Insulators or insulating materials include all substances in which it is very difficult to cause a flow of current with any electrical force which may be applied. Among the insulators which are most useful in electrical work are the following:

Porcelain	Paper
Glass	Cotton
Mica	Linen
Bakelite and similar compounds	Silk
	Various oils
Hard rubber	Various waxes
Soft rubber	Air

In an insulating material it is possible for an electrical force to drive many of the electrons a little way out of their normal positions in the atoms, but nearly all the electrons still remain bound to their atoms and will return to their normal positions the instant the electrical force is removed. In an insulator it is impossible to free more than a very few electrons from the atoms, or to produce more than the most minute trace of electric current.

Supposing the insulating material were a sheet of glass about ⅜ inch thick. Depending on the kind or grade of glass, no appreciable current would flow through it until you had raised the pressure to somewhere between 300,000 and 1,500,000 volts, or to between three thousand and fifteen thousand times the pressure needed in an incandescent lamp. At that terrific pressure the glass would puncture, the electric pressure would force a hole right through the glass. Then current would flow through the air in the hole, because it takes a force of only about 10,000 volts to force electricity through ⅜ inch of air.

Instead of the sheet of glass supposing you were to use a small cube of glass measuring ⅜ inch on one side. The opposition of that piece of glass to flow of current through it would be a thousand million, million, million times as great as the opposition of a piece of copper of the same size. The rate of current flow through the glass would be correspondingly smaller than through the copper, and, as you will agree, could be called infinitesimal.

Every insulating material mentioned in the preceding list has millions and millions of times the opposition or resistance to flow of current that is offered by any of the metals, by graphite, or by conductive liquids. Were it not for this fortunate fact we would have no more success in keeping electricity within the paths which we wish it to follow than would a plumber with water if he had no pipes or other devices to confine the water.

AN ELECTRICAL SYSTEM

We started out to talk about a classification into which might be fitted the parts of any electrical installation, but had to wander rather far afield in getting ready to understand our classification. However, we finally are ready to go ahead.

To begin with we must have available some form of energy. In the case of the dry cell or some other type of "primary" cell or battery, the original energy comes from nothing electrical. Even with the cells and batteries the original energy is not electrical but is chemical. The source of energy may be mechanical motion, heat, light, sound, or radiation. Having the original source of energy we may proceed to the electrical groups, which are as follows:

Group 1. Devices which change the original non-electrical energy into moving electricity or into electric current. Here we shall have electric generators or dynamos like that of Fig. 7, also storage batteries, thermocouples, photovoltaic cells, and piezo-electric crystals.

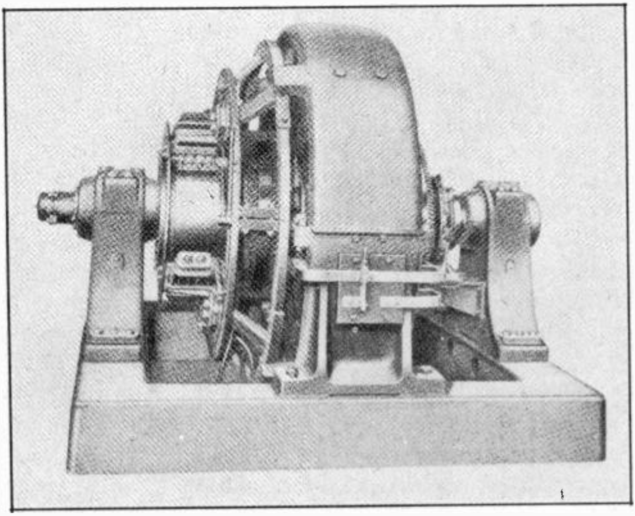


Fig. 7. Photo of a large generator, which produces its voltage by induction.

Group 2. Electrical wiring. This group includes all the conductors which carry the moving electricity from place to place, also the insulators which prevent the escape of electricity from the conductors. In outdoor and long-distance systems this group would include the transmission and distribution lines.

Group 3. Controlling mechanisms; chiefly hand-operated and automatic electric switches of many kinds.

Group 4. Devices which alter the rate of flow, the difference of pressure, or some other characteristic of the moving electricity. This group includes transformers, converters, inverters, motor-generators and other apparatus with which we shall become well acquainted.

Group 5. Meters or measuring instruments for indicating, and sometimes for making records of, the conditions existing in all parts of the electrical system.

Group 6. Apparatus for changing the energy of the moving electricity into some other form of energy which we wish to use. This is a big group. In it we shall find motors, like that of Fig. 8, electromagnets, storage batteries, electrochemical vats, electric arcs, electric furnaces, various inductors or coils, electrical resistors, many varieties of lamps, radiating systems for radio transmitters, electrical discharge devices, and many other parts which are of importance in certain lines of work. All these devices use the electric current to produce mechanical motion, heat, light, sound, chemical changes, or radiation.

A TYPICAL SYSTEM

To learn how our classification will work out when applied to an actual electrical system let's examine the electrical parts used on an automobile. We select the auto-electric system because you probably are more familiar with the starter, lamps, horn and ignition for an automobile.

Fig. 9 shows the auto-electrical parts which we shall consider first. The initial source of energy is the automobile engine which produces mechanical motion. From here we may go on with our classification according to the numbered groups as previously listed. Corresponding numbers are on Fig. 9.

Group 1. The generator receives mechanical energy of motion from the engine through a belt, and changes this mechanical energy into electrical energy. Compare this with our original definition of group 1.

Group 2. Electric current flows to the battery through a copper wire covered with insulation, and from the battery flows through the steel of the automobile chassis back to the generator.

Group 3. The cutout is an automatic electrical switch which, when the generator has attained speed sufficient to force electricity through the battery, connects the internal parts of the generator to the wire going to the battery. The cutout is our controlling mechanism.

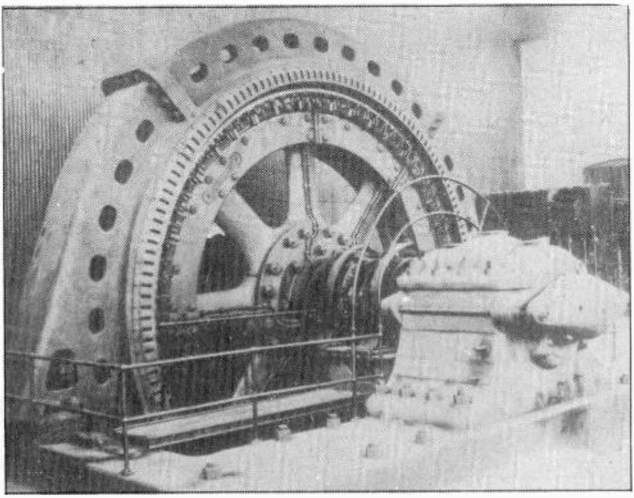


Fig. 8. Type 1-28/56-6500 HP 107/53-6600 Volt Form M Induction Motor with changing switch installed in the 60 in. Universal Plate Mills, Illinois Steel Company, Gary, Indiana.

Group 4. In the system of Fig. 9 the generator is designed and automatically regulated to produce just the right amount of force and other characteristics in the electric current so that this current will produce the desired chemical changes inside the battery. Consequently, in this part of the auto-electric system we require no additional devices for changing the kind of current which is being produced.

Group 5. The ammeter is our measuring instrument which indicates the rate at which electricity moves through the generator and battery.

Group 6. Flow of electric current through the battery produces chemical changes in the plates and liquid inside the battery. Energy is stored in the battery in the form of chemical changes, and later on this chemcial energy will be changed back into electric current for operating the starting motor, for producing sparks at the spark plugs, for lighting the lamps, and for blowing the horn.

In the system of Fig. 9 we started out with mechanical energy taken from the engine and ended with chemical energy stored in the battery. Probably you already knew that a storage battery does not store electricity in the form of electricity, but simply undergoes internal changes during the "charging" process which enable the battery later on to produce electric current while it is "discharging."

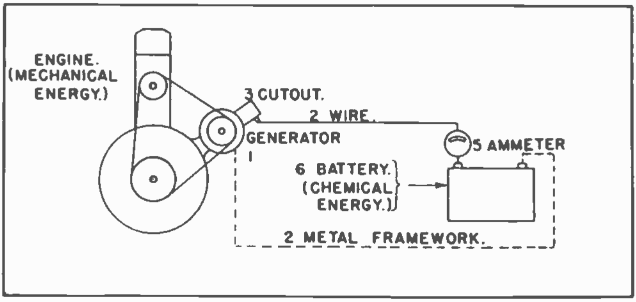


Fig 9 A Portion of the Auto-electric System.

AN ELECTRIC CIRCUIT

The electrical parts and wires in Fig. 9 make up what we call an **electric circuit.** Fig. 10 is a simplified diagram of this circuit in which the parts are represented by "symbols" rather than by pictures. These, and other standard and universally recognized symbols, make it easy for anyone to quickly draw correct electrical diagrams that are understood by everyone else in the business.

An electric circuit is the complete conductive path through which flows, or may flow, an electric current.

A circuit always must include at least the four things which we now shall list.

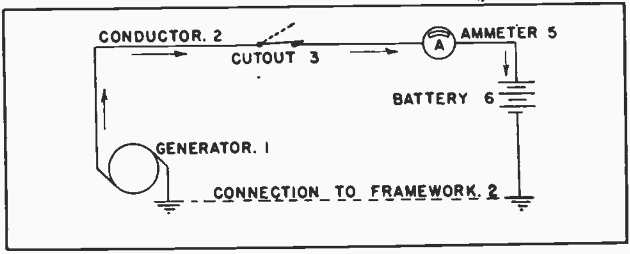


Fig. 10. Simplified Diagram of the Auto-electric System.

First. The circuit must include a source of current, meaning that there must be a generator or some other device which uses some kind of non-electrical energy and which produces a flow of electricity or an electric current. Maybe it should be mentioned that the reason we do not have a generator or similar apparatus in every house lighted by electricity is that the circuit starts from outside the house.

Second. The circuit must include one or more devices which will change electrical energy into some other form of energy such as chemical energy, heat, light, mechanical motion, and so on. It might be natural to argue that one could connect a single length of wire from one terminal of a battery to the other terminal and thus let current flow without going through anything which produces some other form of energy. But current flowing through that wire would heat the wire, and the wire itself would be a device which changes the electrical energy into the energy which is heat.

Even though the heat from the wire might be wasted, it still would be produced. We may waste any kind of energy, but cannot destroy it. The only thing that can happen to one kind of energy is to change to some other kind. That is a fundamental law of nature.

Third. The electric circuit must include a continuous conductor or a succession of joined conductors through which electricity may flow from the source of current to the devices which use the current to produce some other form of energy.

Fourth. The electric circuit must include also a continuous conductive path from the device which uses electric current back to the part which produces the current. Since everything consists of molecules and atoms, and all atoms contain electrons, everything is full of electricity (electrons) to begin with. All we can do is pump them around a circuit. You cannot continue pulling electrons out of the wires inside a generator without letting replacement electrons re-enter the generator, nor can you continue pushing electrons into a battery or anything else without letting an equal number move out and back to the source. Fig. 11 shows a circuit which includes a generator, a switch, a motor, and the necessary conductors.

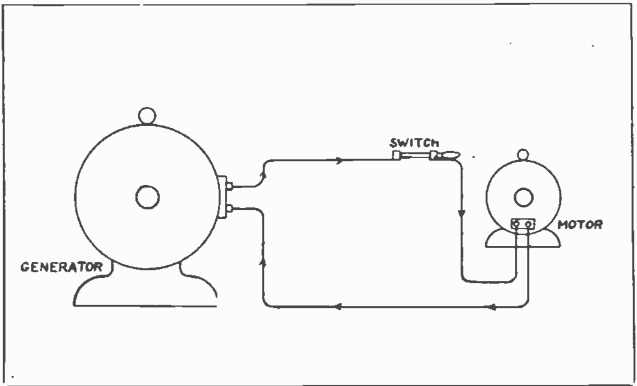


Fig. 11. Complete electric circuit. The current flows over the top wire from the generator to the motor, then back along the lower wire to the generator.

The idea of having a complete electric circuit, out and back, is much the same as having to have a complete and unbroken belt between a steam engine and a machine to be driven. If the belt cannot come back from the machine to the engine flywheel or pulley it won't long continue to move out from the engine to the machine. If you cut either side of the belt you will prevent transfer of energy from the engine to the machine. It makes no difference which side of the belt you cut. Just as truly you will prevent transfer of electrical energy from a source of current to a consuming device if you open either side of the circuit. It makes no difference which side. Many hopeful "electricians" have tried to beat this rule, but none have succeeded.

MORE ELECTRIC CURRENTS

Let's go on to Fig. 12 where we have represented most of the remaining parts of the automobile electrical system. Now we shall assume that the engine and generator are idle, and that the cutout has acted to open the circuit between generator and battery. This leaves chemical energy in the battery as our original source of non-electrical energy. Now for our six groups.

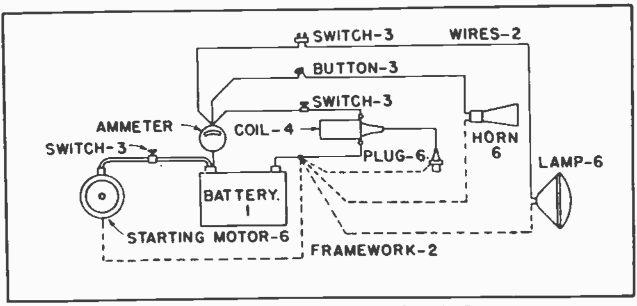


Fig. 12. More Parts of the Auto-electric System.

Group 1. The battery is not only the source of chemical energy, but is also the device which changes this energy into electric current.

Group 2. The battery is connected through wires and through the metal of the automobile framework to the lamps, the horn, the starting motor, and the ignition coil. The coil, in turn, is connected to the spark plugs. This is our wiring,

Group 3. Our controlling mechanisms include the lighting switch, the horn button, the starting switch, and the ignition switch.

Group 4. The maximum difference in pressure (in volts) which the battery can develop is not enough to force electricity across the air gaps in the spark plugs and produce the intensely hot arc that ignites the mixture of gasoline and air in the cylinders. Consequently, we must employ the ignition coil, a device which uses current at the electrical pressure supplied by the battery and furnishes a pressure sufficient to force electricity across the spark plug gaps. The ignition coil is a kind of electrical transformer which converts the 6 volt pressure we have available into a pressure of 10,000 volts or more, suitable for the job to be done.

Group 5. The ammeter which previously we have used to indicate the rate at which electricity flows through the generator-battery circuit is now used to indicate the rate at which electricity flows through the battery and the lamps, the horn, and the ignition coil. In actual practice we probably would not carry horn current through the ammeter. The rate of current flow through the starting motor is so great that it would ruin this small ammeter, so the starting current is not carried through the meter.

Group 6. The apparatus which changes energy of the moving electricity into other forms of energy includes (1) the lamps which produce the energy which is light, (2) the horn which produces the energy which is sound, (3) the spark plugs which produce the energy of heat, and (4) the starting motor which produces the energy of mechanical motion.

In the whole automobile electrical system (Figs. 9 and 12) we commenced with mechanical energy of motion from the engine, changed it to electrical energy in the generator, then to chemical energy in the battery, then changed this chemical energy into light, sound, heat, and more mechanical energy or motion. All electrical systems are like that, just changing one kind of energy into other kinds which suit our needs.

QUANTITIES OF ELECTRICITY

Quantities of potatoes are measured by the bushel, quantities of water may be measured by the gallon or by the cubic foot, and for everything else there are various units in which their quantities may be measured. Quantities of electricity are measured by the coulomb. A coulomb is just as definite a quantity of electricity as is a cubic foot a quantity of water.

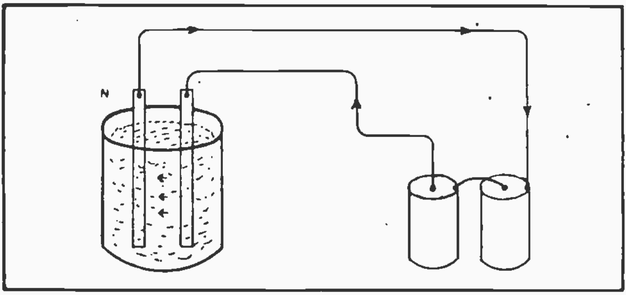


Fig 13. A "Voltammeter" Which Measures Quantities of Electricity.

We might define the coulomb by stating the number of electrons in a coulomb, but rather than get into figures running into uncountable billions of electrons we define a coulomb by stating what it will do. In Fig. 13 the jar at the left contains two copper plates immersed in a solution of silver nitrate, with the plates connected to a battery which will cause a flow of electricity. When one coulomb of electricity flows through the solution from one plate to the other this much electricity will take out of the solution and deposit on one of the plates about 1/25000 ounce of silver. Whether this quantity of electricity passed in a second, an hour or a month, it still would take with it and deposit the same amount of silver.

Except in the eletroplating of metals and similar jobs we seldom need talk about quantities of electricity such as might be measured in coulombs, but an understanding of the coulomb as a unit of quantity makes it easier to understand the real meaning of electric current and how current is measured.

ELECTRIC CURRENT

In order to turn a water wheel so that it will furnish a desired amount of driving power it is necessary that water flow over or through the wheel at a rate of some certain number of cubic feet (or gallons) per second. We may define the rate of water flow as so many cubic feet per second. Just as the rate of flow of water is measured in so many cubic feet per second, so is the electric current measured in so many coulombs per second.

In order to light the ordinary "60-watt" electric lamp bulb to normal brilliancy electricity must flow through the filament in the bulb at a rate of about one-half coulomb per second. To keep a household flatiron normally hot the electricity must flow through the flatiron at a rate of about eight to nine coulombs per second. To run a small fan the electricity must flow through the fan motor at about four-tenths coulomb per second. In none of these cases are we talking about the speed or velocity with which the electricity or the electrons pass through the lamp, flatiron or fan. We are talking about rates of flow in the sense that certain quantities of electrictiy pass through the part in a given period of time.

When electricity flows at a rate of one coulomb per second we say that it flows at a rate of one ampere. This unit of flow (really one coulomb per second) was named the ampere to honor Andre Marie Ampere, a French physicist and scientific writer who lived in the early part of the last century. We should remember that the ampere means a rate of flow of electricity.

Instead of saying that the electric lamp requires a flow of one-half coulomb per second we say it requires a flow of one-half ampere. Similarly, the flatiron takes a flow of eight to nine amperes, and the fan motor takes about four-tenths ampere.

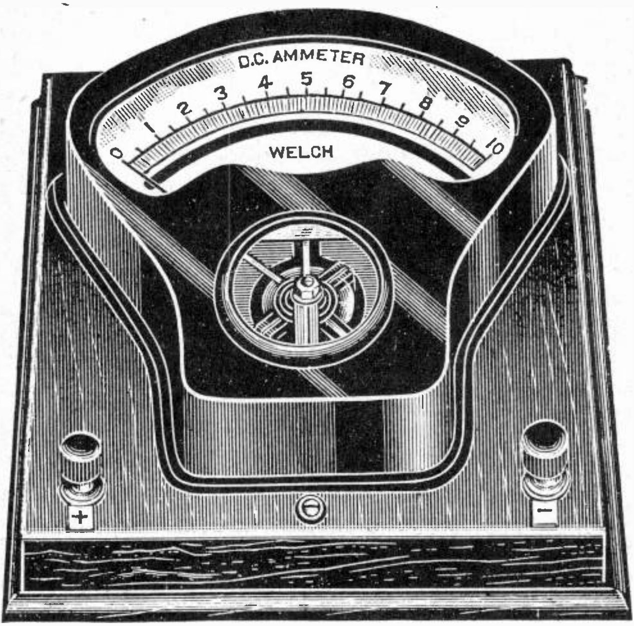


Fig. 14. An Ammeter for Measuring Electric Current Flow.

Rates of flow in amperes are measured and indicated by an instrument called the ammeter, such as pictured in Fig. 14. Fig. 15 illustrates how this and other types of meters are used in practical work.

AMPERE-HOUR, ANOTHER QUANTITY

A coulomb of electricity is a very small quantity, and that unit is too small for convenient use in many kinds of electrical measurements. A more convenient quantity, and one more often used, is the ampere-hour. One ampere-hour of electricity is the quantity that would flow when the rate is one ampere and the flow continues steadily for one hour. The ampere-hour is a unit much used in storage battery work, electroplating, and similar electrochemical processes.

There are 3,600 seconds in one hour. One coulomb of electricity passes during each second when the rate is one ampere. Therefore, in 3,600 seconds the total quantity will be 3,600 coulombs, and we find that one ampere-hour is equal to 3,600 coulombs of electricity.

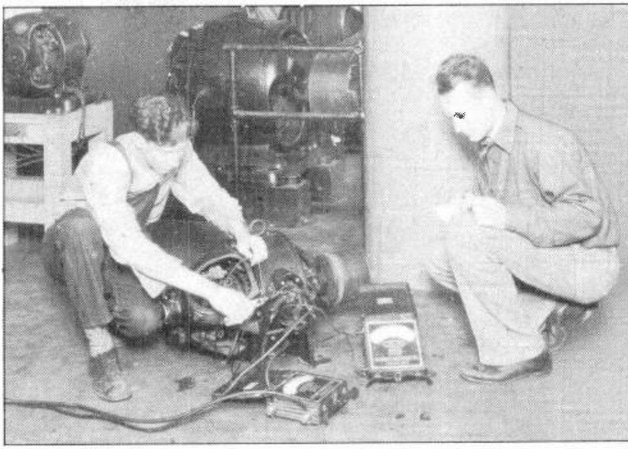


Fig. 15. Using Meters To Test the Operation of an Electric Motor.

ELECTROMOTIVE FORCE

We have learned that all substances are made up of molecules and atoms, and that all atoms contain electrons, which are negative electricity. Consequently, all substances are full of electricity all the time. But in a wire or other conductor there is no particular tendency for the electricity to move, and form an electric current, until some force is applied to the electrons. Forces which move or tend to move electricity arise from mechanical energy of motion, from chemical energy which alters chemical makeup of substances, from light energy, or other forms of energy as these forms are changed into electrical energy.

One of the commonest examples of changing chemical energy into electrical energy is the storage battery used in automobiles. The chemical conditions in a "charged" battery are represented by one of the diagrams in Fig. 16, which shows the active materials or the materials which undergo changes. The positive plate material is oxygen and lead, the negative plate material is lead alone, and the liquid in which they are immersed

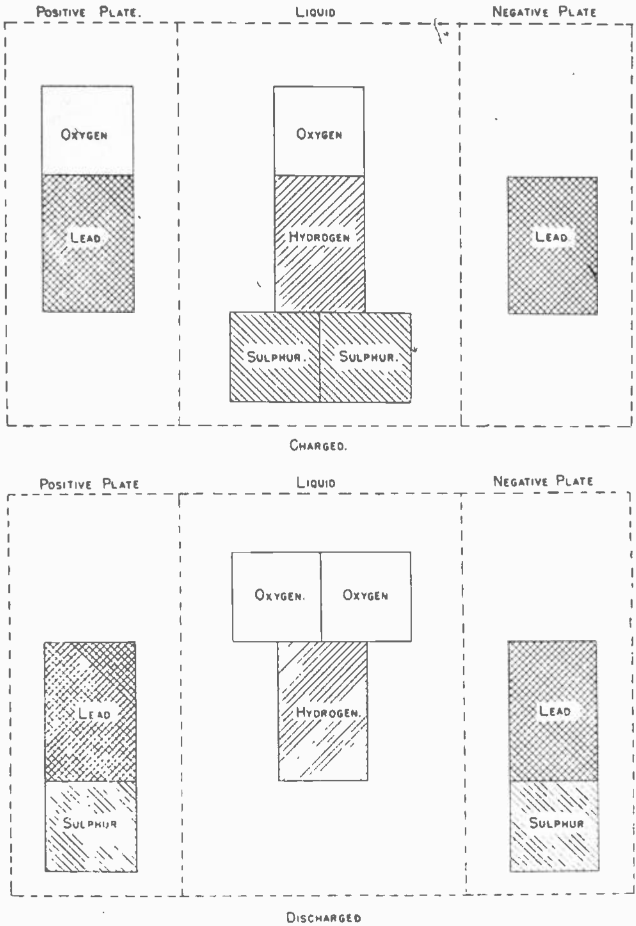


Fig. 16. Chemical Changes in a Lead-acid Storage Battery Cell.

consists of oxygen, hydrogen and sulphur (sulphuric acid). These chemicals do not like to remain in the combinations shown. They are under a strain, and may be thought of as containing pent up chemical energy.

The chemical energy in the charged battery can accomplish nothing until we connect the positive and negative plates to an external circuit in which electricity may flow. Then things commence to happen inside the battery as the chemical energy changes into electrical energy. As shown in the diagram marked "discharged," the oxygen from the positive plate goes into the liquid. The sulphur that was in the liquid splits up, part going into the positive plate and part into the negative plate. So long as these chemical changes continue, the chemical energy changes into electrical energy and changes into a force that causes electricity to move through the battery and around the external circuit.

If we keep the circuit connected to the battery tor long enough, both plates will contain lead and sulphur (sulphate of lead) and the liquid will consist of two parts of oxygen and one of hydrogen, which form water. If electricity is forced to flow through the battery in a reversed direction, oxyge. will leave the liquid and rejoin the lead in the positive plate, and sulphur will leave both plates and go into the liquid. Then the battery has been re-charged, again contains pent up chemical energy, and is again ready to change this energy into electrical energy.

We have examined one method of producing a force which will move electricity or which will produce an electric current. Later we shall examine a method which changes mechanical motion into a force that causes electricity to move.

The forces produced when some other form of energy is changed into electrical energy act with reference to the electricity as do the pressure differences that are applied to water in a hydraulic system. Just as hydraulic differences of pressure tend to cause flow of water, so do differences of electrical pressure tend to cause flow of electricity. An electrical pressure difference or force that moves or tends to move electricity, and form a current, is called an **electromotive force.** The abbreviation for electromotive force is **emf.** We generally speak of such a force as an "ee-em-eff", pronouncing the letters of the abbreviation rather than using the full name.

Devices such as batteries and generators in which some other form of energy changes to electromotive force are called energy sources, since they are the source of the force or energy which causes current to flow. They are not sources of electricity but only of energy in the electrical form, because they produce no electricity but merely place electricity in motion.

The electromotive force produced in a battery, generator or other current source is measured in a unit called the volt, named in honor of Count Volta, an Italian physicist who lived about 200 years ago. The volt is a measure of the difference in electric pressure or electric force, much as the unit called pounds per square inch is a measure of water pressure, steam pressure, and other pressures or forces. A dry cell produces an emf of about 1½ volts, a storage battery cell produces an emf of about 2 1/10 volts, and electric generators or dynamos produce emf's from a few volts up to thousands of volts, depending on the construction of the generator.

ELECTRICAL RESISTANCE

We have said before that the electric current consists of moving electrons which have been temporarily separated from atoms and which travel among the atoms as they progress through the conductor. Movement of the negative electrons through a conductor is opposed not only by the attractions existing between them and the positive parts of the atoms, but by constant collisions of the moving electrons with other electrons and with the atoms.

The degree of opposition to electron flow depends largely on the structure of the conductor—in other words on the kind of material of which the conductor is made.

The opposition of a conductive material to flow of current acts in many ways as does the opposition of piping to flow of water through it. Water flows less freely through a pipe that is rough or corroded on the inside than through an otherwise similar pipe that is smooth and clean. This effect is similar to that of different materials in electrical conductors. For instance, electricity flows much less freely through a steel wire than through a copper wire of the same size and length.

There is no simple unit in which we may define or measure the opposition to flow of water through pipes. We would have to say that a given difference in pressure in pounds per square inch causes a flow of so many cubic feet per second or minutes. But the opposition of a conductor to flow of electricity through it is measured in a simple unit called the ohm. Like other electrical units this one is named after a man, in this case after Georg Simon Ohm, a German scientist, who lived long ago.

Opposition to flow of electricity is called electrical resistance. One ohm of resistance is that resistance which permits electricity to flow at a rate of one ampere when the force causing the flow is one volt. The resistance of the filament of a lighted 60-watt electric lamp is about 220 ohms. The resistance is only one ohm in about 390 feet of the size of copper wire most often used in the electrical wiring for houses. The resistance of materials used for electrical insulators runs into billions of ohms.

It is quite apparent that the greater the resistance of a conductor or of an entire circuit to flow of current through it, the less current will flow with a given applied voltage, or the more voltage will be needed to maintain a given rate of flow. When we say that a resistance of one ohm permits a current of one ampere with a difference in pressure of one volt, we say also that a difference in pressure of one volt causes a flow of one ampere through a resistance of one ohm, and that a current of one ampere will flow through a resistance of one ohm when the difference in pressure is one volt. This simple relationship between the units of resistance, pressure and current is going to make it very easy to solve all manner of electrical problems.

TERMINAL VOLTAGE

We have learned that an energy source, such as a battery or generator, produces electromotive force measured in volts, by changing chemical or mechanical energy into electrical energy. Batteries, generators, and other kinds of energy sources have within themselves various kinds of electrical conductors which form a path through which electricity may flow through the source itself. Were there no conductive path through a source, electricity could not be moved around and around the circuit consisting of the outside connections and the source itself. Like all conductors, those inside a source have more or less electrical resistance. Part of the electromotive force is used up in sending the current through this internal resistance of the source, and only the remainder is available for sending current through the external connections or the external circuit.

The portion of the generated emf that is available at the terminal connections of a source, and which may be used for sending current through the external circuit, is called the terminal voltage of the source. The number of volts available from a source should not be called emf, but should be called the terminal voltage, if we wish to distinguish between the total force or pressure difference produced and that which remains for use outside the source. All electrical pressures differences, wherever they exist, may be measured in volts.

DROP IN VOLTAGE

Consider the water circuit of Fig. 17. In this circuit there is a water pump which changes mechanical energy from its driving belt into the energy contained in moving water, and which furnishes the difference in pressure required to keep water moving around the circuit. At one point there is a pipe coil containing a good many feet of pipe. At several points are gauges which indicate water pressures in pounds per square inch. Water is assumed to flow in the direction of the arrows. In common with the electrical current, it always flows from a point of higher pressure to a point of lower pressure.

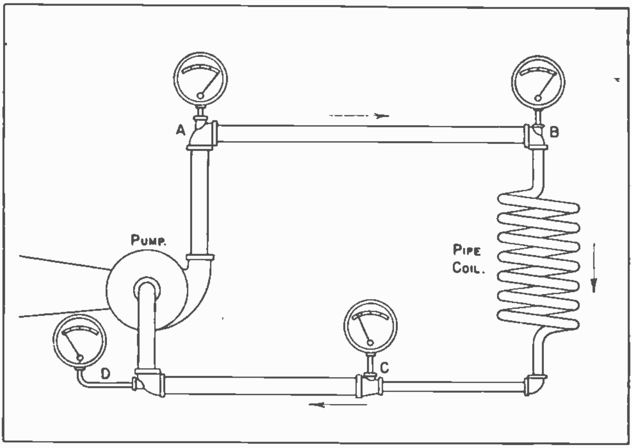


Fig. 17. Water Circuit In Which There Are Drops of Pressure.

It is certain that all pressure difference available from the pump must be used in sending water around the circuit, for there is no pressure at the inlet side of the pump. It is quite apparent, too, that all the pressure available from the pump won't be used up at any one place in the water circuit, but will be used in accordance with the oppositions to flow encountered by the water as it moves around the piping.

The gauge at A will show a pressure almost as high as the total available from the pump, because it takes but little force or pressure to get water from the pump to **A**. It takes some force or pressure to send water through the pipe from **A** to **B**, so the gauge at **B** shows a pressure a little lower than the one at **A**. The pressure at **A** must be enough to drive water from here all the rest of the way around the circuit and back to the pump, but the pressure at **B** need be only enough to drive water from this point back to the pump.

The coil in Fig. 17 is made of a long length of rather small pipe. It takes quite a bit of our available pressure to send water through all this pipe, so the pressure remaining at **C** will be considerably less than we had at **B**. The pressure remaining at **C** must be enough to send water from here back to the pump, but no more. At **D**, the pump inlet, the pressure is zero.

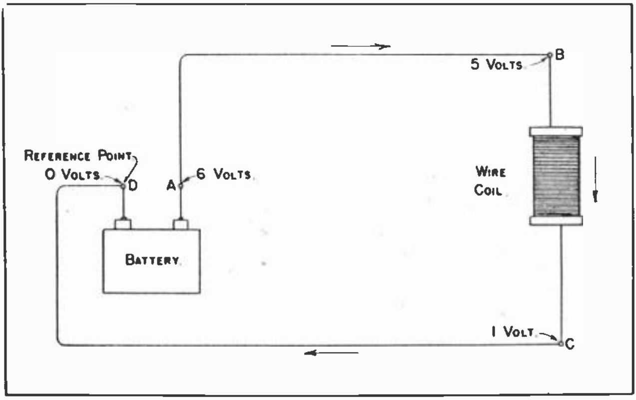


Fig. 18. Electric Circuit In Which There Are Drops of Potential and Differences of Potential.

Fig. 18 represents an electric circuit quite similar to the water circuit of Fig. 17. In this electric circuit there is a battery from which, after using part of the emf to overcome resistance within the battery, there remains a pressure of six volts at one of the terminals. The pressure at the other battery terminal is zero, just as pressure is zero at the point where water returns to the pump in the water circuit. Therefore, the difference in pressure between the terminals is six volts.

The entire six volts is used up between **A** and **D** in the electric circuit, for we start out with six volts and end up with no volts. But, as with the water circuit, all the pressure is not used up in sending electricity through any one part of the circuit, but rather it is used as required to overcome the resistance in various parts of the circuit. The greater the resistance in any section of the electric circuit the more pressure must be used up in that section to force electricity through its resistance.

In Fig. 18 we assume that it takes only one volt of pressure to overcome the resistance of the wire from **A** to **B**, but that in the long length of wire in the coil it is necessary to use up four volts of pressure, which is the difference between the pressures at **B** and **C**. The remaining one volt of pressure sends electricity through the wire from **C** back to the battery.

The pressure in any electric circuit undergoes a continual drop as we progress around the circuit and use up the pressure in overcoming resistance of different sections. The pressure is greatest at one side of the source and is least at the other side.

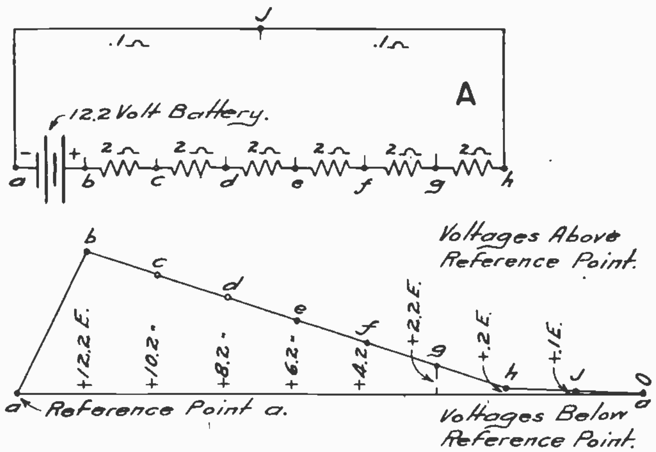
DIFFERENCE IN PRESSURE

It is the difference between the pressures at two points in a circuit which causes current to flow from one point to the other. In Fig. 18 it is the entire pressure difference of the battery that causes current to flow through the entire circuit from **A** to **D**. Current flows from **A** to **B** because the pressure at **A** is higher than at **B**, it flows from **B** to **C** because the pressure at **B** is higher than at **C**, and from **C** to **D** because the pressure at **C** is higher than at **D**.

To determine the difference in electrical pressure between two points in a circuit, it is first of all necessary to establish a reference point.

Difference in Pressure

Unless otherwise specified, the negative terminal of any D.C. source is regarded as the reference point, and the difference in pressure between this terminal and any other point in the circuit is called **the voltage of that point.**



Thus point "d" in Fig. A is marked +8.2 in Fig. C, whereas point "h" is marked +.2, for the last figure indicates that point "h" has a pressure that is 8.0 volts **below** point "d".

Pressure differences are measured in volts. The measurement of the number of volts pressure difference between two points may be made with an instrument called a voltmeter. Fig. 20 shows how

VOLTAGE

When electromotive forces, pressure differences, or pressure drops are measured in volts or in multiples or fractions of volts, the number of volts often is spoken of as the **voltage.** For instance, someone might ask about the voltage of a generator, meaning the pressure difference available for the external circuit, or they might ask about the voltage across a coil or other part of a circuit, meaning the pressure difference across that one part.

In the language of electricity, which we now are learning, each word and term has an exact and precise meaning when used correctly. However, you will find that electrical men are sometimes rather careless in their use of these words, speaking of the emf across something like a coil instead of speaking of the pressure difference.

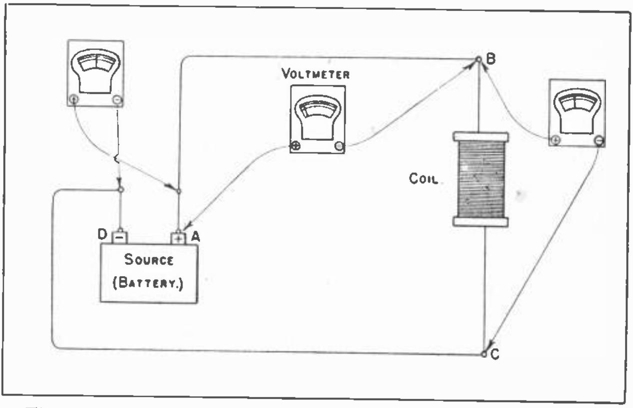


Fig. 20. Using a Voltmeter To Measure Potential Differences.

ELECTRIC POLARITY

One terminal of a source has, at any one instant, a pressure higher than the other terminal. The one of higher pressure is called the **positive** terminal, and the one of lower potential is called the **negative** terminal. This statement is based upon the assumption that the flow of current in an electrical circuit consists of the motion of free positive charges. Since the positive pole of the source repels these charges, and the negative pole attracts them, the direction of **current flow**, which is defined as the movement of free positive charges must always be from positive to negative. Positive terminals may be indicated by the plus sign (+) and negative terminals by the minus sign (—), as has been done with the source terminals in Fig. 20. Positive is also indicated by the letter **P** or the abbreviation **POS**, and negative by the letter **N** or by **NEG.**

Difference in Pressure

Voltmeters and other meters have one terminal marked positive and the other negative. In order that the meter may read correctly its positive terminal must be connected to the point of higher pressure and its negative terminal to the one of lower pressure.

Because of pressure drops and differences in a circuit one point will have a pressure higher than another point. The point of higher pressure is positive with reference to the other one, which is negative with reference to the first point. In Fig. 20 the pressure becomes lower and lower as we progress from **A** to **D.** Then point **A** is positive with reference to **B,** and **B** is negative with reference to **A.** But because the pressure at **B** is higher than at **C,** point **B** is positive with reference to **C** while being negative with reference to **A.**

The words positive and negative, as just used, describe the **polarity** of points in an electric circuit with reference to other points in the same circuit.

The whole mass of the earth or the ground usually is considered as having zero pressure or no pressure at all. Then we may speak of anything whose pressure is higher than that of the earth as being positive, and of anything whose pressure is less than that of the earth as being negative. You may wonder how we can have a pressure less than zero, but this is explained by remembering that the earth's pressure is only arbitrarily taken as zero, just as one certain point on the thermometer is arbitrarily considered zero. We may have pressures lower than the earth's zero pressure just as we may have temperatures lower than zero on the thermometer. In electrical terminology, the term potential is often used in the same sense as the word pressure is here applied; thus the "difference in pressure" in volts and the "difference in potential" in volts mean one and the same thing. For purposes of simplification, the word pressure has been employed in the foregoing material.

RESISTANCE OF CONDUCTORS

Several times it has been mentioned that the resistance of a conductor depends largely on the kind of material in the conductor. When talking about electron flow in conductors we listed a number of materials in the order of the freedom with which electrons pass through them. From our later discussion of resistance it is evident that the material (silver) permitting the freest flow of current must have the least resistance, and that materials permitting smaller rates of flow when a given difference in pressure is applied to them, must have higher resistances.

The resistance in ohms of a conductor is affected by other things as well as by its material. Here are the factors which determine resistance:

1. The material of which the conductor is made.

2. The length of the conductor. If a certain kind of conductor is made twice as long, its resistance will be exactly doubled, since it is twice as hard to force a given current through twice the original

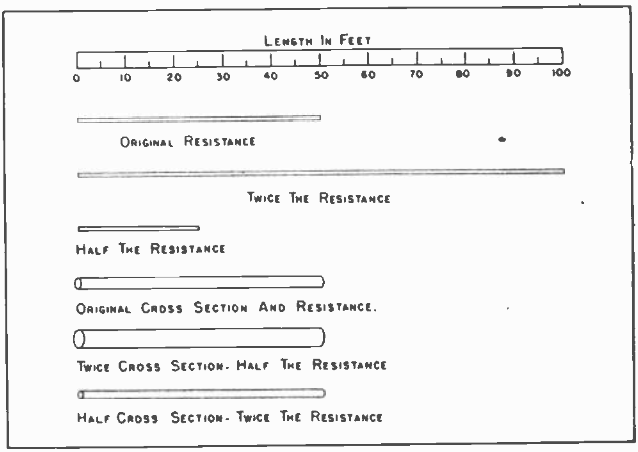


Fig. 21. Effect of Length and Cross Sectional Area On Resistance of Conductors.

length. See Fig. 21. Halving the length of the conductor will drop its resistance to half the original value. Resistance varies directly with **the length** of a conductor that is of uniform size and material throughout.

3. The cross sectional area of the conductor. The cross sectional area is the area of the flat surface left on the end of a conductor when it is cut straight through from side to side. Changes of cross section in the same length of conductor are shown in Fig. 21. If the cross sectional area is doubled the resistance is cut in half. It is easier for electricity to flow through a large conductor, just as it is easier for water to flow through a larger pipe. If the cross sectional area is halved the resistance is doubled. It is harder to force water through a small pipe than a large one, and harder to force electricity through a small conductor than through a larger one.

4. The temperature of the conductor. In all pure metals, and in most mixtures or alloys of metals, the resistance increase as the temperature rises. The resistance of a copper wire is about 9 per cent greater at 70° F. than at 32°, and at 150° is about 27 per cent higher than at 32°. Each different metal has a different rate at which its resistance changes with changes of temperature. An alloy called manganin, much used to provide resistance in electrical instruments, changes its resistance less than one-hundredth as much as does copper for the same change of temperature. Liquids which have been made conductive, such as those used in storage batteries, have less and less resistance as their temperature rises through normal ranges. The resistances of carbon and graphite become less as their temperature rises. In order to specify resistances with accuracy we should know and mention the temperature of the conductor. When no temperature is mentioned it generally is assumed to be 68° Fahrenheit, which is 20° centigrade.

CONDUCTANCE

The **conductance** of a conductor is a measure of the ease with which it permits current to pass through it, as opposed to resistance which is a measure of the opposition to current flow. The unit of conductance is the mho, which is ohm spelled backward. The conductance in mhos is equal to the reciprocal of the resistance in ohms. The reciprocal of a number is 1 divided by that number. Thus, the reciprocal of 10 is 1/10. If the resistance of a conductor is 10 ohms its conductance is 1/10 mho.

Nearly all our practical calculations are made with resistance measured in ohms. Conductances in mhos are seldom used.

ELECTRICAL SYMBOLS

When we wish to show the wiring connections and the parts included in an electric circuit or part of a circuit, it is not necessary to draw pictures of the parts. Conductors and various electrical devices are shown by symbols which represent these parts in a general way and which are understood

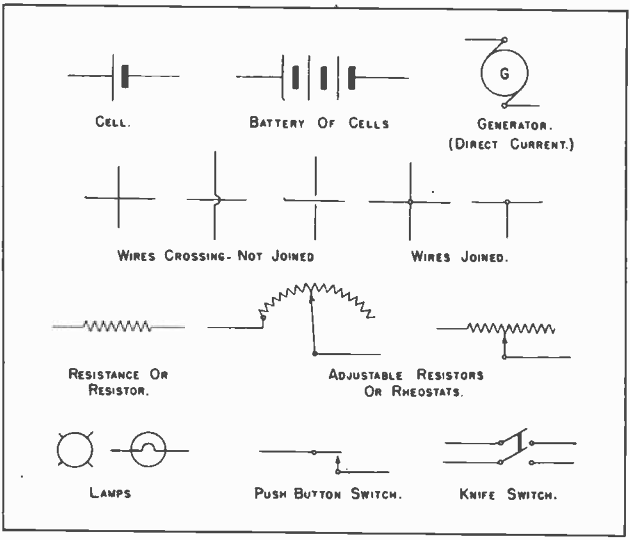


Fig 22 Symbols Used In Electrical Wiring Diagrams.

by all men working in the electrical industries. Several standard symbols are shown by Fig. 22.

The cell represents a single dry cell or a single cell of any other type which produces electromotive force from chemical action. Several cells together form a battery. The number of cell symbols drawn to represent the battery may or may not correspond to the number of cells actually in the battery to be shown. The long line of the cell symbol represents the positive terminal and the short line the negative terminal.

The generator symbol is marked "direct current" because it represents the kind of generator which causes electricity to flow always in the same direction around a circuit. This is the kind of flow we have been considering and shall continue to study until taking up the subject of alternating current later on. Alternating current is a surging back and forth of electricity in the conductors, moving one direction for a brief period and then in the opposite direction for an equal period of time.

Wires which cross over each other without being joined together or in electrical contact may be shown in any of three ways. Electricity cannot flow from one to the other of wires which are not in actual contact, or which are separated by insulation as indicated in these symbols. If two or more wires are in direct contact so that current may flow from one to the other at the point of contact, we show the joining by means of a small dot at the junction.

If a large amount of resistance is concentrated into a small space, as by winding much wire into a compact coil, we may call the unit a resistance or a resistor. The symbol for such concentrated resistance is a zig-zag line. Many resistors are so constructed that a brush or other movable contact point may be slid along the resistance wire, thus including between the contact and one end of the wire more or less resistance or more or less of the total length of the wire. Such an arrangement provides an adjustable amount of resistance for use in a circuit to limit the flow of current. An adjustable resistor may be called a rheostat. The arrowhead in the symbols represents the movable or sliding contact point.

Switches, as you doubtless know, are devices in which metallic conductors may be conveniently brought together so that current may flow through them and through a connected circuit, or which may be separated so that they have between them the insulation of air, which prevents flow of current. A push button switch is of the type used for door bells. A knife switch opens and closes with a motion like moving the blade of a jack knife. The knife switch for which a symbol is shown has two blades, that simultaneously opens or closes two conductive current paths.

Fig. 23 is a diagram of an electric circuit showing how simple and easily understood are the connections and the paths for current when we use symbols to represent the electrical devices. Refer to the symbols of Fig. 22 and see how many of them you can identify in Fig. 23. Fig. 23 shows two coils whose symbols are not included in Fig. 22.

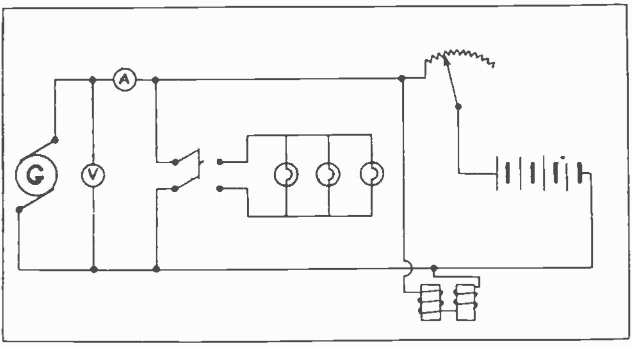


Fig 23. Wiring Diagram In Which Symbols Are Used.

SERIES CONNECTIONS

Fig. 24 shows two circuits. Each contains a generator, a switch, a resistor, and two lamps. If the generator were running and the switch closed, current from one side of the generator would have to pass successively through each of the other parts before coming back to the generator. Furthermore, every bit of current that goes through the generator

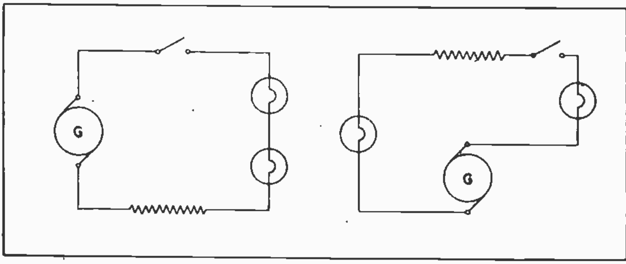


Fig. 24. Series Circuits.

must go also through every other part of the circuit. The current cannot divide at any point. All the current that flows in any one part of the circuit must flow also in every other part.

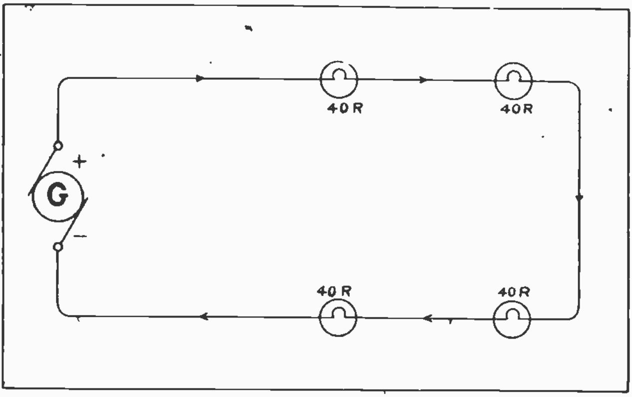


Fig. 25. Four 40-ohm Lamps Connected In Series.

Any circuit in which all the current flowing in any one part must flow also through each other part is called a **series circuit.** When parts are so connected that all the current through one of them must pass also through the other these parts are connected in **series.** It makes no difference in what order the parts come, if they all carry the same current they are in series.

There are three things about series connections that we should understand.

1. The current in amperes is the same in all parts connected in series. If the flow is five amperes in any one part it must be five amperes in every other part.

2. The total résistance in ohms of all the parts connected in series is equal to the sum of their separate resistance in ohms. In Fig. 25 we have four lamps in series. Each lamp has a resistance of 40 ohms. Neglecting the very small resistance of the connecting wires, the total resistance of this circuit is 4 x 40, or is 160 ohms.

3. The total difference in pressure in volts which is supplied to the parts in series, as from a current

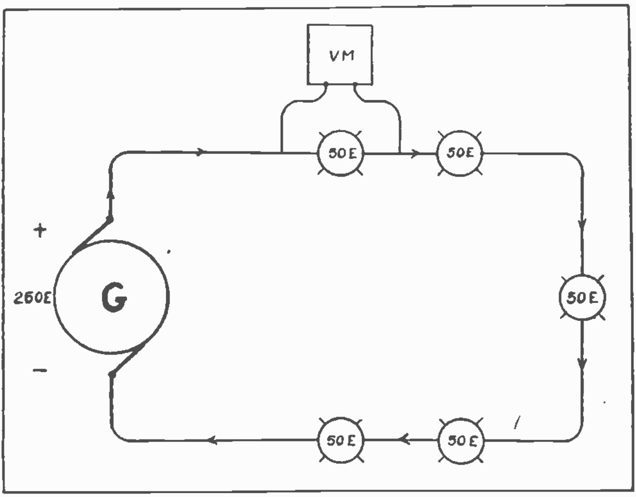


Fig. 26. Five 50-volt Lamps Connected In Series.

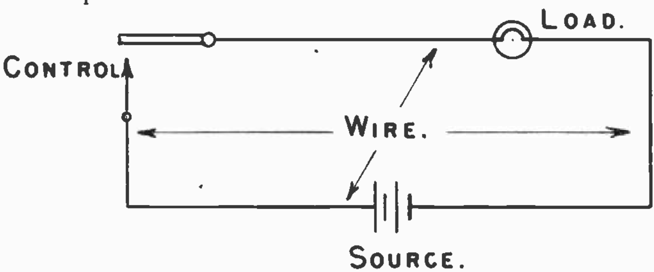
source, must equal the sum of the pressure differences or pressure drops across the separate parts in the circuit. This became apparent when studying Fig. 18. In Fig. 26 we have five lamps, across each of which a voltmeter would show a pressure difference of 50 volts. Neglecting the small pressure drops in the short wire connections, the sum of these voltage or pressure differences is 250 volts, which is the total difference in pressure that must be supplied by the generator.

RELATION OF CURRENT, VOLTAGE AND RESISTANCE

A simple practical electrical circuit will consist of:

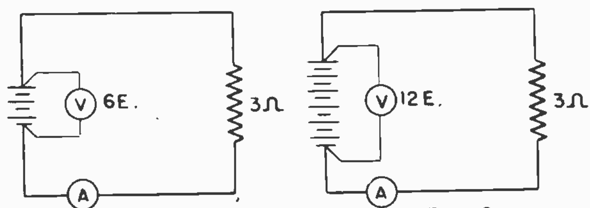
1. A source of energy—generator, battery, etc.
2. A load—lamps, motor, etc.
3. A means of control—switch or variable resistance.
4. Necessary conductors or wires.

Example:



Current designated by this sign (I) is needed to operate any piece of electrical equipment and the rate of flow of current in the circuit supplying such equipment will depend on the voltage (E) applied to the circuit and the resistance (R) of the circuit.

In a D.C. circuit having a constant resistance an increase in voltage causes an increase in current—see "A".



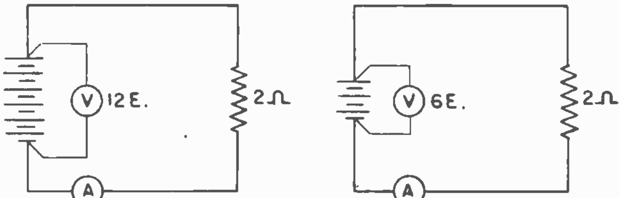
A $I = \frac{E}{R} = \frac{6}{3} = 2I$ $I = \frac{E}{R} = \frac{12}{3} = 4I.$

Likewise a decrease in voltage causes a decrease in current—see "B".

Generalizing "A" and "B"—

1. What causes current to flow in this circuit when the switch is closed?

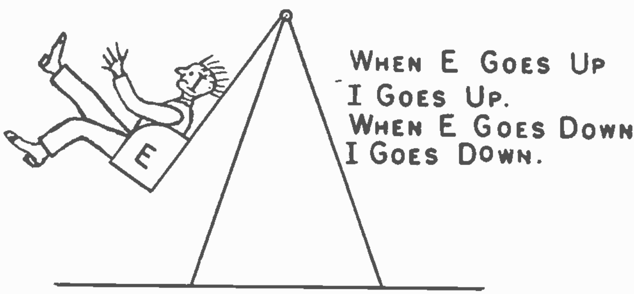
2. What effect is produced when voltage is applied to a closed circuit?
3. What factors change?



B $I = \frac{E}{R} = \frac{12}{2} = 6I$ $\qquad$ $I = \frac{E}{R} = \frac{6}{2} = 3I$

4. How did they vary with respect to each other?
5. Can we draw any conclusions?
6. Can we generalize the relation?

In a D.C. Circuit having constant resistance the current will vary in direct proportion to the voltage—see swing illustration below.



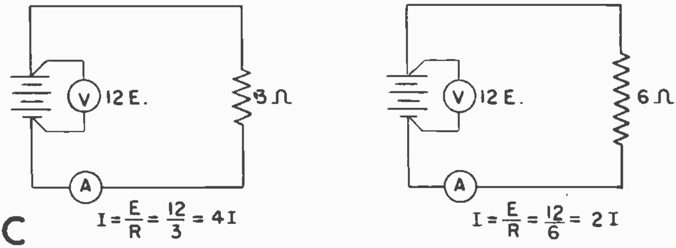
DIRECT RELATION.

In a D.C. circuit having a constant voltage an increase in total resistance causes a decrease in current—see "C".

A decrease in total resistance permits an increase in current—see "D".

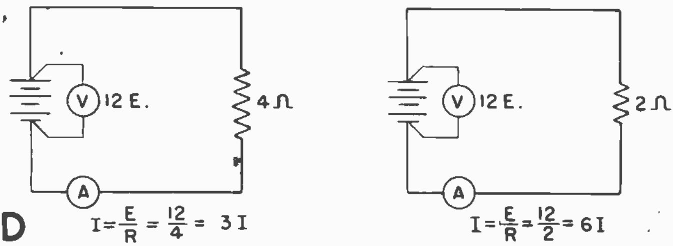
Generalizing C and D—
1. Which factor is constant?
2. Which is the cause?
3. Which is the effect?
4. What were the quantities that changed?

5. How did they vary with respect to each other —up or down?
6. What conclusions can we draw?
7. Can we generalize the relation?



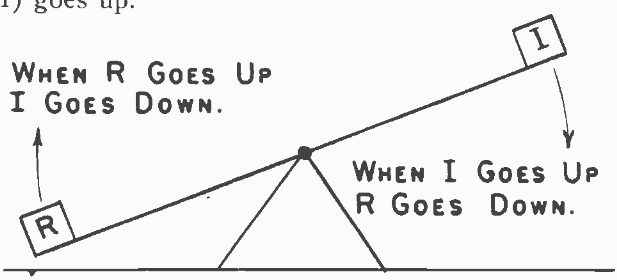
C

In a constant voltage D.C. circuit the current will vary inversely proportional to the resistance—this is illustrated graphically by this seesaw relation.



D

When resistance (R) goes up the current (I) goes down . . . in like manner when (R) goes down then (I) goes up.



INVERSE RELATION.

Can we generalize both these statements?

Now combining A-B-C-D we have what is known as Ohm's law, here is how it reads. The current in any D.C. circuit is directly proportional to the Voltage (E) and inversely proportional to the resistance (R).

OHM'S LAW

Ohm's law is a rule that helps to solve more different kinds of electrical problems than any other one rule or law that we can learn. The law says that if the pressure difference across a circuit or any part of a circuit is doubled, the current will double, and that half the pressure difference will produce half the current. In other words, the current in amperes increases and decreases directly with increase and decrease of the pressure difference in volts. Ohm's law says further that doubling the resistance will permit only half as much current to flow, and that halving the resistance will permit as much current to flow. This means that the current increases proportionately to every decrease of resistance, and that the current decreases proportionately to any increase of resistance. This statement assumes the applied voltage to remain constant.

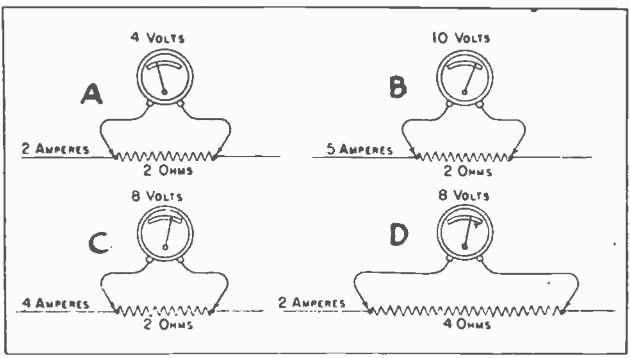


Fig 27 Relations Between Amperes, Volts and Ohms.

At A in Fig. 27 we measure a pressure difference of 4 volts across a resistance of 2 ohms. The current through the resistor will be 2 amperes. At B the pressure difference has been raised to 10 volts, two and one-half times as much as at A, and the current through the resistor now is 5 amperes, which is two and one-half times the original current through the same amount of resistance.

At C in Fig. 27 the pressure difference across a 2-ohm resistance measures 8 volts. The current is 4 amperes. At D the resistance has been increased to 4 ohms, twice as much as at C, and now we have a current of only 2 amperes with the same pressure difference. Doubling the resistance has cut the current to half.

The easiest way to remember Ohm's law is to say that the number of amperes of current is equal to the number of volts pressure difference divided by the number of ohms resistance, or simply that amperes are equal to volts divided by ohms. When one quantity is to be divided by another we often write them as a fraction. For example, the fraction ½ means that 1 is to be divided into 2 equal parts, and the fraction 6/3 means that 6 is to be divided into 3 equal parts. Ohm's law written with a fraction appears thus:

$$\textit{Amperes} = \frac{\textit{volts}}{\textit{ohms}} \quad \textit{or} \quad \textit{Current} = \frac{\textit{pressure difference}}{\textit{resistance}}$$

Instead of using the words for amperes, volts and ohms, or for current, pressure difference and resistance, we generally use letter symbols. For current in amperes we use the capital letter I, which you may think of as standing for intensity of current. For pressure difference in volts we use the letter E, which stands for electromotive force. For resistance in ohms we use the letter R, which stands for resistance. With these letter symbols we may rewrite Ohm's law thus:

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

Ohm's law shows the relation between amperes, volts and ohms in any part of a circuit, or, of course, in a complete circuit. If we use the numbers of amperes, volts and ohms of Fig. 27 instead of the corresponding letters in the formula **I** = **E/R** we will have for **A** 2 = 4/2, and for **B** 5 = 10/2, and for **C** 4 = 8/2, and for **D** 2 = 8/4, all of which work out correctly.

The great usefulness of Ohm's law arises from the fact that if we do not know the current but know only the resistance and the pressure difference we merely divide the volts of pressure difference by the ohms of resistance to find the unknown current in amperes.

In Fig. 28 we have a battery furnishing 10 volts pressure difference (E) to a lamp whose resistance (R) is 5 ohms, and we wish to know the current

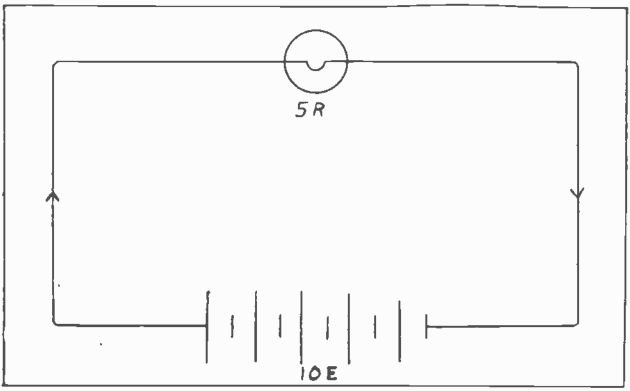


Fig. 28. A 10-volt Battery Supplying Current To a 5-ohm Lamp.

in amperes. We use the known pressure difference and known resistance in Ohm's law thus:

$$I = \frac{E}{R} = \frac{10}{5} = 2 \ amperes$$

In all these simple problems we shall ignore the resistance of the connecting wires. Even were we to have as much as ten feet of ordinary copper wire the resistance of the wire would be only about 1/40 ohm, which would have negligible effect on our figures. Now that the relationships between current, difference in pressure, and resistance have been established, we shall begin to substitute the term "difference in potential" for "difference in pressure" in order to acquaint you with use of the word. Remember that you may substitute the word "pressure" for "potential" in any practical electrical situation, as both terms mean virtually the same thing. The only advantage of using the term potential lies in the fact that it is widely used in electrical literature.

Probably you know that any formula such as **I = E/R** which involves three quantities may be changed around to show any one of the quantities when we know the other two. We already have learned how to find the current in amperes when we know the potential difference in volts and the resistance in ohms, but how about learning the potential difference from known current and resistance, and how about learning the resistance when we know only the current and the potential difference?

Using letter symbols for the three quantities we may write Ohm's law for unknown potential difference as follows:

E = IR, which means **volts = amperes × ohms**

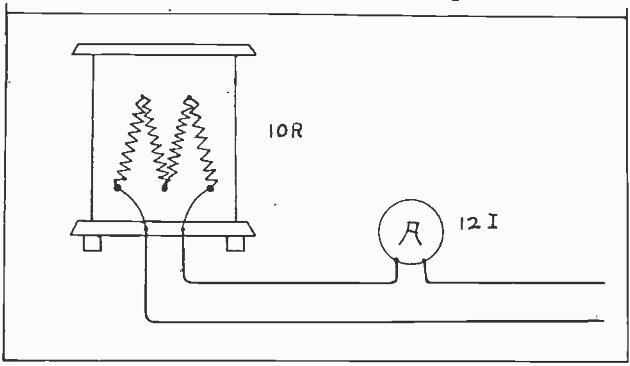


Fig. 29. A Toaster for Which the Potential Difference Is To Be Calculated.

You may easily prove to yourself that this form of the law is a correct one by substituting for volts, amperes and ohms the corresponding numbers from Fig. 27, and you will find that the formula always works out.

In Fig. 29 we have represented an electric toaster whose resistance is 10 ohms, and with an ammeter we measure the current as 12 amperes. What is the potential difference in volts that will cause 12 amperes of current to flow through 10 ohms of resistance? All we need do is place the known values in Ohm's law, thus:

$$E = IR = 12 \times 10 = 120 \text{ volts}$$

In Fig. 30 we have an electric oven in whose heater coils the resistance is 2 ohms, and we

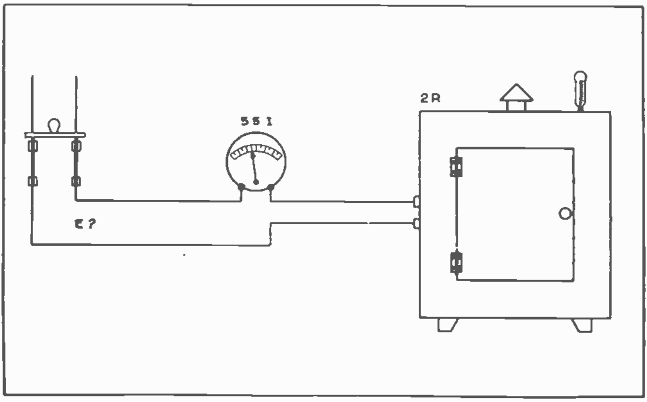


Fig. 30. An Oven of Known Resistance, Taking a Known Current, for Which the Potential Difference Is To Be Calculated.

measure the current as 55 amperes. It is easy to find the potential difference in volts.

$$E = IR = 55 \times 2 = 110 \text{ volts}$$

Just as we changed Ohm's law around to give the value of an unknown potential difference, so we may change it again to show an unknown resistance in ohms when we know the potential difference in volts across the resistance and know the current in amperes flowing through the resistance. Here is the third form of Ohm's law:

$$R = \frac{E}{I} \quad \text{or} \quad Ohms = \frac{volts}{amperes}$$

Again you may prove that this form of the law works out by substituting in it the numbers of ohms, volts and amperes of Fig. 27.

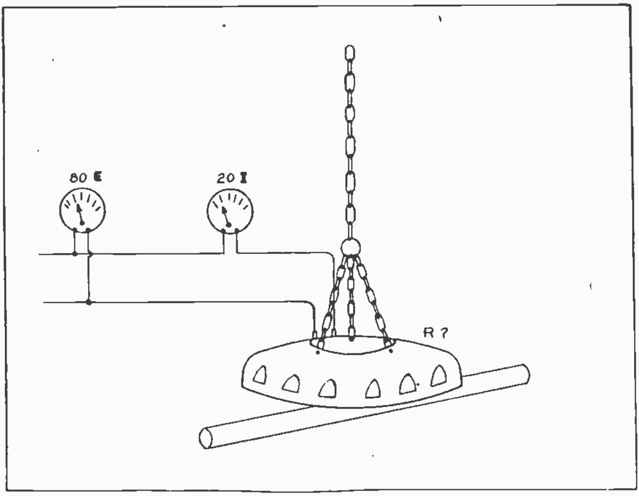


Fig. 31. An Electromagnet for Which the Potential Difference and Current Are Measured, and of Which the Resistance Is To Be Learned.

Fig. 31 shows a powerful magnet or electromagnet used for lifting parts made of iron or steel. An ammeter shows that a current of 20 amperes flows through the coils inside the magnet when the applied potential difference is shown by a voltmeter to be 80 volts. To find the resistance in ohms of the magnet coils we use the measured quantities in Ohm's law for resistance.

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

USING OHM'S LAW

Current voltage and resistance are the three most important things that we have to consider in practical work with the great majority of electrical devices and the wiring that connects them together. Electricity flows only through conductors, and all conductors have resistance. Therefore, every part in every electrical circuit has resistance. The circuit of Fig. 32 includes a generator, an ammeter, a switch, a rheostat, a lamp, and the connecting wires. There are various amounts of resistance in every one of these parts.

The ammeter of Fig. 32 shows the current flowing through the meter. Since this is a series circuit we know that the current in every other part is the same as that in the ammeter. The voltmeter is connected across the terminals of the generator, so it shows the potential difference across these terminals and across the entire external circuit. The voltmeter might be connected across the rheostat, the lamp, the ammeter, the switch, or any of the wires—and then would show the potential difference across each of these parts. In every circuit in which electricity is flowing we have a current which is forced to flow through resistances by the potential differences in the circuit. An understanding of Ohm's law means an understanding of all the relations between current, voltage and resistance, and an understanding of the electrical behavior of every common type of circuit.

An understanding of Ohm's law does not mean merely the ability to say that "amperes equal volts divided by ohms," and to repeat the other forms of the law for volts and ohms, but means understanding of how these rules work out in practice. Supposing that the rheostat of Fig. 32 were enclosed within a box with only the operating handle showing, and that you wanted to know which way to move the handle to increase the resistance. If you understand the relations between resistance and current as shown by Ohm's law you will know that the ammeter in this circuit will show less current when you move the handle to increase the resistance. You will know also that with the voltmeter connected across the rheostat the voltage will increase when you move the handle in the direction that increases the resistance of the rheostat.

Here is a little table showing what happens to each of the three elements—current, voltage, and resistance—when one of them is kept at the same value and another is made more or less. In each part of the table is written the form of Ohm's law that gives the answer shown there.

CURRENT Amperes	POTENTIAL DIFFERENCE Volts	RESISTANCE Ohms
SAME	MORE E = IR	MORE R = E/I
SAME	LESS E = IR	LESS R = E/I
MORE I = E/R	SAME	LESS R = E/I
LESS I = E/R	SAME	MORE R = E/I
MORE I = E/R	MORE E = IR	SAME
LESS I = E/R	LESS E = IR	SAME

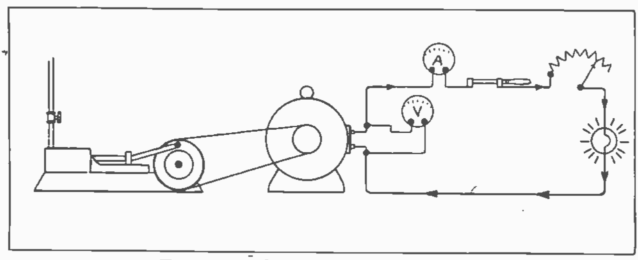


Fig. 32. A Typical Electric Circuit.

In this table we have the answers to the problem about moving the rheostat handle. On the first line of the table we find that more resistance means more potential difference in volts is required if the current is to remain the same, and on the fourth line we find that more resistance means less current in amperes if the voltage remains the same. The formula **R = E/I** answers the questions because if in it you use different values of volts **(E)** with the same value of amperes **(I)**, you will find out what happens to resistance. If you try different values of amperes **(I)** with the same value for volts **(E)** you again will find out what happens to resistance under these conditions.

Supposing you know that a certain electrical device must have a current of six amperes to operate correctly, but an ammeter shows the current to be eight amperes. You can reduce the current by changing either the potential difference in volts or the resistance in ohms. The table shows that less current will flow with more resistance and the same voltage, or with less voltage and the same resistance. Ohm's law will answer thousands of electrical questions.

When Ohm first explained his law for the relations of current, potential difference and resistance he did not write something like **I = E/R,** but he stated that **current varies directly with potential difference,** and **inversely with resistance,** that potential difference varies as the product of current and resistance, and that resistance varies directly with potential difference and inversely with current. This is just a short way of saying all that is shown by our table. The three formulas by which we show Ohm's law are merely convenient ways for working our problems which involve certain numbers of amperes, volts and ohms.

One of the easiest ways to remember all three formulas for Ohm's law is to remember this arrangement of the letter symbols,

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

Supposing you want to know the value of E or volts. Cover the E with the tip of your finger and you see only I × R, which means that multiplying the number of amperes (I) by the number of ohms (R) will give the number of volts. If you want to know the number of amperes just cover up I, the symbol for amperes, and you see E over R, which means to divide the number of volts by the number of ohms. If you want to find the number of ohms, cover up R, the symbol for ohms, and you see E over I, which means to divide the number of volts by the number of amperes.

It is necessary to understand the relations between current, potential difference and resistance as shown in the table, but this requires no memorizing, only a little reasoning for each case. For instance, you can read the first line of the table thus: With the SAME current there will be MORE potential difference with MORE resistance. All you need do to figure this out for yourself is to reflect that it certainly is going to take more potential difference or more force to send the same current through more resistance. Stated in another way, if you have the same current and observe that more potential difference is needed to maintain this current, it is certain that the resistance must have increased, because it takes more force to get the same current through more resistance.

Just as we have analyzed the meaning of the first line of the table, so you should check over each of the other lines for yourself. You will find that the conclusions are just common sense in each case, that they merely state what you already know about the behavior of current, voltage and resistance.

PARALLEL CONNECTIONS

Fig. 33 shows a water circuit in which all the water flowing through the pump P flows also through the water wheel or water motor WW and through every other part of the circuit. The gauge G indicates the pressure available from the pump

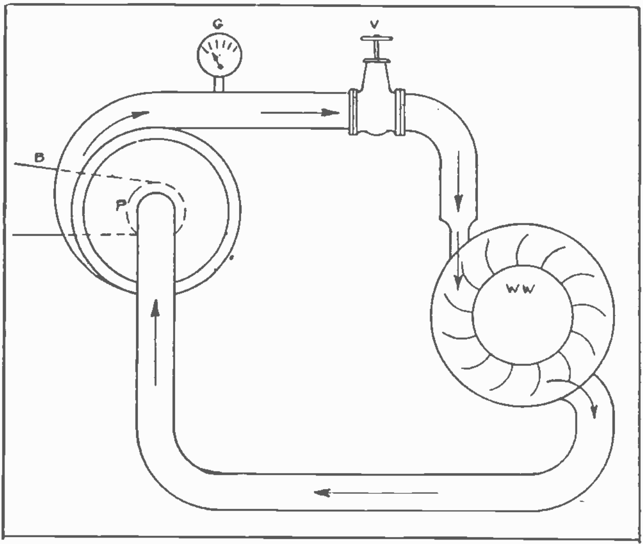


Fig. 33. Water Circuit With Its Parts In Series.

or the source of pressure. Fig. 34 shows an electric circuit which is similar to the water circuit of Fig. 33. All the current that flows through the

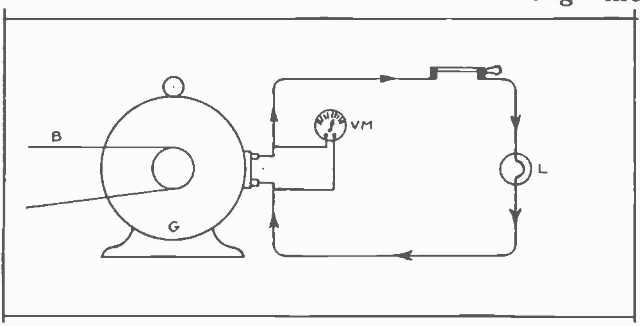


Fig. 34. Electric Circuit With Its Parts In Series.

generator **G** in the electric circuit flows also through the lamp **L** and through every other part of this circuit. A voltmeter **VM** indicated the electrical pressure difference or the potential difference available from the generator. These two circuits, as you will recognize, are series circuits.

In the series electric circuit we have the same current in all parts. The total resistance of the circuit is equal to the sum of the resistance in its parts The total potential difference from the source must equal the sum of the potential differences across the parts of the series circuit. These are the rules for a series circuit, as we learned previously.

In Fig. 35 we have added a second water wheel **WW2** to our water circuit. Both sides of each water wheel are connected directly to the pump through pipes. The two wheels are in **parallel** with

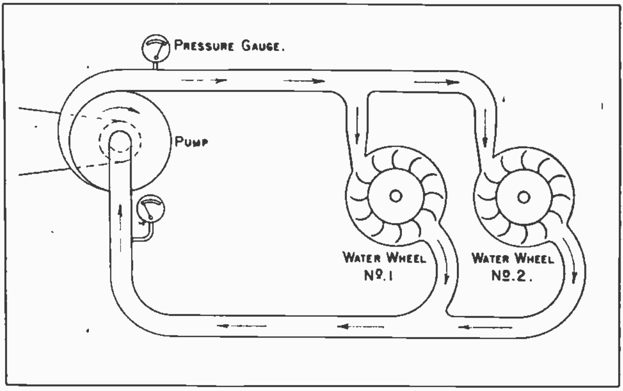


Fig. 35. Water Circuit With Two Water Wheels In Parallel.

each other. Fig. 36 shows an electric circuit like that of Fig. 34 except that we have added a second lamp **L2** and have connected both sides of this lamp directly to the generator through wires. The two lamps are connected together in **parallel.**

A parallel connection of two or more parts may be defined as a connection with which the total current divides, part going through each of the units. If we consider each separate unit in a parallel connection all by itself, Ohm's law will tell us all the relations between current, potential difference and resistance in that unit or in that "branch" of the parallel system.

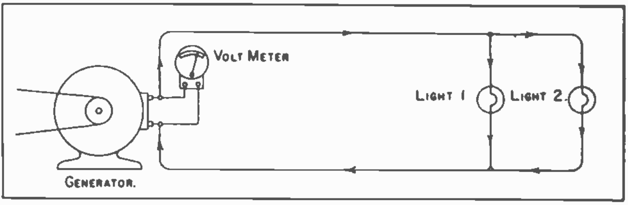


Fig. 36. Electric Circuit With Two Lamps In Parallel.

The first thing to note about a parallel connection is that the potential difference across all the units or across all the branches is the same. In Fig. 35 the pressure difference from the water pump is applied equally to both water wheels, since both are connected directly to the pump. In Fig. 36 the potential difference from the generator is applied to both the lamps, because both lamps are connected directly to the generator. When two wires come together, as do the two from the tops of the lamps and the other two from the bottoms of the lamps in Fig. 36, there can be only one potential at each junction. We cannot have two different potentials or voltages at the same point in a conductor or in a junction of conductors. Then, if the potentials on each side of the lamps are alike, there can be only one potential difference, and this potential difference acts across each of the lamps.

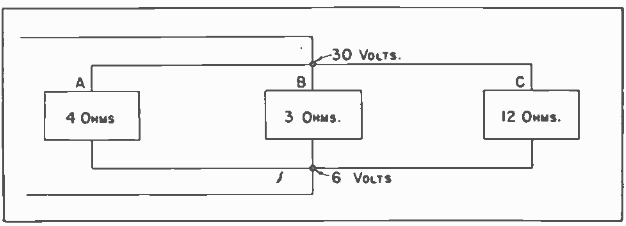


Fig 37. Three Resistances Connected In Parallel.

When we know the potential difference across all the parts connected in parallel, and know the resistance of each part, it is a simple matter to determine the current in each part. All we need to do is use Ohm's law which says **I = E/R.** As an example, consider the parts shown in a parallel connection by Fig. 37. The potential at the top of the diagram is 30 volts, at the bottom is 6 volts, so the potential difference across **A, B** and **C** must be 24 volts. A voltmeter connected across any one of these units would read 24 volts.

The resistances of the units of Fig. 37 are marked in the diagram. Knowing the potential difference (**E**) and the resistance (**R**) for each unit allows finding the currents for each unit as follows:

Unit A	**I = E/R**	=	24/4	=	6 amperes
Unit B	**I = E/R**	=	24/3	=	8 amperes
Unit C	**I = E/R**	=	24/12	=	2 amperes

The total current for the units of Fig. 37 must be the sum of the separate currents, or must be $6 + 8 + 2$ amperes, which makes a total of 16 amperes.

Now let's consider the three units of Fig. 37 as a group. For the entire group we know that the potential difference is 24 volts, which is the same as the potential difference for each unit. We have figured out that the total current is 16 amperes for the group of parts. Now, what is the effective resistance of the entire group of units, or what would be the resistance of a single unit equivalent to the three?

As is usual when having to solve an electrical problem we call on Ohm's law. We wish to learn the effective resistance, so must use the formula for resistance or use **R = E/I.** Let's put our known potential difference (**E**) and our known total current (**I**) into this formula.

R = E/I = 24/16 = 1½ ohms, the equivalent resistance.

Supposing that we do not know the potential difference, but know only the resistance of several units connected in parallel and wish to know their equivalent or effective resistance considered as a group. All we need do is select any voltage, preferably a number of volts into which each of the numbers of ohms resistance will easily divide. For the resistance of Fig. 37 we might select 72 volts. Then we figure out the separate currents for 72 volts instead of 24 volts and find that they will be 18, 24 and 6 amperes. The total current then is the sum, 18 + 24 + 6, or is 48 amperes. Finally we use Ohm's law to find the effective resistance, this way,

$$R = E/I = 72/48 = 1\tfrac{1}{2} \text{ ohms.}$$

This is an easy way to figure out the effective resistance of any number of resistances connected in parallel; just select any voltage, calculate the currents, and use the total number of amperes and the selected number of volts in Ohm's law for resistance, **R = E/I**, and you will have the equivalent number of ohms.

The rule usually used in cases like this says that the sum of the reciprocals of the separate resistances equals the reciprocal of the equivalent resistance. The reciprocal of any number is 1 divided by that number. To apply this rule to the example of Fig. 37 we would have to add the reciprocals of the resistances.

$$\frac{1}{4} + \frac{1}{3} + \frac{1}{12} = ?$$

To add fractions they first must be changed to equal fractions all having the same denominator, or the same number below the line. Our present fractions may be changed so that all have 12 for the denominator, thus,

$$\frac{1}{4} = \frac{3}{12} \qquad \frac{1}{3} = \frac{4}{12} \qquad \frac{1}{12} = \frac{1}{12}$$

Then we may carry out the addition.

$$\frac{3}{12} + \frac{4}{12} + \frac{1}{12} = \frac{8}{12}$$

Here we find that 8/12 is the reciprocal of the resistance. The reciprocal of any fraction is that fraction inverted or turned upside down. Then the reciprocal of 8/12 is 12/8, and 12/8 is equal to 1½, which is the equivalent resistance in ohms.

Fig. 38 shows another example of resistance in parallel. It would be a good idea if, before looking at the answer which will be given, you work out the equivalent resistance for yourself, either by selecting any convenient voltage and using Ohm's law to find currents and then the resistance or else by using the reciprocals of the separate resistances.

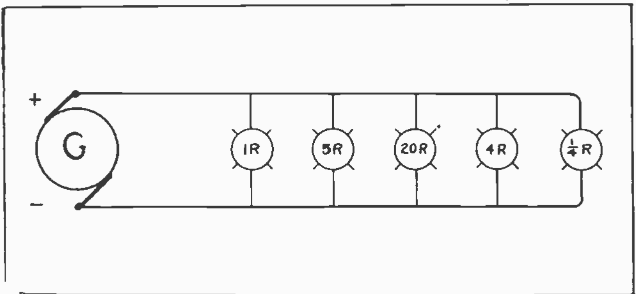


Fig. 38. Resistances In Parallel for Which the Equivalent Resistance Is To Be Calculated.

The reciprocals of the numbers of ohms are,

$$\frac{1}{1} \quad \frac{1}{5} \quad \frac{1}{20} \quad \frac{1}{4} \quad \frac{1}{1/4}$$

To simplify the last fraction, 1 over ¼, we may actually divide 1 by ¼, which gives us 4. To change 4 into a fraction we may write it as 4/1, so instead of working with 1 over ¼ we may substitute 4 over 1, to which it is equal. For the next step we may change all the fractions so that they have 20 for a denominator and add them, thus,

$$\frac{20}{20} + \frac{4}{20} + \frac{1}{20} + \frac{5}{20} + \frac{80}{20} = \frac{110}{20}$$

Since 110/20 is the reciprocal of the resistance we must invert this fraction to get 20/110 as the number of ohms. This fraction 20/110 should be simplified to 2/11, which is the equivalent resistance in ohms of the five parallel resistances.

Fig. 39 shows four lamps connected in parallel, each lamp having a resistance of 40 ohms. When all the parallel resistances are alike their equivalent resistance is equal to the resistance of one unit divided by the number of units. In Fig. 39 the equivalent resistance must be equal to 40 ohms (resistance of one lamp) divided by 4 (the number of lamps), or must be equal to 10 ohms.

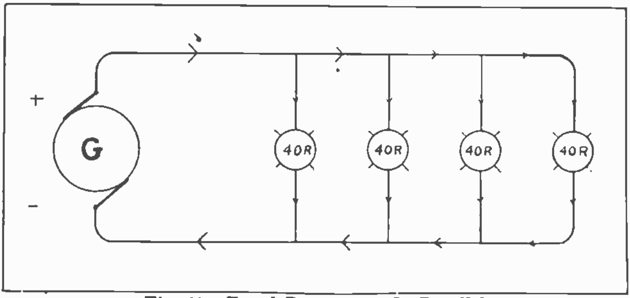


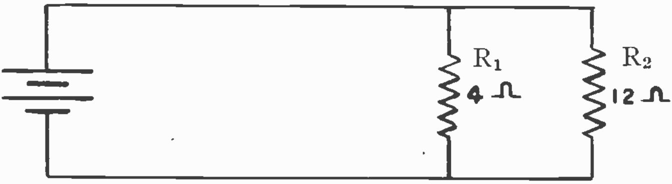
Fig. 39. Equal Resistances In Parallel.

In practice many problems will arise which require the calculation of total resistance of **two** resistances in parallel, and there is a most convenient formula for computations of this type. If one resistance is called R_1 and the other R_2, the total resistance R_T may be found from the formula

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

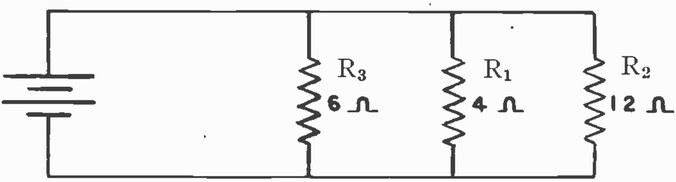
Note that this formula merely indicates that we must take the product of the two resistors and divide this value by the sum of the two resistors. By repeated application of the same formula, the total resistance of any number of parallel resistances may easily be determined.

Below is an example of how the "product over sum" method which shows how the formula may be repeated to find the total resistance of a network of conductors having any number of parallel paths. The solving of a network having three parallel resistors requires two steps; the first takes any two resistors and, by the product over sum method, finds the equivalent resistance of this pair; the second step takes this equivalent resistance and combines it with the remaining resistor as indicated in the example given below.



$$R_T = \frac{R_1 \cdot \quad R_2}{R_2 + R} = \frac{4 \times 12}{12 + 4} = \frac{48}{16} \text{ or } 3\,\Omega \quad R_T = 3\,\Omega$$

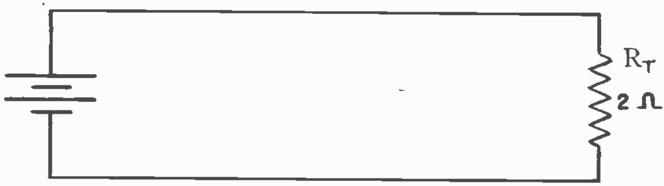
Adding to Example No. 1:



We found the equivalent resistance to R_1 and R_2 in parallel to be 3 , so we can use 3 as R_1 in relation to R_3 and indicate as follows:

$$R_T = \frac{R_1 \quad R_3}{R_3 + R_1} = \frac{3 \times 6}{6 + 3} = \frac{18}{9} = 2\,\Omega \quad R_T = 2\,\Omega$$

The equivalent R can be indicated:



R_T for the network $= 2\ \Omega$

In wiring diagrams such as apply to the electrical equipment in buildings you often will find lamp circuits as shown in Fig. 40. At **A** there are 12 lamps in series, which requires only a single wire or conductor running from lamp to lamp. At **B** the 12 lamps are connected in parallel, which requires two wires or conductors so that both sides of each lamp may be connected directly to the source of current.

There are three important facts to keep in mind about parallel conections. Here they are:

The **current** for the parallel group is equal to the sum of the currents in the several units.

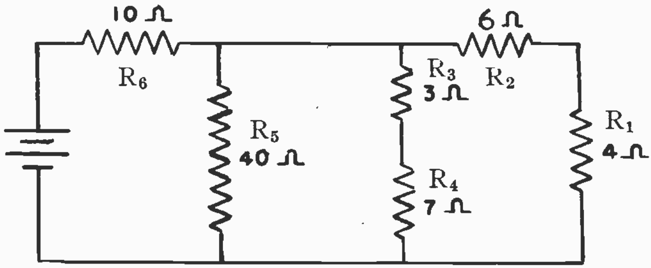
The **potential difference** is the same across all units in the parallel group.

The **equivalent resistance** of the parallel group always is less than the smallest separate resistance.

Networks that have a relatively complicated appearance may be solved without too much difficulty if a logical procedure is employed. The example below shows how this may be done. Note that in this type of problem the network is solved a step at a time, starting at the end of the circuit and working back toward the source.

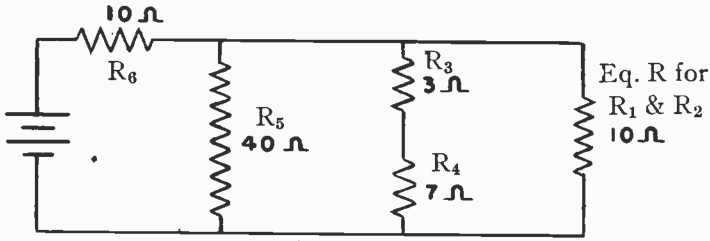
TO FIND R OF A NETWORK

Find equivalent R for R_1 and R_2, which are in series with each other.



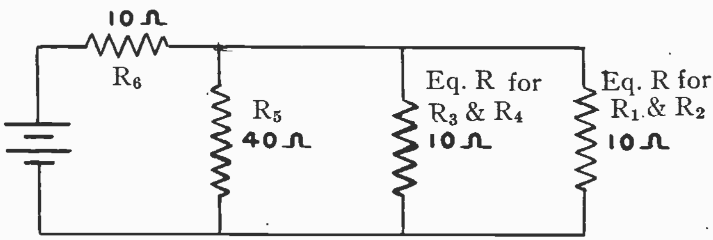
$$\text{Equivalent R} = 6\,\Omega + 4\,\Omega = 10\,\Omega$$

Find equivalent R for R_3 and R_4, which are in series with each other.



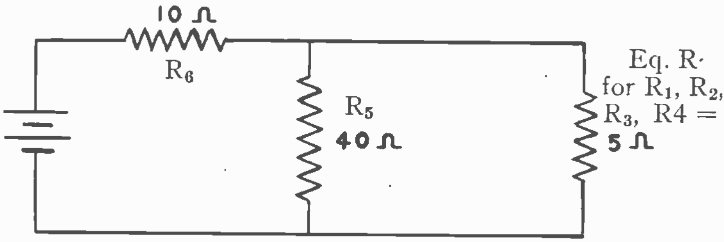
$$\text{Equivalent R} = 3\,\Omega + 7\,\Omega = 10\,\Omega$$

Find equivalent R for R_1, R_2, R_3, R_4.



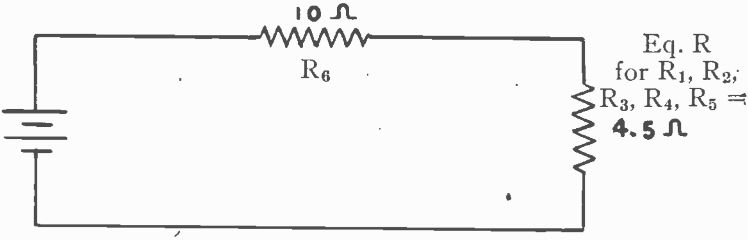
$$\text{Equivalent R} = \frac{10\,\Omega}{2} \quad \text{or} \quad 5\,\Omega$$

Find equivalent R for R_1, R_2, R_3, R_4, R_5.

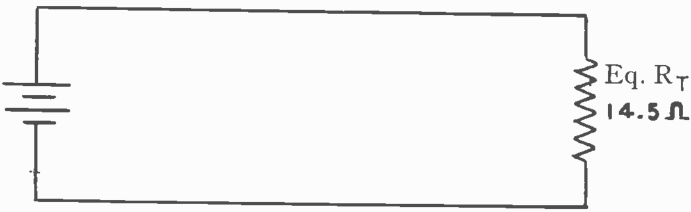


$$\text{Equivalent R} = \frac{5 \times 40}{5+40} = \frac{200}{45} = 4.5\ \Omega$$

Find equivalent R for R_1, R_2, R_3, R_4, R_5 and R_6.



$$\text{Equivalent R} = 10\,\Omega + 4.5\,\Omega = 14.5\ \Omega$$



Final R for entire network = 14.5 Ω

SOURCES CONNECTED IN SERIES

Two water pumps are connected end to end or in series for the water circuit of Fig. 41. With the pumps connected this way it is plain that the rate of water flow, in gallons per minute, must be the same through both pumps. One pump adds to the pressure developed by the other one. If we assume that water comes to the inlet of the lower

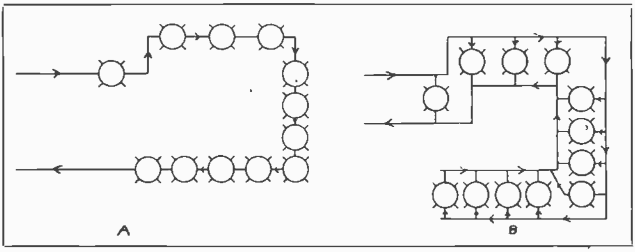


Fig. 40. Diagram for Lamps Connected In Series and In Parallel.

pump with zero pressure, and that this pump is capable of producing a difference in pressure of 50 pounds per square inch, water will issue from the lower pump and pass to the inlet side of the

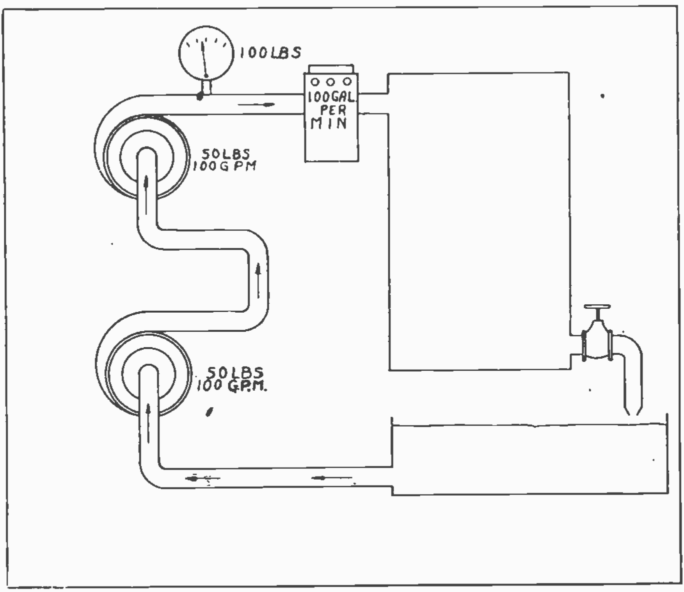


Fig 41. Water Circuit With Two Pumps Connected In Series.

upper pump at this pressure. If the upper pump is capable of producing a difference in pressure of 50 pounds per square inch, this pressure will be added to that already existing at the pump inlet, and from the upper pump water will issue with a pressure of 100 pounds per square inch.

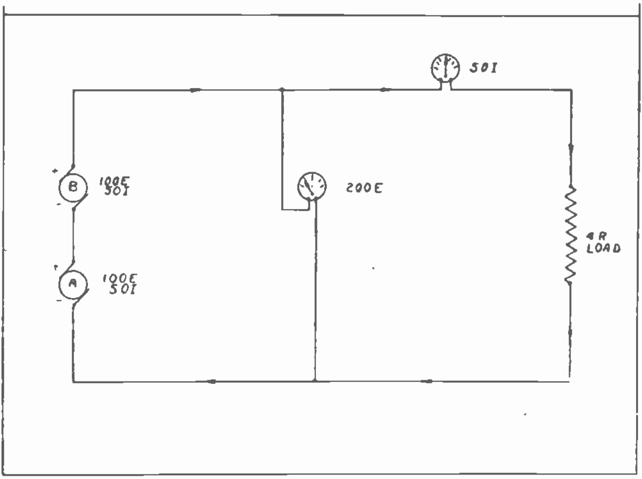


Fig. 42. Electric Circuit With Two Generators Connected In Series.

Fig. 42 shows an electric circuit with two generators connected in series. As in all series circuits, current is the same in all parts, including the generators. The generators are capable of applying a difference in potential of 100 volts each to current flowing through them. Just as with the water circuit of Fig. 41, the electric potential differences will add together and the total for the two generators will be 200 volts.

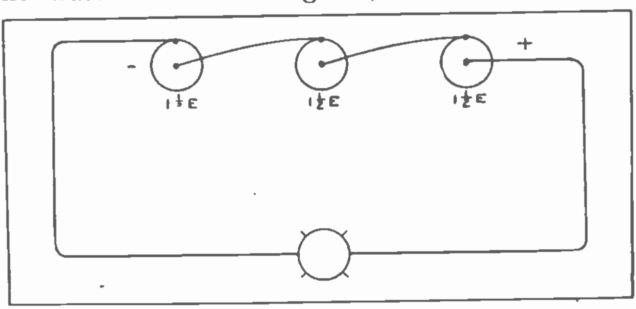


Fig. 43. Sources In Series Add Their Potentials.

Fig. 43 shows three dry cells connected in series and furnishing current to a lamp. Each dry cell produces a potential difference of 1½ volts, so the three in series produce a potential difference of 3 × 1½, or 4½ volts for the battery of cells.

With sources connected in series, **their potential differences add**, but the current can be no more than that through one of the sources. It is not necessary that sources in series provide equal potential differences. If a 110-volt generator and a 10-volt generator are connected together in series they will furnish a total potential difference of 120 volts. But, and this is important, the current taken from the two generators in series must be no greater than safely may be taken from either of the generators alone. If one generator alone is capable of delivering 15 amperes of current, and the other alone is capable of delivering only 3 amperes, then the maximum current from the two in series may be no more than 3 amperes. A greater current will overheat and seriously damage the generator having the smaller current capacity.

SOURCES CONNECTED IN PARALLEL

Assume we have taken the two water pumps which were connected in series in Fig 41 and have re-connected them in parallel. Each pump still is capable of furnishing a pressure difference of 50 pounds per square inch when pumping water at the rate of 100 gallons per minute. If each unit pumps this 100 gallons per minute, the combined flow from the two together passes into the common outlet pipe and makes 200 gallons per minute.

The total difference in pressure from the two pumps in parallel, as they deliver water to the tank circuit, will be equal only to the difference in pressure of one pump. The pressures from the two pumps come together in the common pipe connected to their outlets. If the pressure in this common pipe were any greater than that at the pump outlets, we would have the impossible condition of a high pressure and a low pressure existing at the same point in the water circuit.

Fig. 45 shows two electric generators connected in parallel. Each generator is capable of delivering 50 amperes flow at a difference in pressure of 100 volts. Just as with the parallel water pumps, the current from these parallel generators will add together to make a total flow of 100 amperes, but the potential difference applied to the external circuit will be only that of one generator, or only 100 volts.

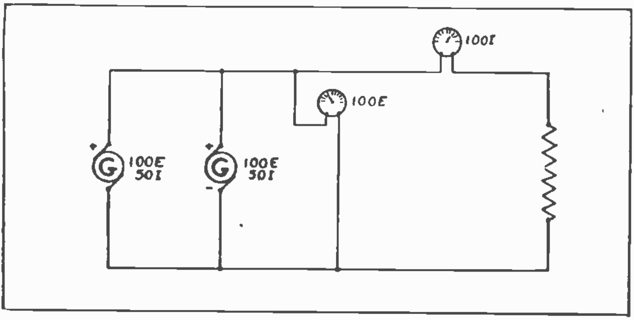


Fig. 45. Electric Circuit With Two Generators In Parallel.

In Fig. 46 we have four dry cells connected together in parallel. The potential difference applied to the resistor will be that of one dry cell, or will be 1½ volts. However, the current which may be sent through the resistor will be four times the current that could be taken from one dry cell. The maximum current from one dry cell ordinarily is considered to be one-quarter ampere, so the four cells in parallel would furnish a maximum of one ampere.

With sources connected together in parallel the combined potential difference will be the same as that from one of the sources alone, but the combined current will be as great as the sum of the currents which might be taken from all the sources.

When sources are connected together in parallel they all must have the same potential difference or voltage. If one of the water pumps in Fig. 44 produced a pressure difference of 100 pounds and the other a pressure difference of 50 pounds, the higher pressure would force water backward

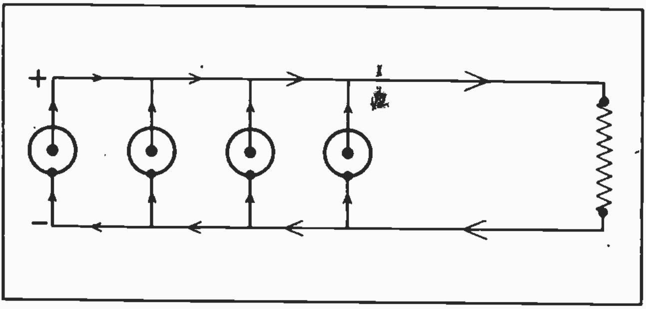


Fig. 46. Sources In Parallel Add Their Currents.

through the pump of lower pressure. If you were to connect a 100-volt generator and a 50-volt generator in parallel, the 100-volt unit would send current in a reverse direction through the 50-volt unit. Connecting a 2-volt storage battery and a 1½-volt dry cell in parallel would send current backward through the dry cell.

Provided that sources in parallel have the same voltage they need not have the same current capacity. You might connect in parallel a large and a small storage cell, because regardless of size all storage cells of a given type provide the same voltage. Each cell would furnish to the external circuit its proportionate share of the total current, and neither cell would force current backward through the other one.

POWER AND ENERGY

When first commencing to study electricity and the electric current we became acquainted with the word energy, and found that energy means the ability to do work. At that time we did not talk about the real meaning of work as the word is used in a mechanical or technical sense. This we must do before we can understand the meaning of electrical power and power measurements.

A common definition says that mechanical **work** is done when any kind of energy is used to produce motion in a body formerly stationary, or to increase the rate of motion of a body, or to slow down its rate of motion. For example, you use muscular energy when you lift a stone from the floor onto a bench, and you do work. Were the stone too heavy for you to lift you would have done no mechanical work no matter how hard you tried, for you would have caused neither motion nor change of the rate of motion in the stone. This latter statement shows how different may be the everyday and the technical uses of a word. Most people would say that you might do a lot of work in trying to lift a stone too heavy to move but the engineer would say that you had done no mechanical work.

The most generally used unit of work is the foot-pound. One foot-pound of work is done when a mass (which us usually call a weight) of one pound is lifted one foot against the force of gravity. The total amount of work done is equal to the number of feet of motion multiplied by the number of pounds moved. If the stone we talked about had a mass (which is usually called a weight) of one through a distance of five feet you would have done 20 times 5, or 100 foot-pounds of work.

Whether you did all the moving of the stone at one time or whether you lifted it through one foot during each hour for five hours the amount of work would have been the same, because work involves only the mass moved and the distance through which it is moved. Time doesn't enter into the matter of mechanical work.

MECHANICAL POWER

Power is the **rate** of doing work. Supposing you lifted the 20-pound stone through the distance of five feet in one second. You would have done 100 foot-pounds of work in one second, and would have worked at a rate of 100 foot-pounds per second.

Your power rate would have been 100 foot-pounds per second. Power involves work and time. One of the units in which power may be measured is "foot-pounds per second". Power is equal to the total amount of work divided by the time taken to do the work. It is assumed that the work is being done at a uniform or constant rate, at least during the period of time measured.

Instead of taking one second to lift the stone supposing you took two seconds. Then your power rate would be 100 foot-pounds per two seconds, or only 50 foot-pounds per second. Taking twice as much time means half the power when the work is the same. If you took four seconds to lift the weight the power rate would be 100 foot-pounds per four seconds, or only 25 foot-pounds per second.

The foot-pound per second is a unit too small to be used in practise. Mechanical power most often is measured in the unit called a **horsepower.** One horsepower is the power rate corresponding to 550 foot-pounds per second. Since there are 60 seconds in a minute, one horsepower corresponds also to 550 times 60, or to 33,000 foot-pounds per minute.

An electric power at the rate of one horsepower would be capable of raising a weight of 33,000 pounds through a distance of one foot in one minute. At the same rate of one horsepower the motor would lift during one minute any number of pounds through a distance such that the pounds times the number of feet equalled 33,000.

ELECTRIC POWER

In order that the electric motor might continue working at the rate of one horsepower we would have to send electric current through the motor at a certain number of amperes when the pressure difference across the motor terminals was some certain number of volts. The number of amperes and the number of volts would have to be such that multiplied together they would equal 746. We now need a unit of electric power to describe this product of amperes and volts. Ordinarily we use a unit called the **watt.** One watt is the power produced by a current of one ampere when the pressure difference is one volt. We could use for our unit of electric power the volt-ampere, meaning the product of volts and amperes which produce the power. The volt-ampere actually is used as a unit of power in some cases, which we shall investigate later on.

The total number of watts of power is equal to the number of amperes of current multiplied by the number of volts pressure difference, both with reference to the device in which power is being produced. In a preceding paragraph we said that the number of amperes times the number of volts must be 746 to produce one horsepower. Then we may say that 746 watts of electric power is equivalent to one mechanical horsepower.

The symbol for electric power in watts is W. We may use this power symbol together with **E** for volts and I for amperes to make a power formula, thus,

$$W = E \times I$$

$$\text{Power in watts} = \text{volts} \times \text{amperes.}$$

With this formula we may learn the number of watts of power when we know the number of volts pressure difference and the number of amperes current. With two more formulas we may learn the number of volts when knowing watts and amperes, and the number of amperes when knowing watts and volts. Here are the formulas:

$$E = \frac{W}{I} \qquad \text{Volts} = \frac{\text{watts}}{\text{amperes}}$$

$$I = \frac{W}{E} \qquad \text{Amperes} = \frac{\text{watts}}{\text{volts}}$$

Here are three typical problems in which we use the three formulas relating to power in watts:

With an ameter in series you find that an electric flatiron is carrying 6 amperes while a voltmeter shows that the voltage difference across the connections to the iron is 120 volts. We may us the formula W = ExI to find the power in watts being used to heat the iron.

$$W = E \times I \qquad W = 120 \times 6 = 720 \text{ watts}$$

Supposing you use an ammeter to measure the current in a lamp as 1½ or 1.5 amperes and find that the lamp is marked as requiring 150 watts. What is the voltage difference at the lamp terminals. To find the number of volts we use the formula, E = W/I.

$$E = \frac{W}{I} = \frac{150}{1.5} = 100 \text{ volts}$$

In this example you are assuming that the lamp actually is using power at the rate of 150 watts. Of course, if the actual power is more or less than the rating of the lamp the number of volts shown by the formula will not be exactly correct.

If the 150-watt lamp were marked with its operating voltage you could use the formua I= W/E to find the normal current in amperes for this lamp. Say that the lamp is marked as requiring 120 volts. The formula would be used thus:

$$I = \frac{W}{E} = \frac{150}{120} = \frac{5}{4} = 1\tfrac{1}{4} \text{ amperes}$$

POWER AND HEAT

When an electric current is forced to flow in a resistance, such as in the resistance of the heating element of an electric range, the rate at which heat is produced depends on the current in amperes and the resistance in ohms. The rate of heat production depends also on the power being used in the resistance, this power being measured in watts. The relation between power in watts, current in amperes, and pressure difference in volts for electrical devices in which there is heating is an important one, and we find that we frequently need a formula which will give the number of watts of power when we know the current and the resistance.

Our first power formula says that $W = E \times I$, or, Watts = volts $\times$ amperes.

Ohm's law for pressure difference says that $E = I \times R$, or, Volts = amperes $\times$ ohms.

Instead of using "volts" in the power formula let's use the equivalent of volts, which, from Ohm's law, we know to be "amperes x ohms". Making this substitution gives a new power formula, like this:

$$\text{Watts} = \text{amperes} \times \text{ohms} \times \text{amperes}$$
$$\text{or} \qquad I \times R \times I$$

In this power formula we have only amperes and ohms, we have gotten rid of the volts. Let's use the formula to learn the power in watts being used in a resistance of 10 ohms when the current is 5 amperes.

$$\text{Watts} = I \times R \times I = 5 \times 10 \times 5 = 250 \text{ watts}$$

Instead of writing this formula as $I \times R \times I$, we might write it as $I \times I \times R$, which would give the same result. When we multiply a quantity by itself, as $I \times I$, we usually say that the quantity is squared. Instead of writing $I \times I$ we would write I^2, which means the same thing. Then our new power formula becomes $W = I^2R$.

You will find as we proceed with our study of electrical apparatus that this formula, $W = I^2R$, is one of the most useful in our whole collection. It always will tell us the number of watts of power used in producing heat in a resistance.

ELECTRIC ENERGY.

The total available energy which may be changed into work, or which will do work, must be a measure of the total amount of work that can be done with that particular source of energy, such as a battery for example. If less than the total available energy does work, then the amount of energy actually used must correspond to the amount of work actually done. Energy and work are so closely related that we use the same units of measurement for both. For instance, the foot-pound is a unit of work and also is a unit of energy which may do work.

The foot-pound is a unit of mechanical energy or work. The foot-pound per second and the horsepower are units of mechanical power. We already have become acquainted with a unit for electric power, the watt, but so far we have no unit in which to measure electric energy.

Our unit of mechanical energy or work, the foot-pound, measures a total quantity of work, such as the work done in lifting the 20-pound stone onto the bench. The foot-pound does not measure a rate of working, or a power rate, but measures a definite quantity of work. To have a unit of electrical energy or work we must have one that represents some total quantity and not a rate of working. Such a unit is the watt-hour.

One **watt-hour** of electric energy is the quantity of energy used with a power rate of one watt when this rate continues for one hour. That is, the watt-hours of energy are equal to the number of watts multiplied by the number of hours during which power is used at this rate. A 60-watt electric lamp uses energy at the rate of 60 watts so long as it is lighted to normal brilliancy. But the total quantity of energy used by the lamp depends also on the total length of time it remains lighted. If the 60-watt lamp is kept lighted for 10 hours it will have used 60 x 10, or 600 watt-hours of electric energy.

Just as we use the kilowatt instead of the watt for measuring large powers, so we use the **kilowatt-hour**, abbreviated **kwhr**, for measuring large quantities of electric energy. Most bills for electric light and power are rendered in kilowatt-hours. It is the total quantity of energy that you use that is the

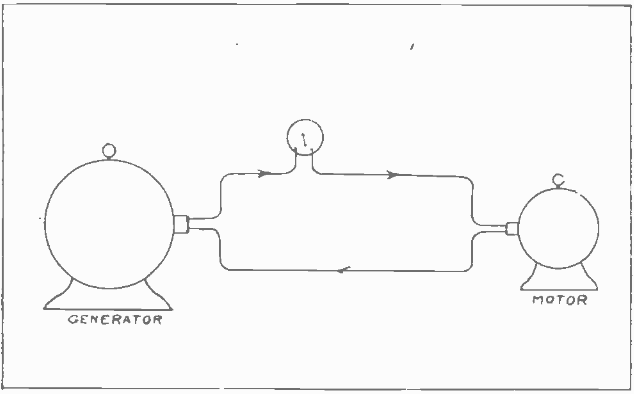


Fig. 8. 200 volt generator supplying 4000 W machine.

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.

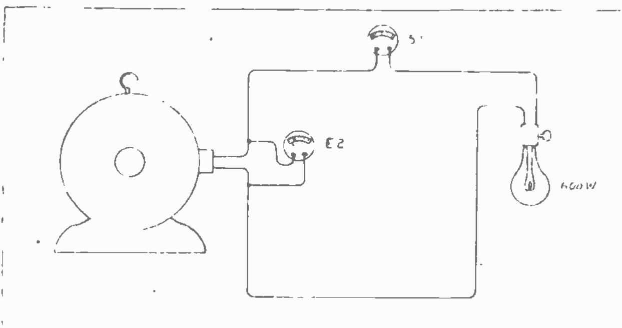


Fig. 9. Generator supplying 5 amps to a 600 watt lamp. What is the generator voltage?

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.

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

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:

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

In which:— $\quad E^2 \div R = W$

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.

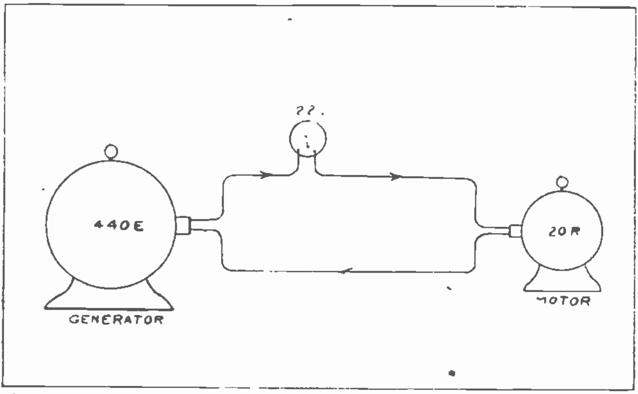


Fig. 10. 440 volt motor supplying 22 amperes to a device of 20 ohms resistance. Check all three of watts law formulas carefully on this circuit.

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.

LINE DROP

In electrical work we often hear the term **Line Drop** used. This refers to the voltage required to force the current through the line resistance alone. This 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 voltage 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:—

E_d. equals line drop in volts.

I equals current in amperes, flowing through line.

R equals line resistance.

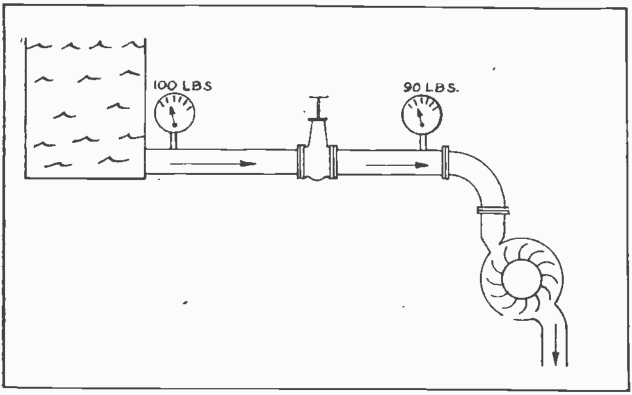


Fig. 11. Water pressure tank and pipe line to water turbine. Note drop in pressure in the pipe line, by readings of the two gauges.

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

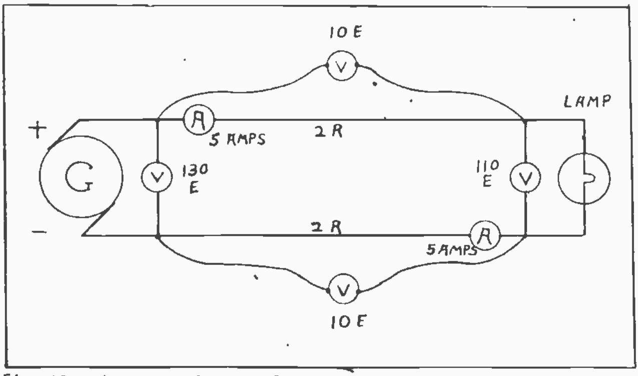


Fig. 12. Generator, lamp and meters connected for testing "voltage drop" and proving Ohms Law Formulas. This is typical of problems encountered by the head electrician in the field.

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.

In Fig. 12 is shown a generator producing 130 volts, 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 has 2 ohms resistance, then by using the formula $I \times R = Ed$, 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.

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 $I \times Ed = W$, or $5 \times 20 = 100$ 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.

POLARITY OF CONNECTIONS

All sources which are connected together in series or in parallel must have their positive and negative terminals connected together in such a way that all of them act to send current in the same direction through the external circuit. With a series connection of sources the positive terminal of one source is connected to the negative terminal of the one following, as shown by the "Correct" diagram in Fig. 47. If one or more of the units are reversed, as in the "Wrong" diagram, the potential of the reversed unit will oppose or buck the potentials of the other units. If the units have equal potentials each one that is reversed will cancel the effect of one that is correctly connected. If the units of Fig. 47 were 2-volt storage battery cells the three conected right would deliver a total of 6 volts, but with one reversed the total external potential difference would be only 2 volts, because two of the cells cancel each other. This has puzzled many men who have assembled a storage battery with one cell reversed.

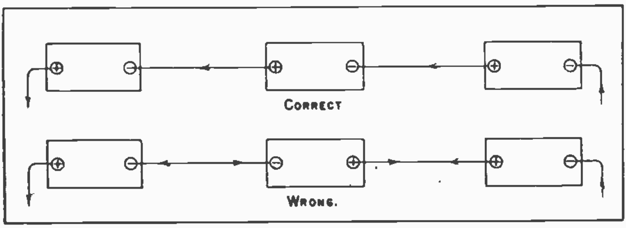


Fig. 47. Polarities of Sources Connected In Series.

Fig. 48 shows three sources connected together in parallel. One diagram shows the right method of connection, with which all three units send current the same way to the external circuit. In the wrong connection one unit is reversed. Then the current from this unit circulates as shown through the other units instead of going to the external circuit. Because of the low internal resistance of sources, such an incorrect parallel connection will cause immense currents to circulate, and the units quickly will overheat and be ruined. In a parallel connection of sources all positive terminals must be connected together and all negative terminals must be connected together.

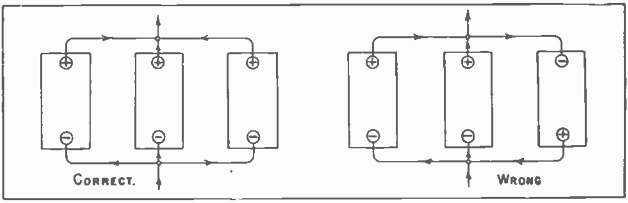


Fig. 48. Polarities of Sources Connected In Parallel.

COMBINED SERIES AND PARALLEL CONNECTIONS

Fig. 49 shows six cells. Three are connected in series to make one group, and the other three are connected in series to make a second group. If these are dry cells furnishing 1½ volts each, the total voltage of each group will be 4½ volts, but the current from the group should be no more than

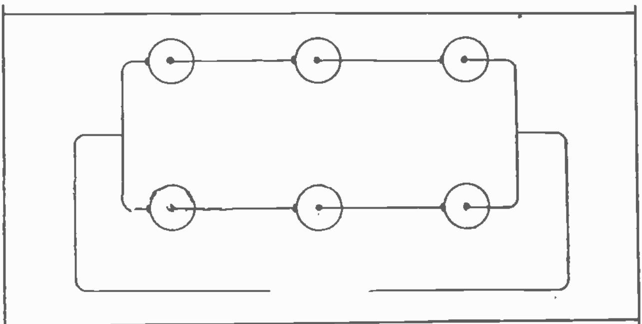


Fig. 49. Six Dry Cells Connected In Series-parallel.

from a single cell. The two groups of Fig. 49 are connected together in parallel. The voltage of sources in parallel is the same as that from one source, so here we still have only 4½ volts. But a parallel connection permits a current equal to the sum of the currents from the sources so connected.

This means that the current from the arrangement of Fig. 49 may be twice the current from one group, or twice the current from one cell.

When units are connected in series to form groups, and the groups connected in parallel, the combination is called **series-parallel** connection. The overall voltage is that of one of the series groups and the overall current is the sum of the currents from the groups.

In Fig. 50 the six cells have been re-connected with pairs in parallel. Two cells in parallel will deliver the same voltage as one cell, but twice the current. The three parallel groups are connected together in series. Sources in series will deliver a total voltage equal to the sum of the separate voltages, so here we have three times the voltage of one cell. But sources in series will deliver a current only as great as that from a single source. Each source in the series connection is a two-cell group whose current is twice that of a single cell, so the curent from the entire combination is only twice that from a single cell.

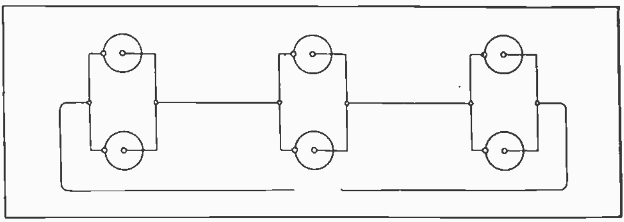


Fig. 50. Six Dry Cells Connected In Parallel-series.

Cells or other sources connected in series to form a group must be considered as though the group were a single source when it comes to making the parallel connection. It would not do to have three cells in one series group to provide 4½ volts, and six cells in the other series group to provide 9 volts. This violates the rule that the voltages must be the same for sources connected together in parallel. The voltages of all series groups must be made alike by using the same number of similar cells in each group.

ELECTRICITY IN MOTION

In the preceding pages we have discussed the behavior of electricity in motion or of the electric current, and have studied most of the important rules and laws which tell just what will happen when electricity flows in a circuit. The subject of the electric current was given first consideration because nearly all practical and useful electric devices and machines depend for their action on flow of current in them; also because an understanding of how this flow takes place will make it easier to understand everything which is to follow.

We have dealt primarily with the action of direct current, which is a current flowing always in one direction around a circuit, but when we come to study alternating current you will find that everything learned about direct current will help in that field, too.

In the following section we shall learn something about how chemical changes produce an electric current, and how things may be turned around to produce useful chemical changes from a flow of current.

VOLTAGE DROPS AROUND A D.C. CIRCUIT

Consider the following facts concerning a series circuit:

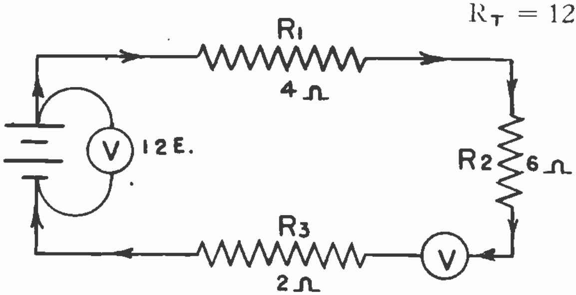
A. The current (I) has only one path.
B. Current in amperes will be the same in all parts.
C. The voltage drops will add to equal the source voltage.
D. R^T will equal the sum of all resistors added together.

Combined Series and Parallel Connections

Example No. 1:

$R_T = R_1 + R_2 + R_3 = 4\,\Omega + 6\,\Omega + 2\,\Omega = 12\,\Omega$

$R_T = 12\,\Omega$



$I_T = \frac{E_T}{R_T} = \frac{12}{12} = 1 I \qquad I_T = 1 I$

E_d across $R_1 = I \times R = 1 \times 4 = 4$ E

E_d across $R_2 = I \times R = 1 \times 6 = 6$ E

E_d across $R_3 = I \times R = 1 \times 2 = 2$ E

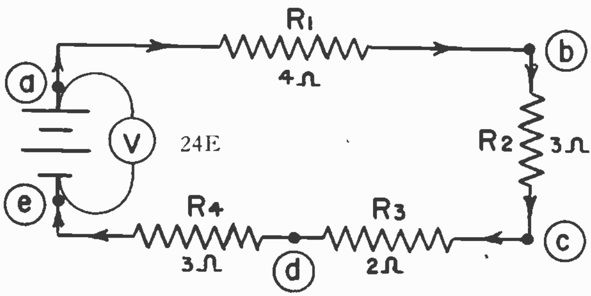
The total E = the sum 12 E

Source Voltage 12 E

The sum of the voltage drops = Applied Voltage.

Example No. 2:

$R_T = R_1 + R_2 + R_3 + R_4 = 4\,\Omega + 3\,\Omega + 2\,\Omega + 3\,\Omega = 12\,\Omega \qquad R_T = 12\,\Omega$



$= \frac{E_T}{R_T} \quad \frac{24}{12} = 2 I \qquad I_T = 2 I$

E across $R_1 = I \times R = 2 \times 4 = 8\ E$

E_d across $R_2 = I \times R = 2 \times 3 = 6\ E$

E_d across $R_3 = I \times R = 2 \times 2 = 4\ E$

E_d across $R_4 = I \times R = 2 \times 3 = 6\ E$

Total $E_d = 24\ E$

Source $E = 24\ E$

Questions Example No. 2:

1. What is the rate of current flow in R_1, R_2, R_3, R_4?
2. What is the rate of current flow in the battery?
3. What is the drop in voltage from a to b, b to c, c to d, d to e?
4. What is the drop in voltage from a to b, a to c, a to d, a to e?
5. Does the sum of the voltage drops equal the voltage drop from a to e?
6. What is the value of the rise in voltage from e to a.
   What is this voltage called? (Terminal voltage)—(Not EMF)
7. Does the sum of the voltage drops across R_1, R_2, R_3, R_4 = Source E?
8. Can we conclude that this would be true in all cases?
9. What general statement can we make concerning this relation?

Summarizing

Kirchoff's Voltage Law:

The sum of the voltage drops around a D.C. circuit will equal the source or applied voltage.

DISTRIBUTION OF CURRENT IN PARALLEL CIRCUITS

Consider the following facts concerning parallel circuits:

A. Current has two or more paths.
B. I^T will be the sum of all currents.
C. Equal voltage will be applied to all paths joined to the same two points.

Combined Series and Parallel Connections

Example No. 1

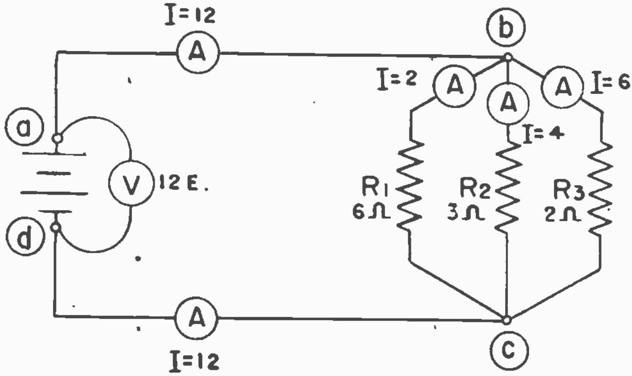
Note: E applied to each path is the same

$$I \text{ in } R_1 = \frac{E}{R_1} = \frac{12}{6} = 2\ I$$

$$I \text{ in } R_2 = \frac{E}{R_2} = \frac{12}{3} = 4\ I$$

$$I \text{ in } R_3 = \frac{E}{R_3} = \frac{12}{2} = 6\ I$$

The sum $= 12\ I$ $\qquad I_T = 12$



Special Notice—

Current flows in all paths but it flows at highest rate in the path of lowest resistance.

Questions:

1. What is the current flow from a to b?
2. Does current divided at point b?
3. What is the current in the path of R_1?
4. What is the current in the path of R_2?
5. What is the current in the path of R_3?
6. Does the sum of these currents equal the current flowing from a to b?
7. Does the current flowing toward point b equal the sum of the current flowing away from that point?
8. Does the sum of the currents in R_1, R_2 and R_3 equal the current flowing from c to d?
9. Does the sum of the currents flowing toward point c equal the current flowing away from c?

10. Would the same be true in all parallel circuits?
11. What conclusions can be reached?

Summarizing

Kirchoff's Current Law:

The sum of the currents flowing toward any point in a network will equal the sum of the currents flowing away from the same point.

ELECTRICITY AND CHEMICAL ACTION

The fact that chemical action will produce a direct current of electricity was accidentally discovered in 1785 by Luigi Galvani, an Italian professor of physiology, while dissecting a frog. He touched the frog to a piece of iron and noticed that one of the legs twitched, just as your leg would do when traversed by an electric current. While trying to explain what really happened in the frog leg, Volta, after whom the volt is named, devised an arrangement of alternate pieces of two different metals separated by paper moistened in water and acid. This "voltaic pile" produced a continuous flow of electricity.

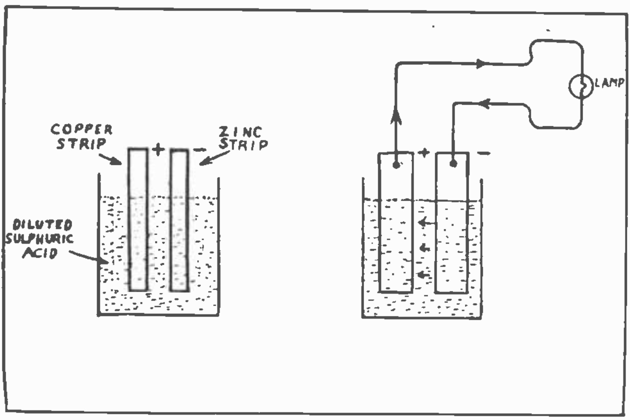


Fig. 52. The Simplest Type of Voltaic Cell for Producing a Current.

The simplest "voltaic cell" consists of a strip of copper and a strip of zinc immersed in a solution of sulphuric acid and water as in Fig. 52. The metals are called elements or plates, and the liquid is called the **electrolyte.** An electrolyte is a mixture with water of any substance which permit the liquid to act as a conductor for electricity. The substances used are salts, acids or alkalies.

PRIMARY AND SECONDARY CELLS

If the elements of the cell in Fig. 52 are connected to an external circuit, current will flow through this circuit from the copper element to the zinc element. The copper has become positive with reference to the zinc, which is negative. At the same time the zinc will commence dissolving into the acid electrolyte and be destroyed. Hydrogen gas will separate from the acid and collect as bubbles on the copper. The gas is an insulator, and after a short time will so cover the copper as to prevent further flow of current.

All practical cells which produce current by destruction of a metal have zinc or some compound of zinc for one of their elements, and the zinc element always is negative. In all these cells the zinc is gradually dissolved or eaten away, but nothing happens to the other element, which is positive. In all cells there is a pronounced tendency for gas to collect on the positive element and to retard or prevent flow of current. This action of the gas is called **polarization** of the cell. Most of the differences between various types of cells are due to the different methods of removing the gas or of **depolarizing** the cell so that it may continue to furnish current. When nearly all of the zinc has been eaten away, or when there is practically no more hydrogen to separate from the electrolyte, the useful life of the cell is ended.

An electric cell which produces an emf and a flow of current while its elements and electrolyte undergo changes which render them no longer useful is called a **primary cell.**

When discussing Fig. 16 we talked about a cell in which the chemical changes may be reversed by sending through the cell a current in a direction the opposite of that which the cell furnishes to an external circuit. There the elements or plates and the electrolyte are restored to their original condition and the cell again is ready to provide an emf and current flow. Such a reversible cell is called a **secondary cell** to distinguish it from a primary cell. Secondary cells usually are called **storage cells,** and two or more connected together are a storage battery. Fig. 53 illustrates a number of large storage batteries used for furnishing current in telephone work.

CELL CURRENT AND VOLTAGE

The emf and potential difference produced by any voltaic cell, primary or secondary, depends entirely on the materials in the plates and in the electrolyte and not at all on the size or construction. A cell the size of your little finger would furnish just the same potential difference as any cell in the batteries of Fig. 53, provided both contained the same kinds of elements and electrolyte.

The current that may be taken from a voltaic cell as a source depends on the the emf of the cell, on the internal resistance of the cell and the resistance of the connected circuit, and on the degree to which polarization increases the internal resistance and thus cuts down the current. Current flow from a cell follows Ohm's law, $I = E/R$, just as does current in every other circuit containing an emf and resistance.

The total quantity of current that may be taken from any voltaic cell before the cell becomes discharged depends on the quantities of active chemical materials in the plates and the electrolyte. Since more material means a bigger cell or battery, it follows that the bigger the cell or battery the more electricity it will deliver. The quantity of electricity delivered might be measured in coulombs, but nearly always is measured in ampere-hours. The quantity actually is measured as the number of

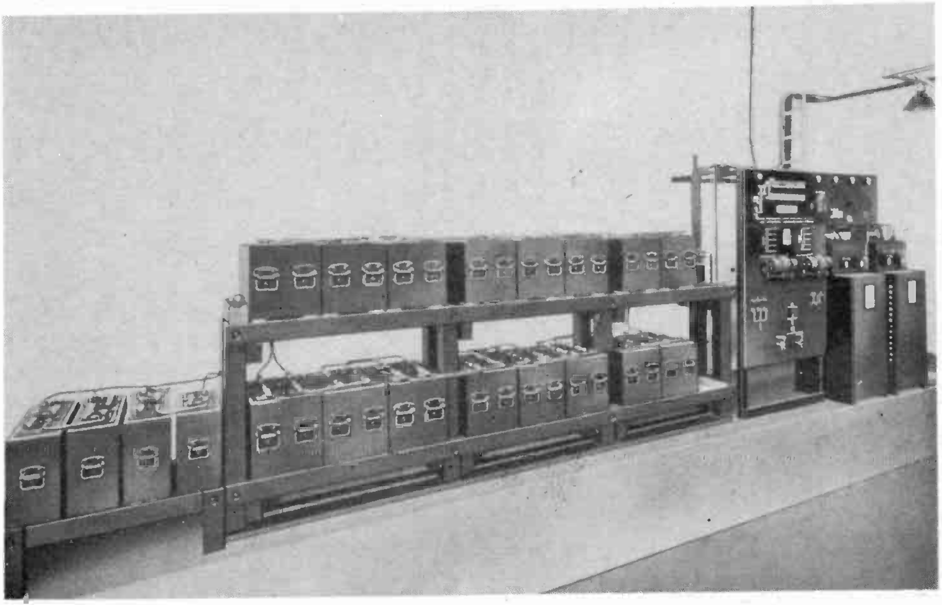


Fig. 53. Storage Batteries Which Furnish Electric Power for a Telephone System.

ampere-hours that are delivered before the terminal voltage or potential difference drops to some specified value.

TWO-FLUID CELLS

The most practical way of preventing excessive polarization is to provide in the electrolyte, or mixed with the electrolyte, some substance which will furnish a plentiful supply of oxygen. The oxygen combines with the hydrogen to form water which remains harmlessly in the electrolyte space. Several types of cells accomplish such depolarization by using two different fluids or liquids.

One of the earliest two-fluid cells is the Daniell cell of Fig. 54. Inside the glass jar is a copper cylinder on one side of which is a copper basket in which are placed crystals of copper sulphate or "blue vitriol". Inside the copper is a jar made of porous earthenware and around the outside of the copper is a solution of copper sulphate in water. Inside the porous jar is a piece of zinc with which has been mixed mercury. This amalgamated zinc is immersed in a water solution of zinc sulphate.

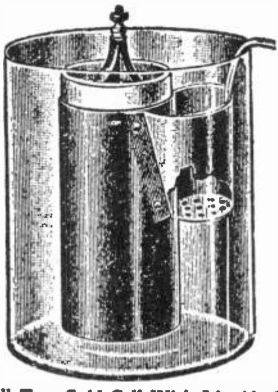


Fig. 54. A Daniell Two-fluid Cell With Liquids Separated By a Porous Cup.

The porous jar keeps the two liquids separate, but allows electricity to pass through the liquid-filled pores.

A less costly type of Daniell cell is the gravity cell of Fig. 55. The copper sulphate solution is much heavier than the solution of zinc sulphate, so the zinc sulphate solution floats on top of the copper sulphate and they remain separated. In the copper sulphate solution at the bottom is placed a star-shaped arrangement of copper strips, and in the zinc sulphate at the top is suspended a "crow-foot" of amalgamated zinc.

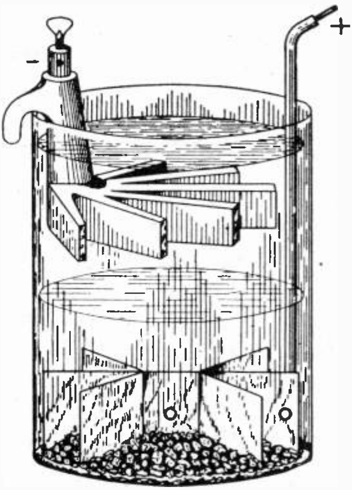


Fig. 55. Gravity Cell In Which the Lighter Liquid Floats Above the Heavier One.

Either type of Daniell cell furnishes a potential difference which remains almost constant at 1.08 volts. In order that the materials shall not deteriorate too rapidly these cells must be used in circuits where there is a continual small flow of current, hence these types may be called closed-circuit cells. These and other varieties of two-fluid cells are no longer commonly used, having been displaced by dry cells by the Edison primary cell, and by power furnished by lines which now enter most buildings to furnish electric light and power from central stations.

EDISON PRIMARY CELL

The only primary cell of present-day importance using liquid electrolyte in jars is the Edison type, called also the Edison-Lalande cell, illustrated by Fig. 56. This cell is much used for telephone work,

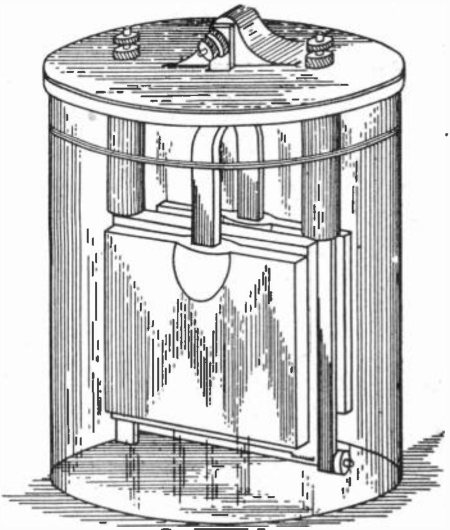


Fig. 56. The Edison Primary Cell.

for railway signals as installed in Fig. 57, for many other kinds of signal systems, alarms, beacons, electric clocks, and for any small current requirements such as for operating electric time stamps and similar devices.

There are three plates. The two outer ones, made of zinc and mercury, are connected together and to the negative terminal. The center plate (positive) contains copper oxide, the oxide furnishing oxygen for depolarizing action. This plate is covered with a thin layer of metallic copper to provide good conductivity. The liquid electrolyte is a 20 per cent solution of sodium hydroxide (caustic soda) in water. The liquid is covered with a layer of mineral oil which prevents evaporation of the electrolyte and prevents air from reaching and combining with the caustic.

Edison Primary Cell

The Edison primary cell has a potential of 0.95 volt when no current is flowing. When current flows the potential difference drops to between 0.6 and 0.7 volt. Various sizes of cells will furnish currents of from one to six amperes intermittently, or from 0.6 to four amperes continuously. The total discharge ability varies from 75 to 1,000 ampere-hours in the several sizes.

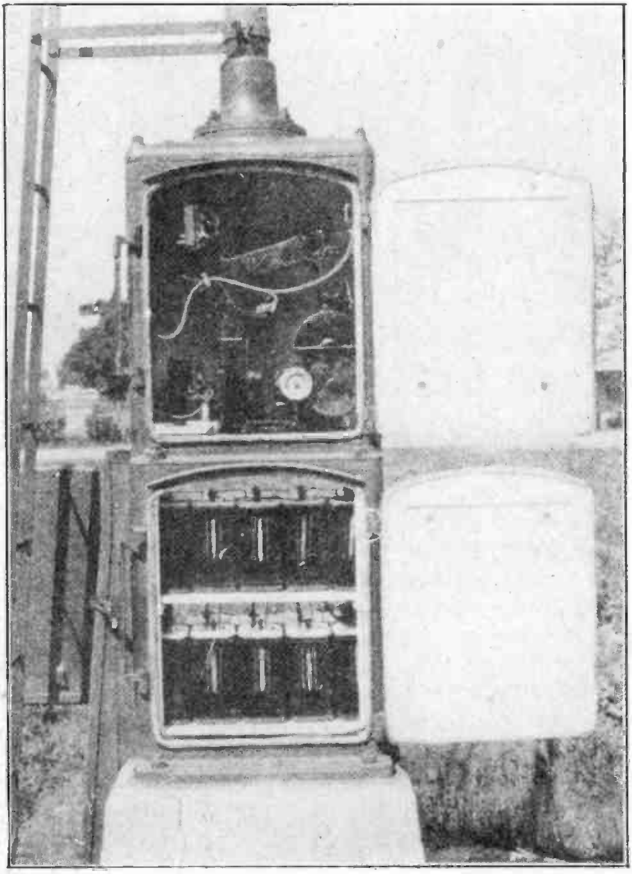


Fig. 57. Edison Primary Cells In a Railway Signal Tower.

When the cell has been used enough to dissolve the zinc to the limit of practical discharge a thin section, called an indicator panel, at the bottom of the zinc element will break through as shown in Fig. 58. The panel at the left has been eaten partly through, and the one at the right has completely disappeared, indicating complete exhaustion. Small sizes of cells may be discarded when exhausted, but in all the larger sizes it is economical to renew the plates and electrolyte, and put in fresh oil. These supplies are obtainable from the manufacturers or from electrical supply stores.

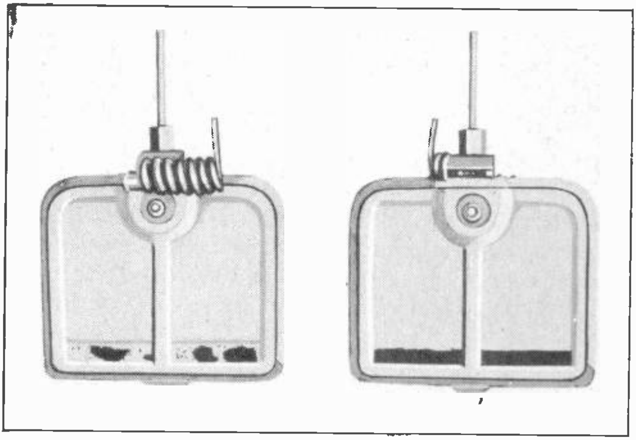


Fig. 58. Zinc Elements of Edison Primary Cell, Illustrating Indicator Panels Which Show When Cell Is Exhausted.

To renew a cell the old plates are taken out of the cell cover and thrown away, the liquid is emptied out and the jar washed clean. The new elements are held in the cover with the original nuts and washers. The jar is partly filled with clean water, then the caustic soda is added slowly while constantly stirring the liquid with a clean stick or a glass rod. The solution must be handled very carefully, as it will burn the flesh and clothing if spilled on them. The liquid level then is brought up to the correct point by adding more water.

If the cell is to be used on open-circuit work, where there is not a continual flow of current, a piece of copper wire should be connected between positive and negative terminals and left in place for a couple of minutes after the plates are immersed in the hot solution. The wire then must be removed. The electrolyte level should be kept within ¾ inch of the top of the jar by adding water to replace any evaporation. After adding water the electrolyte should be stirred to mix it.

DRY CELLS

From the standpoint of general usefulness the dry cell is the most important of the primary cells, since millions are made and sold every year. Fig. 59 shows the external appearance and internal construction of the usual form of dry cell. The cell is contained within a cylinder or can of zinc which is the active negative element and which forms the negative terminal when connections are made by contact with other conductors, or to which may be fastened some style of screw or clip terminal for wire connections. Around the outside of the zinc is a cardboard cover which is the insulator for the cell.

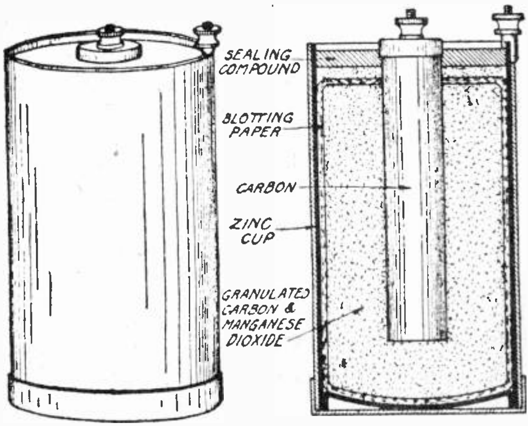


Fig. 59. The Outside and the Internal Construction of a Dry Cell.

The positive element of the cell is a rod of carbon, on top of which is a brass cap to which may be fastened a screw or clip terminal when such a connection is used. Surrounding the carbon rod is a mixture of black oxide or manganese and powdered carbon. The black oxide furnishes oxygen for depolarizing and the carbon provides good electrical conductivity. The positive carbon rod and the surrounding conductive mixture are insulated from the negative zinc cup by a layer of porous pulp paper or blotting paper which lines the zinc. The electrolyte is a solution of sal ammoniac in water, which saturates the mixture and the paper liner. The top of the mixture around the carbon rod is covered with sand or other porous material and is sealed with a hard insulating compound. The largest size of the so-called "dry" cell actually contains about 3.4 fluid ounces of water.

The largest dry cell is 2½ inches in diameter and 6 inches high, the No. 6 size, and the smallest is 7/16 inch in diameter and 1 1/16 inches high, the size N. There are many intermediate sizes. Regardless of size, one dry cell furnishes a potential of 1½ volts when delivering no current or a very small current, and smaller voltages as the current increases. A cell in good condition will show from 1.50 volts for the larger sizes down to 1.47 volts for the smallest size when a voltmeter is connected across the cell terminals. The testing voltmeter must be of a high-resistance type, which means it has a high resistance of its own and consequently takes little current. Usually, dry cells should not be tested with an ammeter or any other instrument of low resistance which allows the flow of a larger current than the cell is designed to deliver.

When a dry cell has been discharged to the limit of its useful life its voltage will have dropped to between 0.75 and 1.1 while a normal current is flowing from it. This "end voltage" depends on the class of cell tested. The large No. 6 cells should show 0.85 volt if of industrial types, 0.93 volt if of general purpose type, and 1.08 volt if of telephone type. Flashlamp cells are discharged when they show 0.75 to 0.90 volt while delivering normal current. Hearing aid cells are discharged at 1.0 volt, and radio batteries are discharged when they drop to

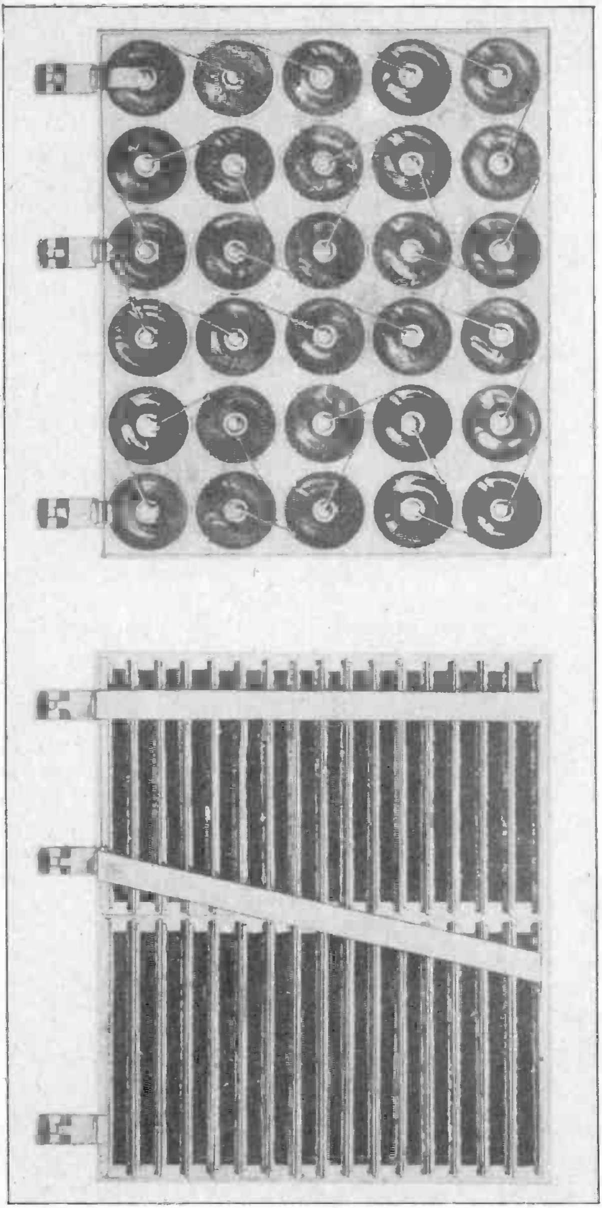


Fig. 60. Internal Construction of Two Types of Radio "B" Batteries.

between 1.0 and 1.1 volts per cell.

Radio batteries consist of a number of dry cells assembled in a case and connected togehter in series to furnish various total voltages. Fig. 60 shows at the left a battery assembled with a special form of flat cells which save space and at the right an otherwise similar battery made up from cylindrical cells. The series connection shows up clearly in the right-hand picture. Here the left-hand terminal is the negative terminal. From here to the middle terminal there are 15 cells in series, providing 22½ volts at 1½ volts per cell. From the middle to the right-hand terminal there are 15 more cells, providing an additional 22½ volts. Consequently, between the left-hand terminal and middle terminal, or from the middle to the right-hand terminal we may obtaain 22½ volts, and from the left-hand to the right-hand terminals may obtain 45 volts. Radio batteries in standard types may contain as many as 60 cells, to provide 90 volts. All the internal series connections are soldered or welded.

Dry cells deteriorate even if not used. A good cell may be kept idle or stored for about a year before deterioration is at all serious. Of a number of cells stored, five or six per cent will show a noticeable drop in voltage at the end of six months. Deterioration will be much worse if the cells are stored where it is damp, or where the temperature is very high. When the voltage of a dry cell has dropped, the internal resistance has increased to a high value. Therefore, **one low-voltage cell used in a series or parallel group with other good cells will greatly reduce the voltage or current from the whole group.** A badly discharged dry cell often will show bulges or wet spots on the cardboard cover where the zinc has been eaten nearly or entirely through.

Being of the primary type, dry cells cannot be recharged; however, the life of such cells may be considerably extended by periodically passing through them a low value of current. Commercial charging devices are now available to simplify such recovery, and the procedure consists merely of connecting the dry cell to the proper voltage and allowing current of a relatively low value to flow through it for about 24 hours. Proper restoration procedure may increase the life of the ordinary dry cell many times.

AIR-CELL BATTERY

The air-cell battery or air-depolarized battery is a type designed for radio use. The negative element is zinc. The positive element is a rod of porous carbon which extends through the cell cover to the outside of the battery so that oxygen from the outside air may enter through the pores of the carbor to effect depolarization. The electrolyte is a solution of caustic soda in water.

Each air cell furnishes a potential difference of 1.25 volts while delivering its normal current. The cell potential will drop gradually to about 1.15 volts at the end of its useful life. The air cell cannot be recharged nor can its elements be renewed. The only care required during the life of such a battery is to periodically add clean water through a filler opening to keep the electrolyte level at the correct point.

STORAGE CELLS AND STORAGE BATTERIES

Storage battery cells may be of the type using plates of lead and lead peroxide with an electrolyte of diluted sulphuric acid. This is called the **lead-acid** type. Another type uses plate materials of iron and nickel with a caustic electrolyte. This is the Edison storage battery or the **nickel-iron-alkaline** storage battery. Both of these types of storage batteries will be examined in detail during a later section of our work.

ELECTROLYTE CELLS

At the left-hand side of Fig. 61 we have a plate of zinc and another of carbon immersed in an electrolyte and connected through an external resistor.

This voltaic cell will produce an emf or voltage, and current will flow through the external circuit from the carbon to the zinc while flowing inside the cell from zinc to carbon. We call the zinc the negative plate or element and the carbon the positive plate or element, these polarities referring to the potentials applied to the external circuit. Zinc dissolves from the negative plate and combines with other chemicals in the electrolyte.

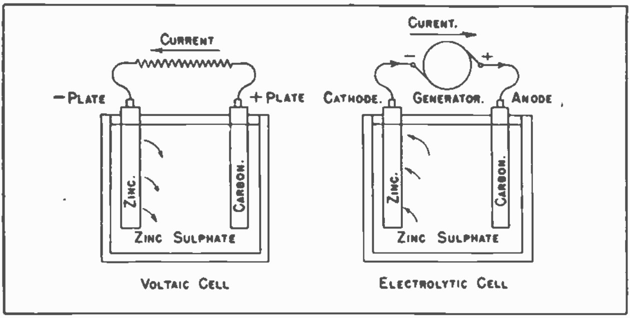


Fig. 61. Current Flow In Voltaic and Electrolytic Cells.

At the right-hand side of Fig. 61 we have a cell with the same elements and with an electrolyte containing zinc in the form of zinc sulphate. If direct current is sent from an external source so that the current flows from carbon to zinc through the electrolyte, zinc will leave the electrolyte and will be deposited as pure metallic zinc on the plate or element toward which the current flows. This is an **electrolytic cell** and the action in the cell is called **electrolysis.**

When talking about electrolytic cells we speak of the elements or plates as the **electrodes.** The electrode through which current enters the cell and passes into the electrolyte is called the **anode.** The one through which current leaves the electrolyte and the cell is called the **cathode.** The anode is connected to the positive side of the external current source and the cathode to the negative side of the source.

When one ounce of zinc has been dissolved from the negative plate in the voltaic cell the cell will have delivered a total quantity of 23.24 ampere-hours of electricity. If the same quantity of 23.24 ampere-hours of electricity is put through the electrolytic cell there will be deposited one ounce of zinc on the cathode from an electrolyte which contains zinc in some chemical form. The accompanying table lists the number of ampere-hours required to either dissolve or deposit one ounce of various common metals, depending on the direction of current flow.

AMPERE-HOURS PER OUNCE OF METAL DEPOSITED OR DISSOLVED IN CELLS

Gold	3.85	Copper	23.90
Silver	7.05	Tungsten	24.80
Lead	7.33	Nickel	25.90
Cadmium	13.53	Iron	(27.20 (40.83
Tin	(12.9 (25.6	Chromium	43.80
Platinum	15.57	Aluminum	84.50
Zinc	23.24		

Where two values are shown the quantity depends on the chemical form of the metal.

Electrolysis may be defined as the separation or addition of chemicals in an electrolyte, and the dissolving of metals from the anode and depositing of metals on the cathode, or at least the production of certain gases at the electrodes, when current flows. With many metals the process will work either way, the metal may be either dissolved or deposited, but with some metals, including nickel, iron and cobalt, the process can result in depositing the metals.

EFFICIENCY OF ELECTRICAL APPARATUS

As has been previously stated, the devices designed to generate electrical energy do not really generate at all; instead, they **convert** some other form of energy into electrical energy; for example, the regular D.C. generator merely converts mechanical energy provided by the driving unit into electrical energy, while the dry cell or the storage battery **converts** chemical energy into electrical energy.

The process of converting energy from one form to another always involves a loss of some of the **useful** energy; in other words, it is not possible to obtain from any conversion device as much useful energy as was put into it. In the case of the generator, some of the mechanical energy required to drive it is lost in overcoming bearing friction, windage, and brush friction; moreover, some of the electrical energy produced is wasted inside the generator due to the heat generated by the armature current flowing through the resistance of the armature winding.

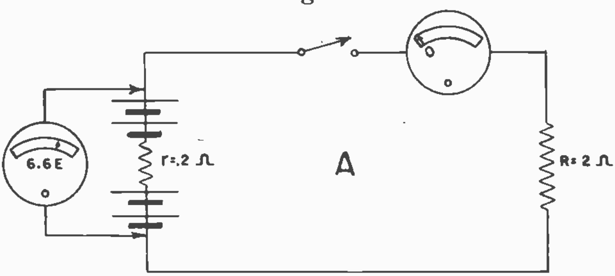
As it is impossible to get out of any conversion device as much useful energy as was put into it, it becomes of interest to consider just how effective a given device will be in converting some other form of energy into electrical energy; this question brings us to the problem of efficiency. If we put into the input end of a given conversion device a given amount of energy, and if we were able to take from the output end the same amount of energy, then we would have a conversion device that had an efficiency of 100 per cent. If we were able to obtain from the output end only one half of the energy put in, then the efficiency of the device would be only 50 per cent. Although large generators usually have an efficiency considerably above 90 per cent, there are many types of electrical apparatus that have much lower efficiencies; for example, many fractional horsepower types of motors such as those used on fans, sewing machines, washers, drills, and similar applications convert less than 50 per cent of the electrical energy supplied to them into useful mechanical energy, the rest being converted mostly into useless heat inside the machine. Such machines may then be said to be less than 50 per cent efficient.

Consideration of the above material shows that the efficiency of a conversion device is the relationship between the input and the output, the formula for percentage efficiency being as follows:

$$\text{Per cent Efficiency } \frac{\text{output}}{\text{input}} \times 100$$

In electrical problems involving efficiency, the output and input is usually expressed in watts. Consideration of the formula shows that the greater the output obtained for a given input, the higher will be the efficiency of the device.

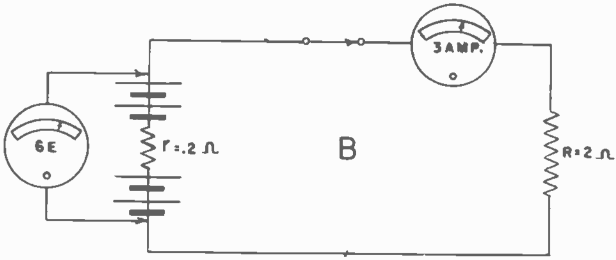
To illustrate the effect of the **internal** resistance of a conversion device, and to show the effect this internal resistance will have on the per cent efficiency of the unit, let us take an automobile battery as an example. Here we have a simple circuit consisting of a battery having an **internal** resistance (r) and **external** resistance (R) an ammeter to measure the circuit current, and a voltmeter to measure the circuit voltage.



When the circuit is open as shown in figure A the battery is supplying practically no current, for the amount drawn by the meter is just a few milliamperes. As the internal resistance of the ordinary battery is quite low, the voltage drop due to this small current flowing such a low resistance would be negligible. As the external circuit is open, the voltmeter reads 6.6 volts and this value is called the "open circuit voltage" of the battery. For all practical purposes, this 6.6 volts may be regarded as the e.m.f. of this battery, since the voltage drop across the internal resistance (r) is so small that it can be neglected.

It might be well to note here that the e.m.f. of any battery, cell, or generator is the total voltage that such a unit can produce. When this voltage is measured by any device that draws current, it is obvious that this current, flowing through the internal resistance of the device, causes a voltage drop inside the unit; therefore, the meter reading in this case will be less than the e.m.f. by an amount equal to the internal voltage drop caused by the small meter current.

Due to the fact that most voltmeters draw a very small current, the internal voltage drop is usually so small, when compared with the meter reading, that it can be disregarded; for this reason, the open circuit voltage reading obtained from most voltage generating devices may be rgearded as being equivalent to the e.m.f. of the device.



When the switch is closed as shown in figure B, current flows through the external resistor R and the voltmeter reading falls to 6 volts; this voltmeter reading is called the "closed circuit voltage". As the difference between the two readings is 0.6 volts, it is evident that the load current, flowing through the internal resistance of the source is producing a voltage drop inside the battery of 0.6 volt. The internal resistance of the battery can therefore be found by Ohms law, for the resistance of any part of a circuit is equal to the voltage drop across that part divided by the current through that part, therefore if the ammeter indicates 3 amperes, and Er represents the voltage drop across r and Ir is the current through r then:

$$r = \frac{Er}{Ir} = \frac{0.6}{3} = 0.2 \text{ ohms}$$

The internal resistance of the battery is 0.2 ohms. It has been previously stated that

$$\text{Per cent Eff.} = \frac{\text{output}}{\text{input}} \times 100$$

But, as we have no direct means of measuring the input to a battery, we must use a different formula. As the input of any device is equal to the output plus the losses in the device, we may substitute "output + losses" for input and this gives

$$\%\ \text{Eff.} = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

Expressing all values in watts we have

$$\text{output} = I^2R = 3\text{x}3\text{x}2 = 18 \text{ watts}$$
$$\text{losses} = I^2r = 3\text{x}3\text{x}0.2 = 1.8 \text{ watts}$$

$$\text{per cent Eff.} = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

$$= \frac{18}{18 + 1.8} \times 100$$

$$= \frac{18}{19.8} \times 100$$

$$= 91\% \text{ approx.}$$

Since only 91% of the total energy appears in the external circuit 9% is lost, mostly in uselessly heating the battery.

If the internal resistance were increased, the efficiency of the battery would be still further reduced until, when the **internal** resistance became equal to the **external** resistance, the efficiency of the battery would have fallen to 50 per cent. Thus it is evident that for high efficiency, the internal resistance should be kept as low as possible.

ELECTROPLATING

One of the most useful applications of electrolysis is in the plating of certain metals over other base metals to provide decorative effects, to provide protection against rust and corrosion, to provide a wear-resisting surface, or even for the building up and replacement of worn surfaces. Most electroplating is done with chromium, gold, silver, nickel, brass, copper, chromium and zinc although some

such work is done also with platinum, tin, cobalt, iron and lead. As an example, a very thin plating of chromium provides a surface harder than the hardest steel, which protects the base metal, will reduce wear, lessen friction, and at the same time provide a fine appearance.

As shown by Fig. 62, the object to be plated is made the cathode in an electrolyte containing in some chemical compound the metal which is to be plated onto the base material. Anodes are used on both sides of or all around the cathode so that electricity may flow from all directions to the article being plated and cause an even deposit of the plated metal.

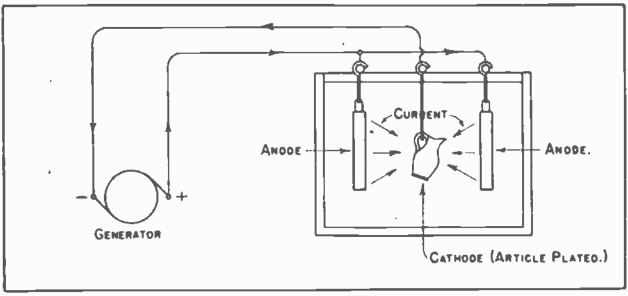


Fig. 62. Principle of Eectroplating.

The exact chemicals, currents, voltages, temperatures and general procedure vary not only with the kind of metal being plated but with the ideas of those in charge of the shop. For example, nickel plating often is done with an electrolyte containing nickel sulphate or nickel ammonium sulphate, to which may be added ammonium sulphate to increase the conductivity, some acid to help keep the anode rough, and something like glue or glucose to make the plating extra bright.

When plating with gold we obtain the effect called red gold by adding copper cyanide or copper acetate to the electrolyte, obtain white gold by adding some nickel cyanide, and obtain green gold by adding silver cyanides.

The anodes may be of some material, such as carbon, which is not affected by the electrolytic action whereupon all the plated metal must come from the electrolyte and chemicals containing this metal must be added to the liquid at intervals. In other cases the anode is made of the metal to be plated, as in Fig. 63. Here, in plating with copper, the anode is of copper. Then copper dissolves from the anode into the electrolyte while being deposited from the electrolyte onto the cathode. The object of the operator is to get metal dissolved into the bath (electrolyte) as fast as it plates out. As the anode metal dissolves, it generates an emf just as dissolving a metal generates an emf in a voltaic cell. Under ideal conditions this generated emf would equal the emf consumed in depositing metal on the cathode, so the external source would need to provide only enough voltage to overcome the resistance in the cell and the connections.

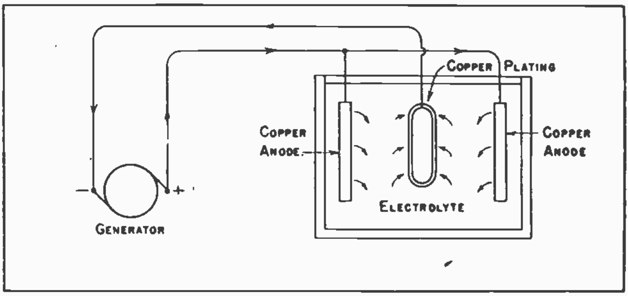


Fig. 63. Plating With Anodes of the Metal Being Plated.

Used tin cans are detinned by making them the anode in an electrolytic cell having a caustic soda electrolyte. The tin is recovered as it plates out of the solution, while the iron of the old cans is left in a pure state.

A variety of electroplating called electroforming is used for making the electrotypes used in printing and engraving, also for making the dies or stamps for reproducing phonograph records. The original phonograph recording, which is in wax, is covered with a layer of conductive graphite and then electroplated with copper. The shell of hard copper thus formed is used as a master plate on which are made a number of copies by another depositing of metal in an electrolytic cell. These copies are used for stamping or molding the records to be sold. Similar processes are used for coating cheap plaster images with copper so that they look like bronze statues, for plating baby shoes which are to be preserved, and even for plating of such delicate things as flowers and plants.

ELECTROLYSIS OF WATER AND OF SALT

Water consists chemically of two parts by volume of the gas hydrogen and one part of the gas oxygen. With an electrolysis cell, whose principle is shown by Fig. 64, it is possible, by decomposing water, to produce these two gases in the relative volumes mentioned. A little caustic soda is added to the water to make it conductive. When direct current flows as shown by the diagram, hydrogen bubbles up from the cathode and oxygen at the anode. The water disappears, but the caustic soda remains. The electrodes usually are made of nickel-plated iron.

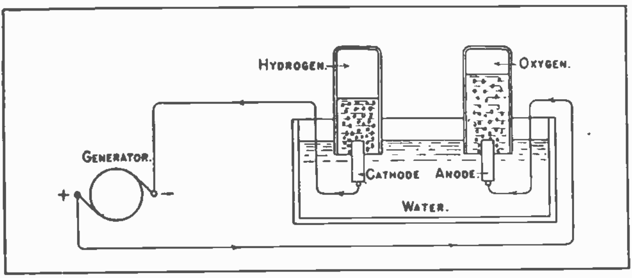


Fig. 64. Electrolysis of Water, Producing the Gases Hydrogen and Oxygen.

The hydrogen thus produced is used in combination with the oxygen in the process of oxy-hydrogen welding, for the manufacture of ammonia and of wood alcohol, for help in separating metals from their oxides, for the making of cooking fats from various oils, and for inflating balloons and dirigible airships. The oxygen is used for welding in the oxy-acetylene process, and in great amounts for dozens of chemical processes and medicinal uses.

When a water solution of sodium chloride, ordinary salt, is decomposed in an electrolytic cell it is possible to obtain a whole variety of some of the most important chemicals used in commerce and industry as well as in the home. We obtain caustic soda for use in making soaps, as a cleaning agent, and in various electrolytes. We obtain chlorine for use in bleaching of cloth, paper and other materials, for use as a disinfectant and for purification of city drinking water, for use in medicine and in photography, and for use in certain processes of extracting metals from their ores. We obtain sodium chlorate which is used in the manufacture of dyes, medicines, and explosives. Finally, we obtain hydrogen, whose uses already have been mentioned.

ELECTROLYTIC REFINING

In the processes of electrolytic refining of metals we start out with an alloy or mixture of metals which is used as the anode in a cell. The principal metal to be recovered dissolves into the electrolyte, as do also all other metals which are less "noble". By a noble metal we mean one that resists corrosion, a form of chemical decomposition. Platinum, gold and iridium are examples of highly noble metals, because they remain unaffected by most acids and other chemicals. Zinc and iron are not noble metals, they are base metals, because they are easily attacked by many chemicals. The electrolyte, current, voltage, temperature and the general operating conditions are such that the principal metal and those less noble pass into the electrolyte, while all those more noble remain in the anode.

The principal metal to be recovered is deposited in a pure state on the cathode of the cell. The less noble metals remain in the electrolyte where they sink to form the "mud". About nine-tenths of all the refined copper is produced electrolytically. Gold, silver and arsenic are recovered in the same process.

Cell circuits are operated at about 200 volts and 12,000 amperes. The cathode builds up from an original weight of about 10 pounds to 200 pounds with addition of copper to it. Total copper refining capacity before recent expansions was about 1,600,000 tons a year, which, for the electrolytic action alone would take a current of about 250,000 amperes at 200 volts flowing day and night every day if all the work were done in one spot.

In refining at the United States mints the bullion (alloy for the anodes) consists of about 50 to 60 per cent silver and base metals, 30 to 35 per cent gold, and 10 to 15 per cent copper. The electrolyte is made with nitric acid and silver nitrate. Silver crystals are deposited on the cathodes, from which they are scraped off. From the remains of the anodes is recovered gold which is 80 to 90 per cent pure. This is sent to the gold refinery where the

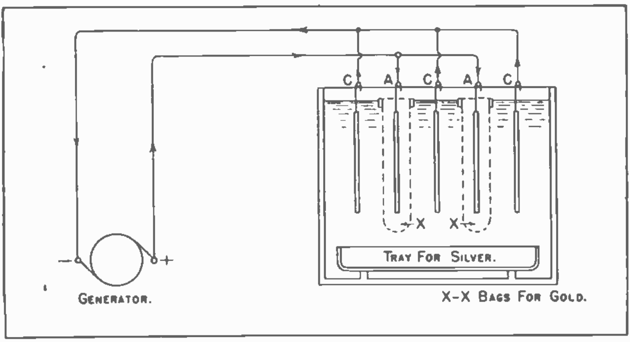


Fig. 65. Cell for Electrolytic Refining of Silver.

gold is purified and where such valuable metals as platinum and palladium are recovered at the same time.

One style of electrolytic refining cell is shown by Fig. 65 where the cathodes are marked **C** and the anodes **A**. The anodes are encased in cloth bags which catch the slime that contains gold. The cathodes are of stainless steel, from which the deposited silver is scraped mechanically into trays.

ELECTROLYTIC FURNACE

Fig. 66 shows the action of an electrolytic cell which is at the same time a furnace, and with which is produced aluminum. Electrolytic furnaces are also used for the production of magnesium, sodium, calcium, cerium and beryllium. Some of these names may sound strange, but the substances are of great practical usefulness. For instance, steel alloyed with beryllium has such strength, toughness and other valuable properties that the results are almost unbelievevabe.

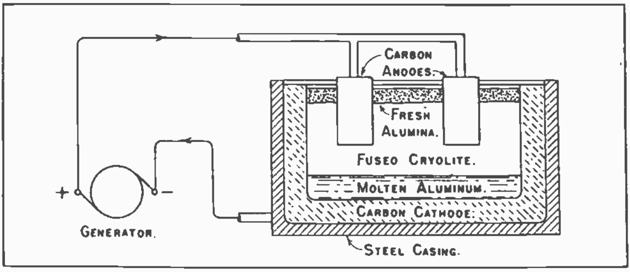
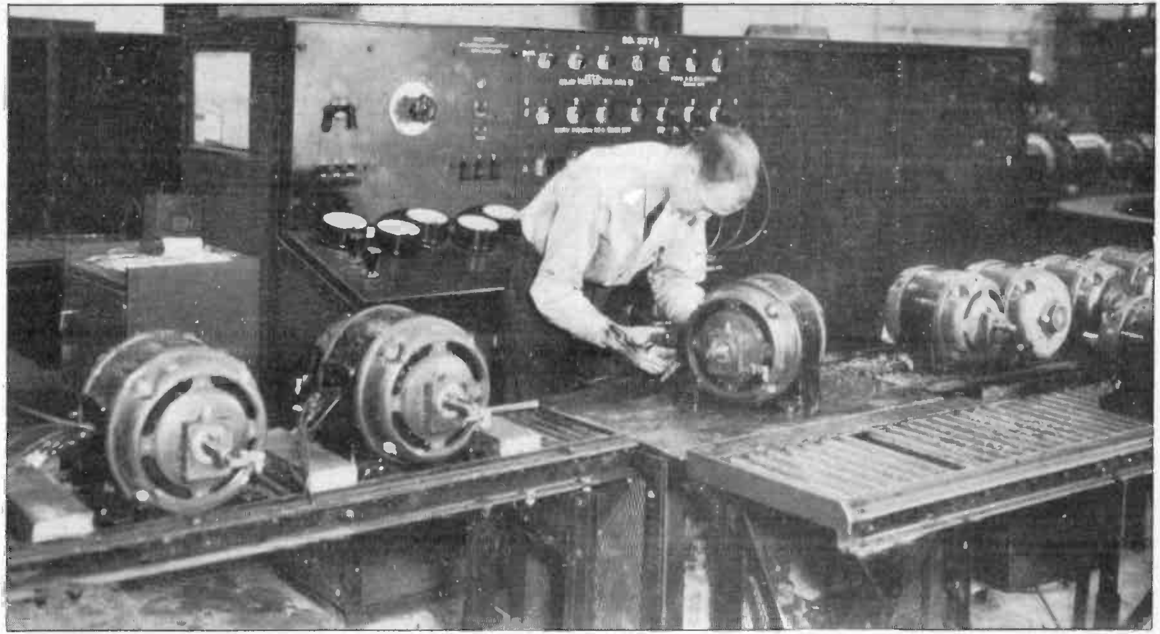


Fig. 66. Electrolytic Furnace for Producing Metallic Aluminum.

The ore of aluminum is called bauxite, which occurs naturally in earthy masses and in small rock-like grains. The bauxite is treated in another kind of electric furnace to produce alumina, which is aluminum and oxygen. This alumina is added on top of the electrolyte in the electrolytic furnace. The electrolyte is cryolite, a substance of icy or waxlike appearance coming from Greenland, and containing aluminum, sodium and fluorine. The current that causes the electrolysis keeps the temperature of the bath at about 1,800° F., which is the reason for calling this a furnace.

The anodes through which current enters the cell are blocks of carbon. The cathode is the molten aluminum itself which settles to the bottom of the cell, and the carbon lining which is encased by steel.

All voltaic cells produce direct current and all electrolytic cells require the flow of direct current. These two fields are by far the most important present uses of direct current. The other great fields of electricty require the use of alternating current, with which we now shall prepare to get acquainted. As the first step in this preparation we shall study magnetism and electromagnetism in the following section. It is the combination of magnetism and the electric current that is the foundation of all alternating-current applications and also of some direct-current applications which we still have to investigate.



Completed electrical motors being given final tests.

MAGNETISM AND ELECTROMAGNETISM

A magnet is a piece of iron or steel which has the ability to attract and hold other pieces of iron and steel, and which is attracted and held in certain positions by another magnet. Doubtless you have used a toy magnet to pick up nails and similar articles. Magnets are put to practical use in magnetic tack hammers which hold the steel tack to be driven, in magnetized screw drivers which will hold a screw, in the compass which points north and south because it is attracted by the earth which itself is a huge magnet, and in many other ways.

NATURAL MAGNETS were first found in Magnesia, a country in Asia Minor, about 600 B. C., and for this reason were called magnetic or magnets. (See Fig. 67.)

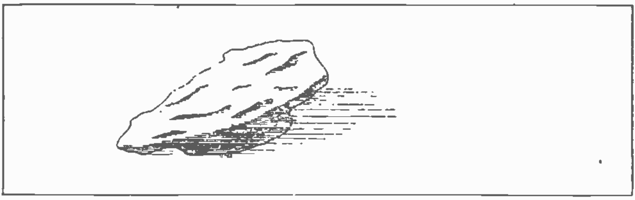


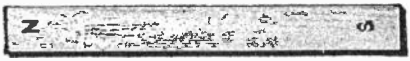
Fig. 67. Sketch of natural magnet or lodestone.

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.

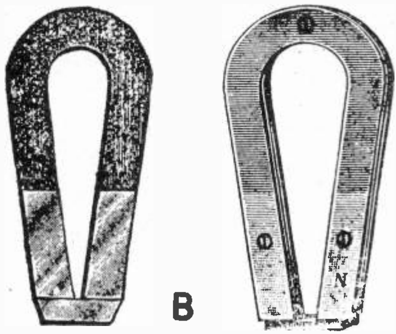
ARTIFICIAL MAGNETS are made of steel and iron, in various forms. Common types are the straight bar and horseshoe forms. (See Fig. 67A and

67B.) 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. 67A. Common bar magnet.
Fig. 67B. 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. 68, 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

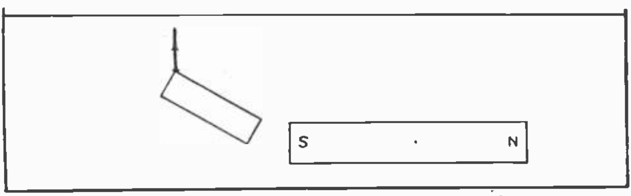


Fig. 68. The small bar or iron attracting the nails, obtains its magnetism by induction from being near the large magnet.

lose its charge. This is an example of induced magnetism.

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. 69.)

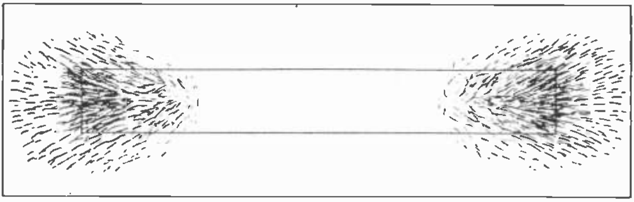


Fig. 69. Sketch of bar magnet showing how iron filings are attracted almost entirely at its ends or poles.

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.

EARTH'S MAGNETISM

We have learned that the north pole of one magnet attracts the south pole of another magnet, and that the south pole of one attracts the north pole of the other. We know also that the north pole of the compass points toward the geographic north on the earth. Since the north pole of the compass must be pointing toward the south pole of the magnet which is attracting it (the earth), the earth's south magnetic pole must be near its north geographic pole. This is shown by Fig. 70.

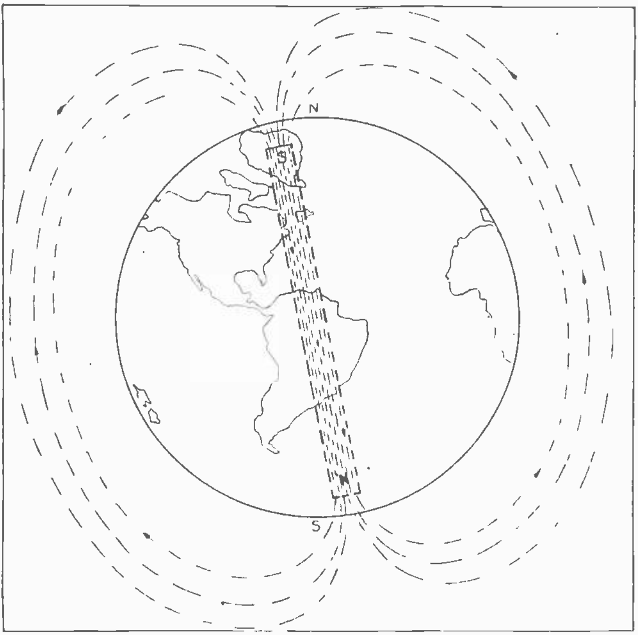


Fig. 70. Sketch showing earth's magnetic field and poles. Note that the magnetic poles do not exactly align with the geographical poles.

The earth's magnet poles are not exactly at its geographic poles or are not exactly at the ends of the earth's axis. Consequently, the magnetic compass does not point to the true geographic north and south. Aviators, marines and surveyors make suitable allowances for the difference between magnetic north and geographic north. The difference varies at various places.

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 Figs. 71A and 71B.

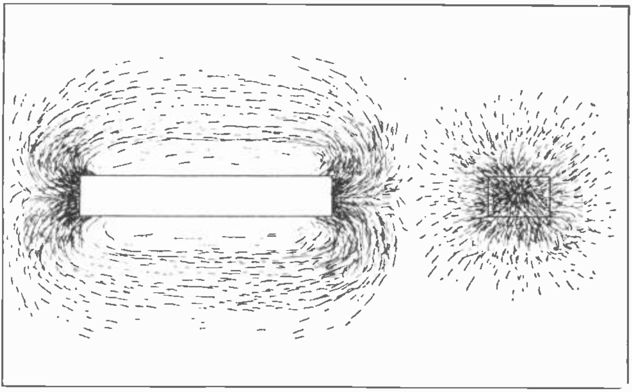


Fig. 71-A. Iron filings on a paper over a bar magnet, show shape of lines of force around the magnet. (Left).
Fig. 71-B. Filings over end of magnet. (Right).

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. 72.

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.

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. 72, 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.

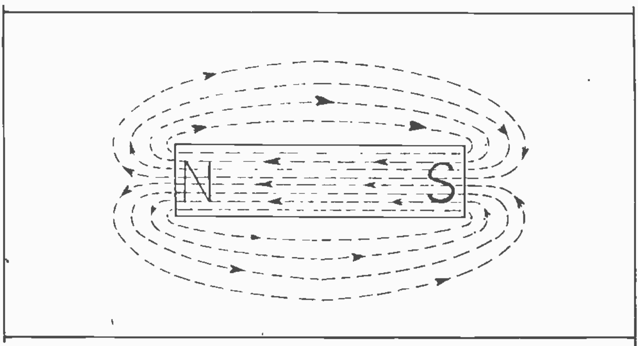


Fig. 72. Sketch of magnetic field, showing direction of lines, inside and outside the magnet.

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. 73.

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.**

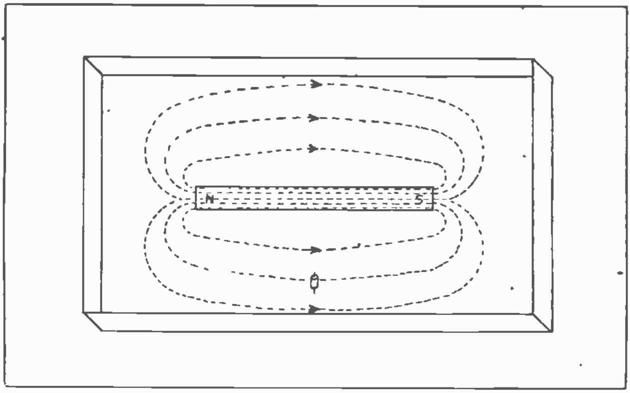


Fig. 73. Floating a needle in a cork, in water over a magnet, to show shape of lines of force.

ACTION OF MAGNETIC FIELDS

When two magnets are placed with unlike poles near each other as in Fig. 74, we find that their lines of force combine in one common path through them both as shown by the dotted lines.

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. 75, 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

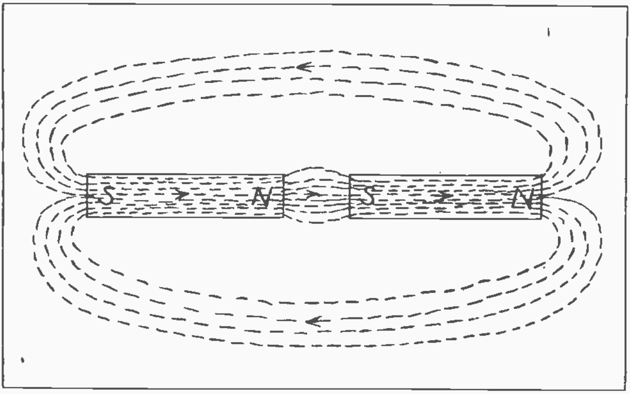


Fig. 74. Two bar magnets with unlike poles near each other, and attracting. Note how their fields join.

the magnets push apart or repel each other to avoid this conflict or crowding of the opposing fields.

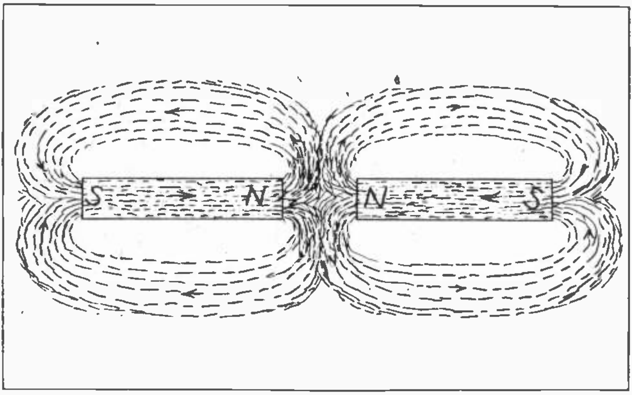


Fig. 75. Two bar magnets with like poles near each other and repelling. Note how their fields oppose.

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. 76.

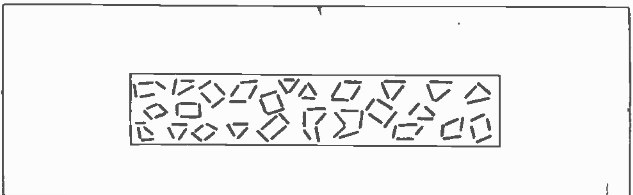


Fig. 76. Simple sketch showing the supposed arrangement of molecules in an unmagnetized bar of iron.

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. 77.)

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.

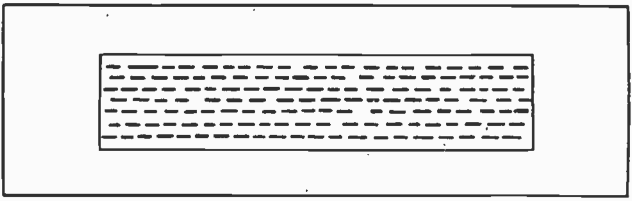


Fig. 77. Molecules lined up, in a fully magnetized bar.

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 one method of 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.

MAGNETIC AND NON-MAGNETIC MATERIALS

Iron and steel are the only materials having such magnetic properties as allow making them into useful magnets. That is, only iron and steel can be magnetized strongly enough to make them useful in magnetic circuits. Nickel and cobalt are weakly magnetic, but not enough so to be useful for making magnets, especially in view of the fact that these metals are much more costly than iron or steel.

Other metals mixed with iron or steel to make various "alloys" change the magnetic properties. Using half iron and half cobalt makes an alloy more easily magnetized than the purest iron. Chromium and nickel mixed into iron to make stainless steel will produce an alloy that cannot be magnetized, but using straight chromium to make another type of stainless steel produces one that is magnetic.

Using small quantities of chromium, tungsten, cobalt, aluminum or nickel to alloy the steel produces magnets which not only are very strong but which retain their magnetism with but little loss over long periods of time, thus making excellent permanent magnets. Among the most generally used permanent magnets are those of the Alnico alloys containing aluminum and nickel along with the iron. These are stronger and more permanent than the older cobalt magnets which, in turn, are better than the still older types using tungsten and chromium.

Among the metals which are entirely non-magnetic or which cannot be magnetized when used alone are copper, aluminum and manganese. Yet when these three are mixed in certain proportions to make Heusler's alloys the result is a metal about one-third as good as cast iron for a magnet. Tin is another non-magnetic metal, yet an alloy of copper, tin and manganese is slightly magnetic.

When we wish to use steel for its strength, yet wish to have the metal non-magnetic, we make alloys containing small quantities of copper, nickel, chromium and manganese. Steel thus alloyed to be non-magnetic is called paramagnetic.

Antimony and bismuth act very peculiarly. The stronger the magnetic field in which these metals are placed the fewer lines of force travel through the antimony or bismuth. These metals are said to be diamagnetic.

All materials which have not been mentioned in the preceding paragraphs are wholly non-magnetic. They canot be magnetized and they have not the slightest effect on a magnetic field in which they are placed. The non-magnetic materials include air and all other gases, all the liquids, all metals not already mentioned, and all other solid substances such as glass, wood, paper and so on.

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.

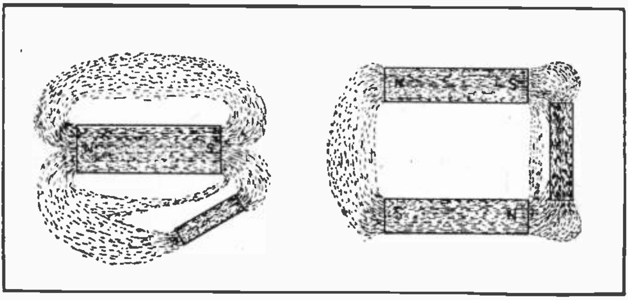


Fig. 78A & B. Sketches showing how lines of force can be distorted and made to follow the easier path through the small iron bars.

If we place a small bar of soft iron in the field of a larger magnet as in Fig. 78A or near the ends of two magnets as in Fig. 78B, 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 has 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. 79A and 79B.)

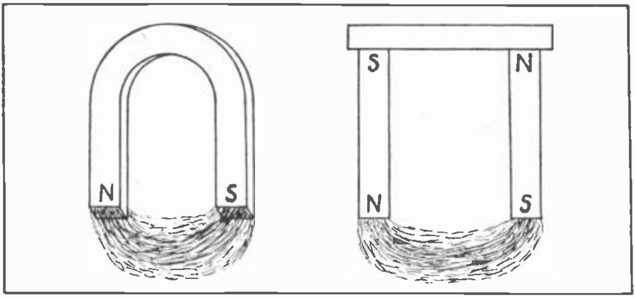


Fig. 79A. Horseshoe magnets have a much shorter flux path through air from pole to pole.
Fig. 79B. Double magnet constructed in horseshoe shape, also to shorten its air gap.

In Fig. 79B, 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. 80, 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.

PULLING STRENGTH

Horseshoe 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 Figs. 80 and 81.)

In Fig. 81, the lines must pass a considerable distance through air, which greatly weakens them. In Fig. 80, the lines can travel entirely within a closed iron path or circuit of much lower reluctance, and give a much stronger pull.

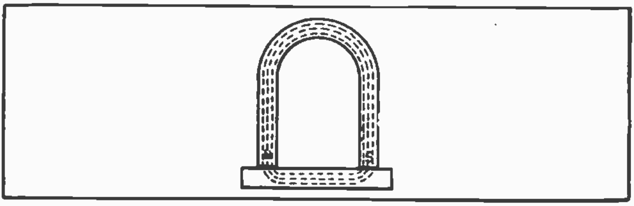


Fig. 80. Horseshoe magnet with keeper bar across its poles to decrease air gap when not in use.

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

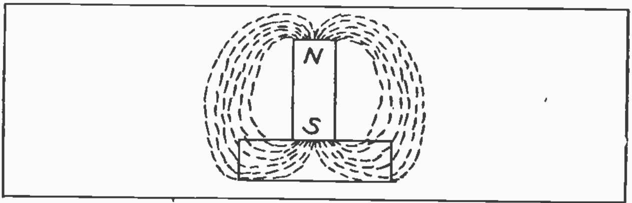


Fig. 81. Bar magnet attracting a piece of iron. Note the long path through air, which the lines of force must take.

EFFECTS 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.

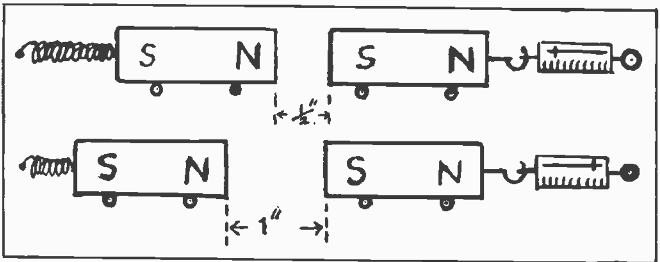


Fig. 82.-A. & B. Doubling the distance between two magnets, decreases their pull to ¼ of what it was.

If two magnets are placed as in Fig. 82A, and their pull measured, and then they are moved farther apart as in Fig. 82B, 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.**

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**

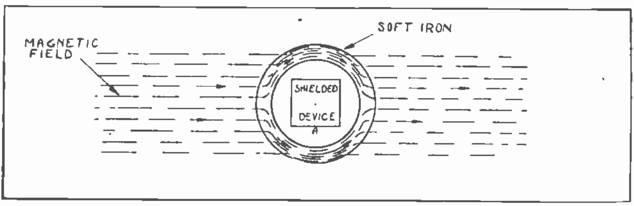


Fig. 83. Iron shield to deflect lines of force away from instrument or device (A).

spaces or objects, by leading it around through an easier path. As before mentioned the line of force will largely choose the easiest path. So if we arrange a shield of iron around a device as in Fig. 83, we can distort the flux around, and prevent most of it from entering the shielded area.

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. 84.)

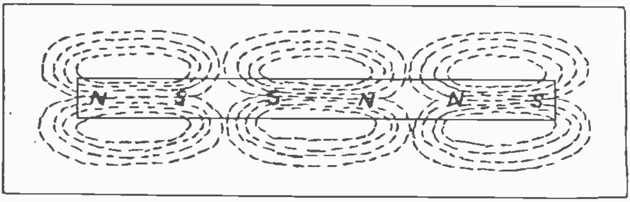


Fig. 84. Consequent poles in a bar magnet.

If a long magnetized bar is broken into several pieces, each piece will take on separate north and south poles. (See Fig. 85.)

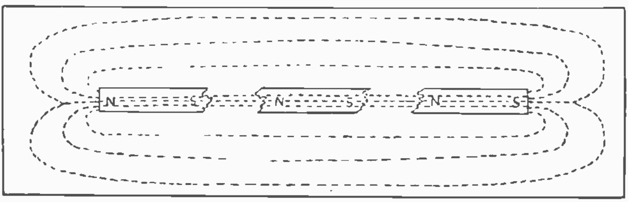


Fig. 85. Bar magnet broken into several pieces. Note each piece takes on separate poles in this case.

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 Figs. 86A and 86B.)

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.**

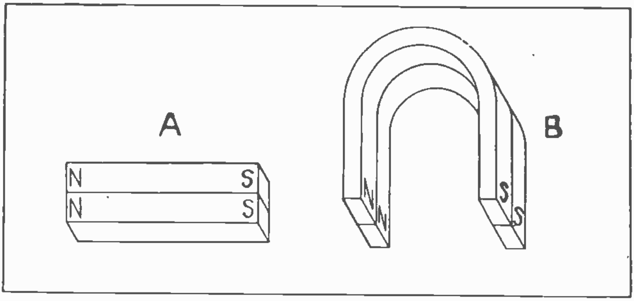


Fig. 86A. Compound bar magnet.
Fig. 86B. Compound horseshoe magnet.

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. 70.

ELECTROMAGNETISM

We have become familiar with the behavior of the electric current in electric circuits and have learned how magnetic lines of force act in a magnetic circuit. Now we are going to learn how to produce magnetic lines of force and magnetic fields by using an electric current, or how to produce the kind of a magnet called an **electromagnet.**

For several hundred years the early scientific experimenters knew something about the electric current and something about magnets and magnetism. Yet it was only a little more than 100 years ago that our modern electrical industry and science got its real start when it was found possible to produce a magnet with an electric current and then to produce electric current from magnetism. The first "strong" electromagnet was made in 1830. It would lift nine pounds. Later that year Joseph Henry, a famous American physicist, made an electromagnet that would lift more than 700 pounds, and in 1831 made one that would lift nearly a ton.

The fundamental fact on which depends all our uses of electromagnetism is that magnetic lines of force appear around a conductor when current flows in that conductor. That is, we may use electric current to produce a magnetic field around a wire.

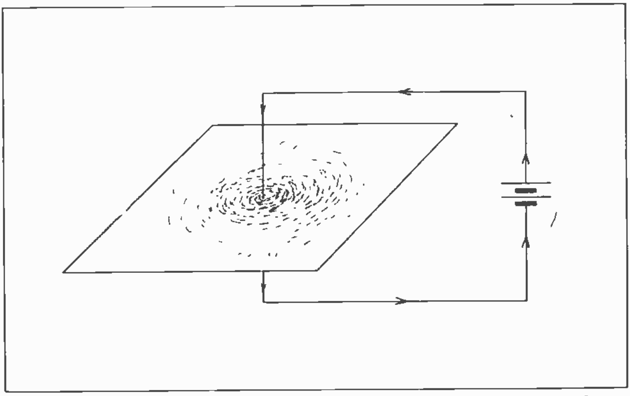


Fig. 87. Electro-magnetic lines shown by iron filings around a conductor.

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. 87, and sprinkle iron filings on the paper, they will arrange themselves in a pattern as shown.

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. 88. 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 direc-

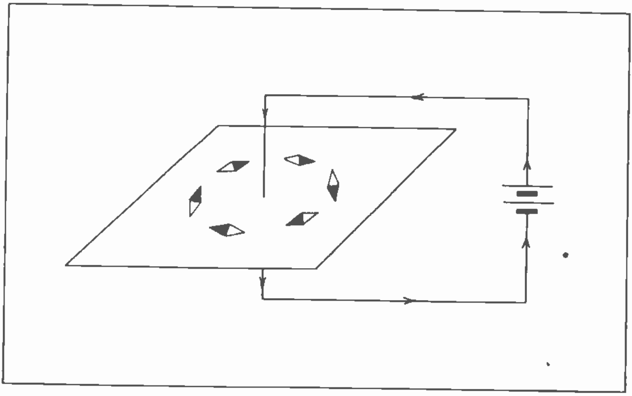


Fig. 88. Small compass needles showing shape and direction of lines around a conductor.

tion 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.

DIRECTION OF LINES AROUND CONDUCTORS

Note the direction of current in the wire in Fig. 88, 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. 89.

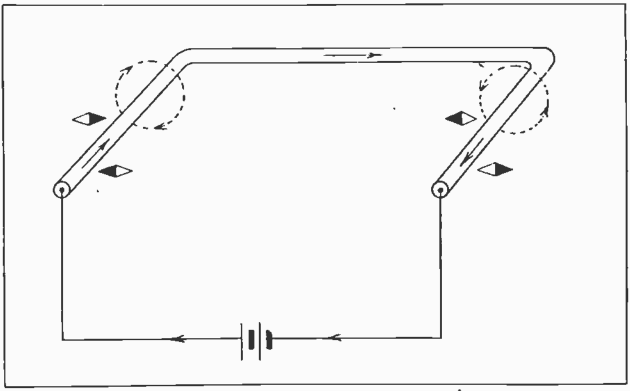


Fig. 89. Convenient compass test for direction of flux around conductors. Note carefully the direction of current and flux of each end of the wire.

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.

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. 91A.

In Fig. 91B, 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.

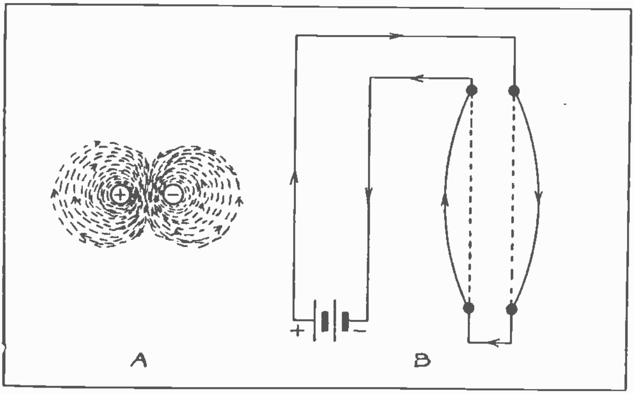


Fig. 91. This sketch shows the repulsion of parallel wires, carrying current in opposite directions.

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 Figs. 92A and 92B.

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. 92B, 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.

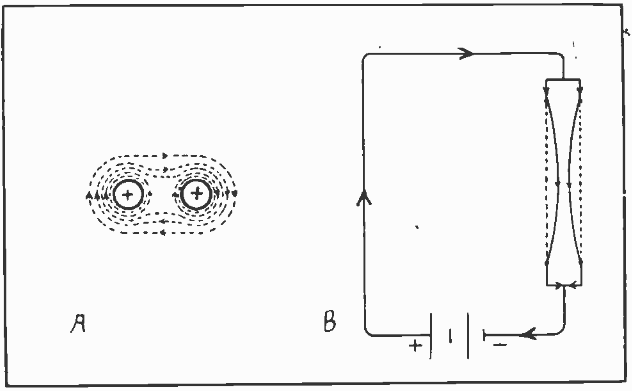


Fig. 92. When parallel wires carry current in the same direction, their flux tends to draw them together

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.

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. 93A.

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. 93B, 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.

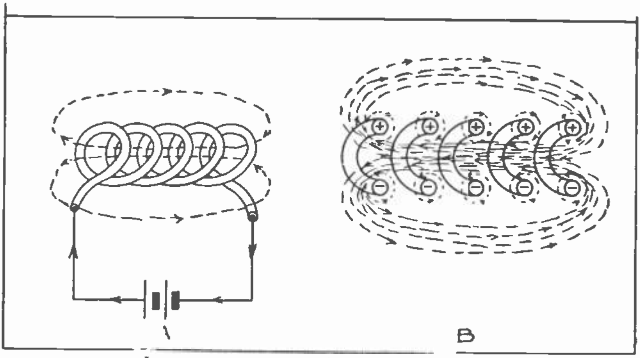


Fig. 93-A. The lines of force around the turns of a coil join together, in one very strong field.
Fig.. 93-B. Sectional view, note how the lines join around all turns, and the dense flux set up in the center of the coil.

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. 94.

By referring to both Figs. 93 and 94, 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.

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. These are called plunger magnets.

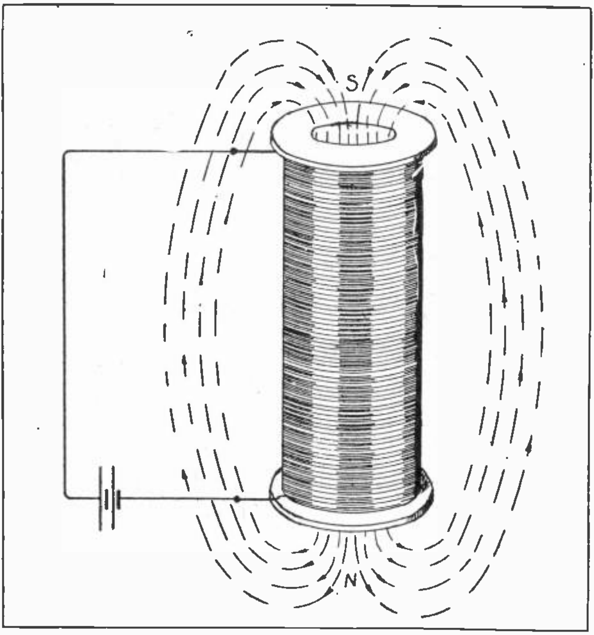


Fig. 94. Solenoid, or coil wound on a non-magnetic tube. Note the direction of the lines, and polarity of this solenoid.

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. 95 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 tons of metal at one time. Then when we want it to drop the iron the current is simply turned off.

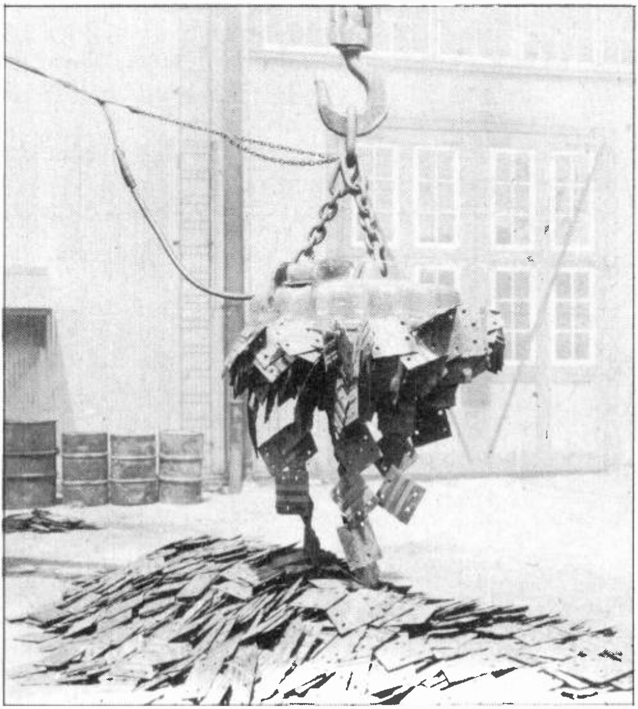


Fig. 95. Electro-magnet used for handling iron and steel. This magnet has a number of coils inside its frame or cover.

Attraction and repulsion is the same with electro-magnets as with permanent magnets. That is, unlike poles of two electro-magnets attract each other and their like poles repel each other. This rule holds also when one of the magnets is an electro-magnet and the other a permanent magnet. The same rule holds when one of the elements is a solenoid or when there are two solenoids. The fact of the matter is that the actions of permanent magnets, solenoids, and electro-magnets are alike in every way. It makes no difference whether a magnetic field is produced by a permanent magnet or by an electric current, the behavior of the field or the flux is just the same in either case.

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

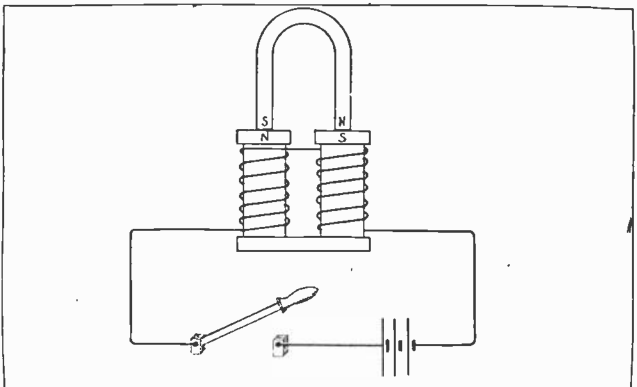


Fig. 96. Powerful electro-magnet for charging permanent magnets. The horseshoe magnet is in position to be charged and its poles will be as shown.

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 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. 96.

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.

POLARITY OF ELECTRO-MAGNETS

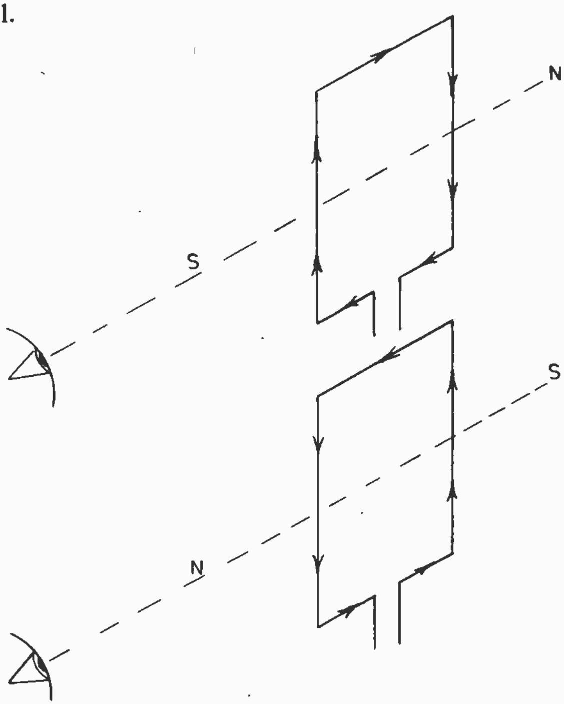
It is very important to be able to determine the polarity of solenoids and electro-magnets. A compass will, of course, show the north pole by the attraction of its tail or south pole. But if we know the direction of winding of a coil, and the direction current passes through it, we can quickly find the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

Place yourself in line with the current carrying coil or loop and observe the direction of current flow around the coil. If the current circulates **clockwise** around the coil, then the end of the coil closest to the observer is a South Pole. If the current circulates **counter clockwise** around the coil, then the end of the coil closest to the observes is a **North Pole.**

The above rule applies regardless of whether the coil in question has but one turn, or whether it has any other number of turns; whether the coil is long or short, round, square, or any other shape. It is a general rule applicable to all practical cases . . . learn it well.

Polarity of Electro-Magnets

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.

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. 98.

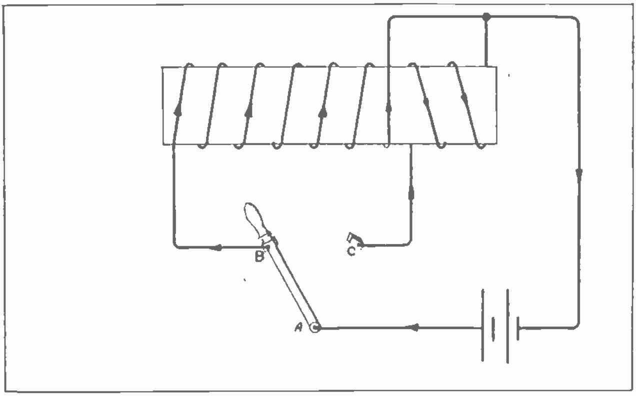


Fig. 98. Electro-magnet with demagnetizing coil for destroying residual magnetism.

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. 99.

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,

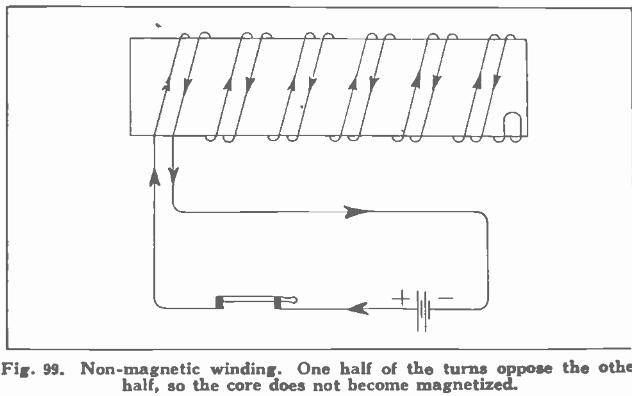


Fig. 99. Non-magnetic winding. One half of the turns oppose the other half, so the core does not become magnetized.

so practically no magnetism will be set up in the core. Non-magnetic coils of this type are often used in meter construction.

THE MAGNET CIRCUIT

A magnetic circuit includes the entire path around which flow the magnetic lines of force, just as the electric circuit includes the entire path through which the current flows. Just as an electric circuit must include a source of electromotive force which causes current to flow so must the magnetic circuit include a source of the force that causes magnetic lines to move around the circuit. In a magnetic circuit this source is a permanent magnet or an electromagnet. Just as there is resistance or opposition to flow of electric current in its circuit so there is opposition to flow of magnetic lines of force in the steel and other parts of the magnetic circuit.

Magnetic circuits are illustrated in Figs. 78 to 81. Note that in each case we show the complete path followed by the lines of force or the flux, sometimes through steel or iron and sometimes through air. In each of these illustrations we might replace the permanent magnet with an electromagnet and still have the same form of magnetic circuit. In paragraphs which follow we shall deal with some of the laws relating to the force, the flux, and the magnetic oposition in magnetic circuits. You will find that the rule and laws are similar in many ways to those for the electric circuit.

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.) Ampere-turns measure also the 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. 100, 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.

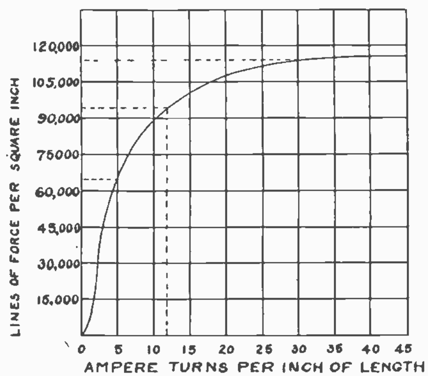


Fig. 100. Curve showing number of lines of force that can be set up in soft sheet iron, with various numbers of ampere turns.

The **Rel** is a name often used for the unit of reluctance. Its symbol is $\mathcal{R}$

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.

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.
$\mathcal{R}$ 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?

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

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:

$\mathcal{R}$ 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?

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

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?

$$\mathcal{R} = \frac{\nu \times L}{A}, \text{ or } R = \frac{.313 \times 1''}{4} = .07825 \text{ rel.}$$

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:

$$\phi = \frac{M}{\mathcal{R}}, \text{ or flux } = \frac{5000}{.07861} \text{ or } 63{,}605 \text{ lines.}$$

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?

$$\text{Lbs.} = \frac{4 \text{ X } 100{,}000^2}{72{,}134{,}000} \text{ or } 554.5 + \text{ pounds.}$$

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.

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,** equal to 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 Electromagnets, 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.

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. 101, which shows a sectional view of an electromagnet.

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

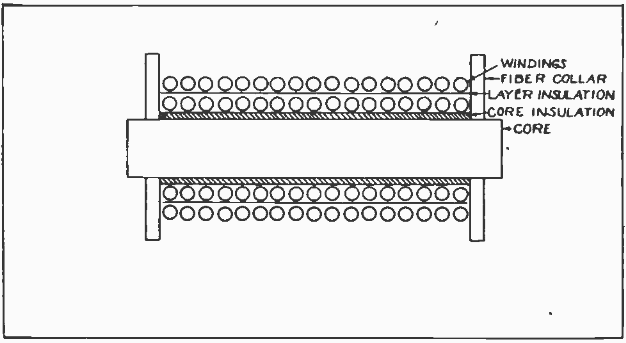


Fig. 101. Sectional view of electro-magnet, showing core, insulation and winding.

magnet. But they should be wound as smooth and compact as possible.

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.

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. 102-A, B and C.

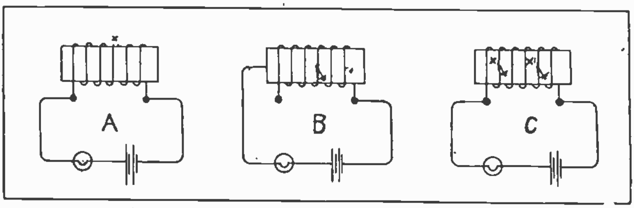


Fig. 102. Methods of testing coils for faults.

In Fig. 102-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. 102-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.

In Fig. 102-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. 103 to 106 show several types of electromagnets.

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. 104 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. 105, are also wound oppositely for the same reason.

Those in the motors in Fig. 106 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.

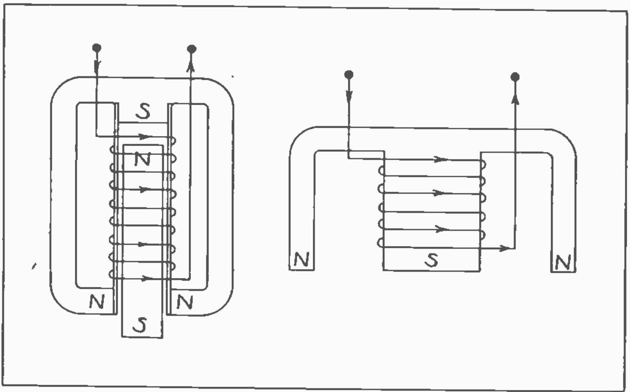


Fig 103. Plunger type magnet at left. Shell type magnet at right.

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.

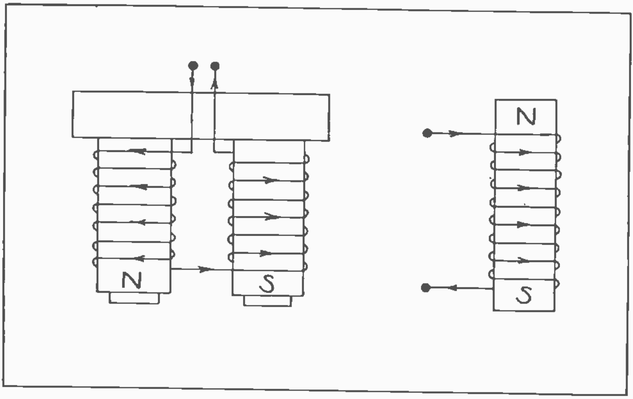


Fig. 104. Double and single electro-magnets.

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.

ELECTROMAGNETIC INDUCTION

Whenever a wire or other conductor is moved in a magnetic field so that the conductor cuts across the lines of force there is an electromotive force produced in that conductor. If a conductor remains stationary and the magnetic field moves so that its lines cut across the conductor an electromotive force is produced in the conductor. This action of producing or "inducing" electromotive force by movement between a conductor and a magnetic field is called electromagnetic induction.

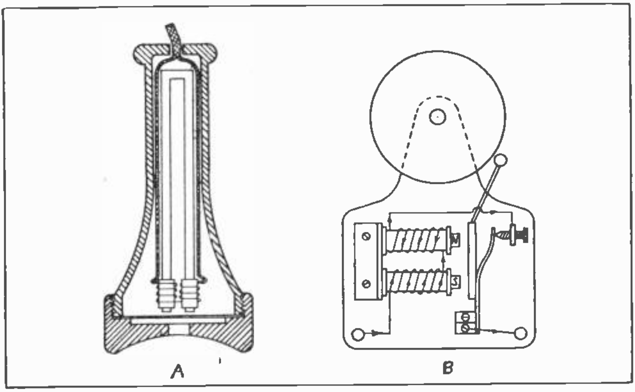


Fig. 105. Sketches showing use of electro-magnets in telephone receiver and door bell.

Without electromagnetic induction we would have no electric generators and would be reduced to using batteries for all the current we need. Much of our need for current would disappear, because without electromagnetic induction we would have no electric motors, no transformers, and none of the dozens of other devices on which our present electrical industry depends.

GENERATING ELECTRIC PRESSURE BY INDUCTION

If we move a piece of wire through magnetic lines of force as in Fig. 107, so the wire cuts across the path of the flux, a voltage will be induced in

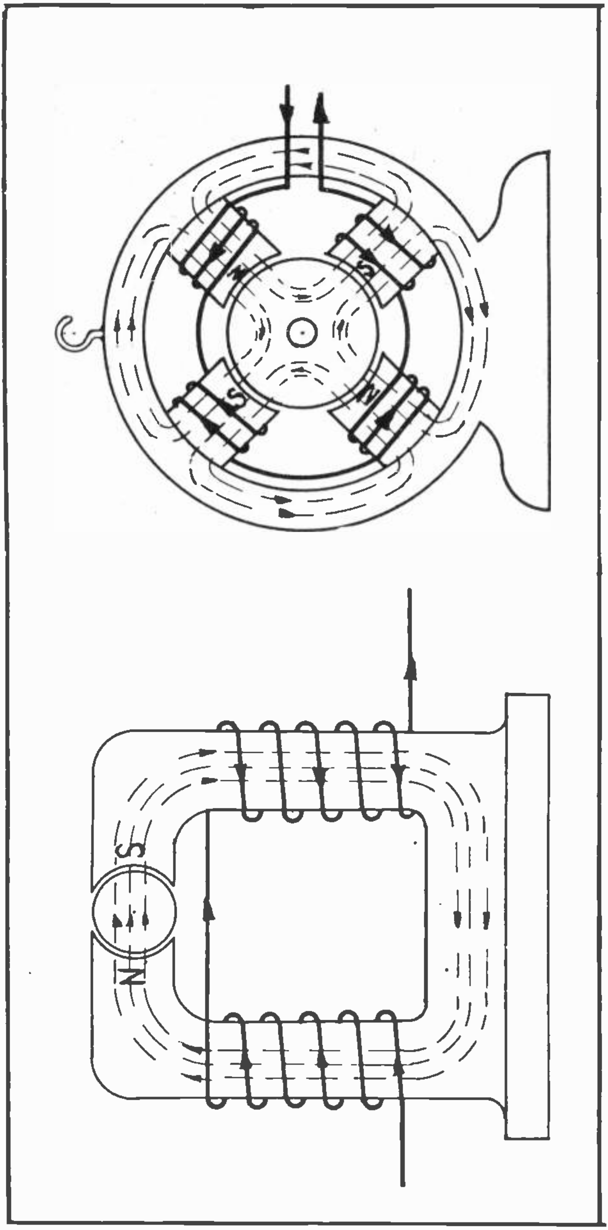


Fig. 106-A. Flux path in a simple early type of motor.
Fig. 106-B. Note the several flux paths in this modern 4 pole motor frame and poles.

this wire. Faraday first made this discovery in 1831.

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. 107. So it is possible to

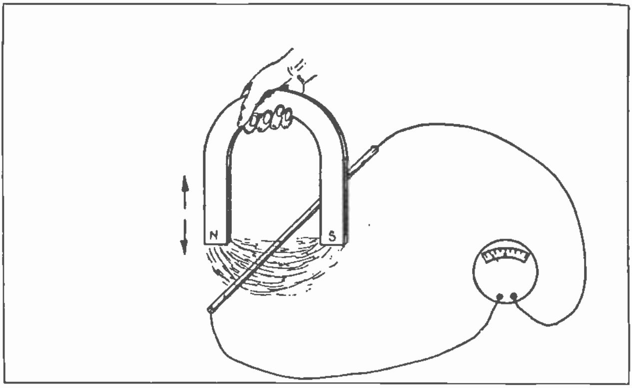


Fig. 107. When a wire is moved through magnetic flux, voltage is generated in the wire.

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.

DIRECTION OF INDUCED PRESSURE AND CURRENT

Referring again to our experiment in Fig. 107, 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. 108.)

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.

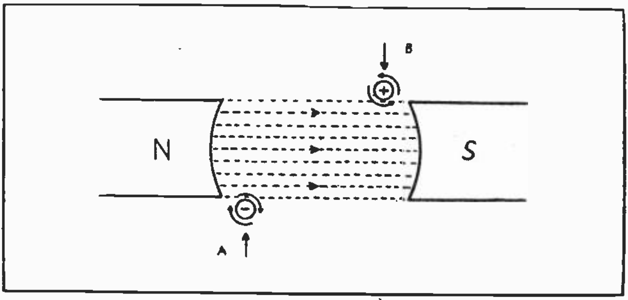


Fig. 108. Sketch of conductors moving through flux, as in a simple generator. Note direction of induced pressure.

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. 109.)

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.

AMOUNT OF PRESSURE GENERATED DEPENDS ON SPEED AT WHICH LINES ARE CUT

Referring back again to Fig. 107, if we hold the wire still, even though in the magnetic field, no

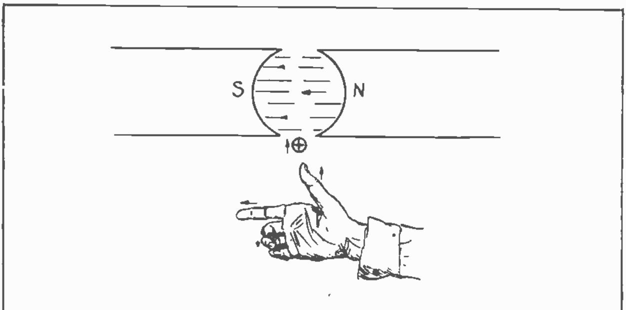


Fig. 109. Right hand rule for direction of induced voltage. Compare position of fingers with direction of flux and wire movement.

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 difference in 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 difference in 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. 110A and 110B.

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.

SIMPLE GENERATOR PRINCIPLES

In Fig. 111A and 111B 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.

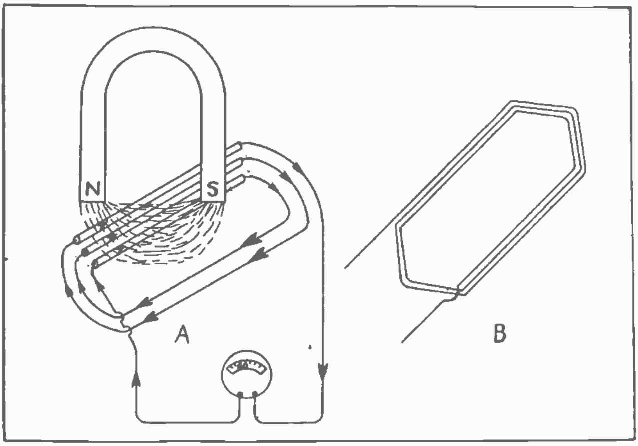


Fig. 110-A. Using several wires connected in series to obtain higher induced voltage.
Fig. 110-B. Coil of several turns, as used in generators.

Assume that the coil A, B, C, D in Fig. 111A 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.

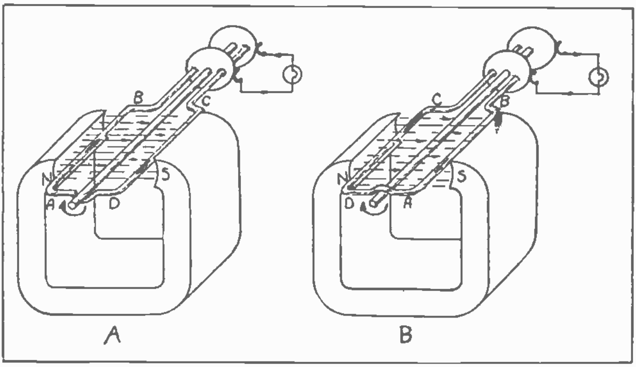


Fig. 111-A. Simple electric generator of one single wire loop, in the flux of a strong permanent magnet.
Fig. 111-B. Here the coil has revolved one-half turn farther than in (A).

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. 111B 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.

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.

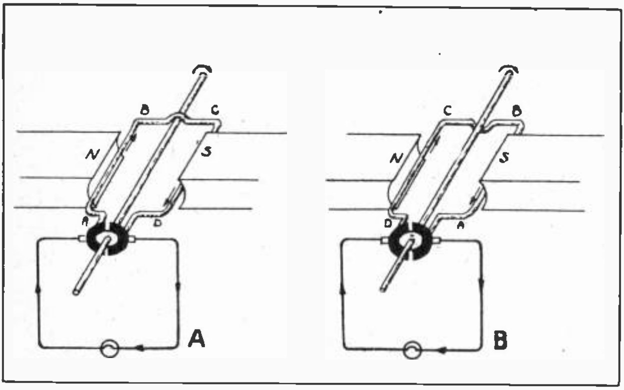


Fig. 112-A and B. Single loop generators with simple commutators, for producing direct current. Note how current continues in same direction through the lamp, at both positions of the coil.

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. 112-A and B.)

Here again we have a revolving loop. In Fig. 112A 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 aroun(with the wire, so we find the current still flows in the same direction in the external circuit through the lamp.

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. 113.)

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. 114A and B.

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.

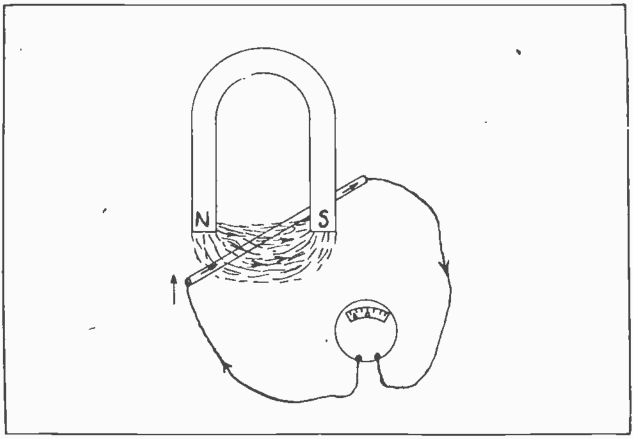


Fig. 113. Induction experiment, moving the magnet and its field instead of the wire.

After the flux has been established the meter needle drops back to zero, and remains there as

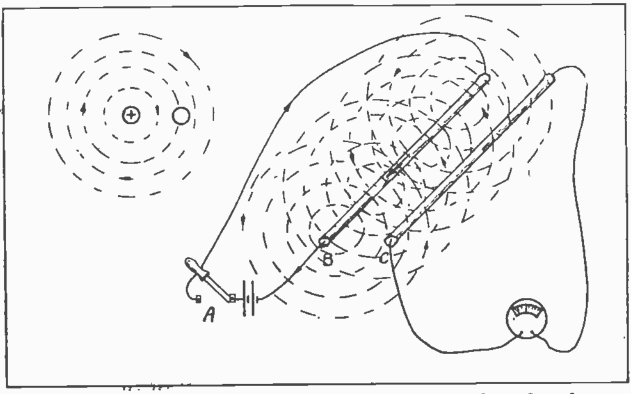


Fig. 114-A and B. Sketches showing how induction takes place between two wires, when current and flux are varied.

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.

If we arrange two coils as in Fig. 115, 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. 115, 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.

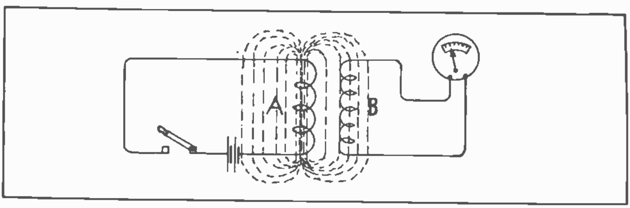


Fig. 115. Induction between two coils. A is the "primary coil" in which exciting current flows. B is the "secondary coil" in which current is being induced.

TRANSFORMERS

PURPOSE

A transformer is a device designed to change an A.C. voltage—or a periodically varying D.C. voltage—from one value to another without any change in frequency. It should be noted, however, that while the input to a transformer may be pulsating D.C., the output will always be A.C.

CONSTRUCTION

The ordinary transformer consists of a primary winding — connected to the source of energy — a laminated iron core, and one or more secondary windings. Theoretically, any winding may be used as the primary, provided the proper voltage and frequency be applied to it. The laminated iron core serves as an efficient means of magnetically coupling together the primary and secondary windings.

ACTION

A periodically varying voltage applied to the primary winding produces a varying current that in turn develops a varying flux in the iron core. This varying flux cuts all windings, inducing in each of them a voltage proportional to the number of turns.

TURNS RATIO

The ratio of the primary voltage to any secondary voltage is practically equal to the ratio of the primary turns to the secondary turns as indicated by the formula:

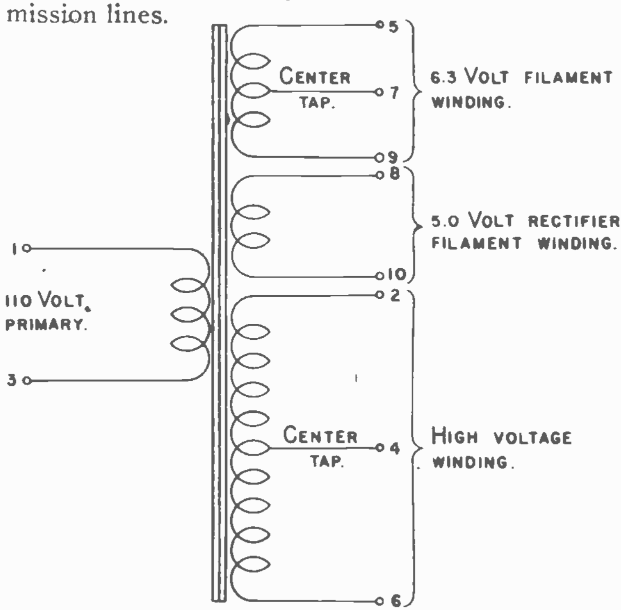
$$\frac{\text{Primary turns}}{\text{Secondary turns}} = \frac{\text{Primary voltage}}{\text{Secondary voltage}}$$

ACTION UNDER LOAD

The voltage induced in the primary winding by the growing and dying core flux is practically equal to the applied voltage; moreover, this induced voltage directly opposes the applied voltage; therefore, the current drawn from the supply is small.

When a secondary circuit is completed, current circulates around the iron core in the opposite direction to the primary current, reducing the core flux and the counter voltage of the primary. This action causes the current in the primary to vary in accordance with the secondary load. It is through this action that the transformer automatically adjusts itself to changes in secondary load.

Two coils or windings on a single magnetic core form a transformer. With a transformer we may take a large alternating current at low voltage and change it into a small current at high voltage, or may take the small alternating current at high voltage and change it into a large current at low voltage. This ability of the transformer makes it possible to use generators which produce moderately large alternating currents at moderately high voltages, and to change over to a very high voltage and proportionately small current in the transmission lines.



Do you wonder why we want smaller currents in our transmission lines? It is because the power required for forcing the electricity to flow against the resistance of the lines varies with the square of the current. Twice as much current means four times as much power just to overcome resistance, while half as much current means only one-fourth as much power to overcome resistance. Then when we drop the current to one-tenth its original value by using a transformer we have cut the power loss due to resistance to one one-hundredth what it might have been.

With such a cut in the effect of line resistance on power loss we are enabled to use smaller wires containing less copper for our long-distance transmission lines. The cost of large copper wires and the difficulty of handling and supporting their great weight in large sizes make it uneconomical to transmit direct current more than a mile or two, yet by using alternating current with transformers it is economically possible to have transmission lines hundreds of miles long.

The elementary principle of a transformer is shown by Fig. 116. Here we have two windings on opposite sides of a ring-like core made of iron. Actually it is more common practice to wind one coil around the outside of the core and to have both of them on one part of the iron core. Later on we shall study all types of transformers and their uses.

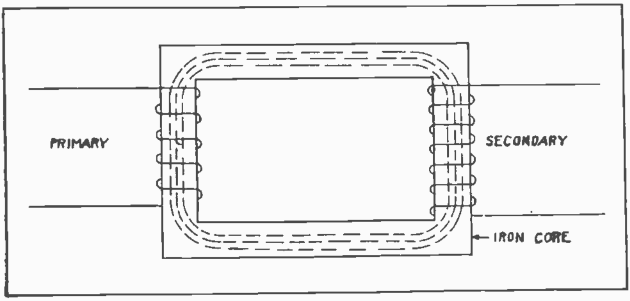


Fig. 116. Core and windings of a simple transformer.

The source of alternating current and voltage is connected to the primary winding of the transformer. The secondary winding is connected to the circuit in which there is to be a higher voltage and smaller current or else a larger current and smaller voltage than in the primary. If there are more turns on the secondary than on the primary winding the secondary voltage will be higher than that in the primary and by the same proportion as the number of turns. The secondary current then will be proportionately smaller than the primary current. With fewer turns on the secondary than on the primary the secondary voltage will be proportionately lower than that in the primary, and the secondary current will be that much larger. Alternating current is continually changing, continually increasing and decreasing in value. Every change of alternating current in the primary winding of the transformer produces a similar change of flux in the core. Every change of flux in the core, and every corresponding movement of magnetic field around the core, produces a similarly changing movement of magnetic field around the core, produces a similarly changing electromotive force in the secondary winding and causes an alternating current to flow in the circuit which is connected to the secondary.

In discussing the action of the transformer we have mentioned electric power and loss of power. As you well realize, the production, transmission and use of power represent much of the practice of electricity. In the following section we shall talk about power, what it really means, and how it is measured.

STATIC ELECTRICITY

CHARGES OF ELECTRICITY

Imagine that you have a sheet of mica, glass, hard rubber or some other insulating material and that on each side of the insulating material are metal plates. The metal plates are insulated from each other by the material between them. If you were to connect the metal plates to the two terminals of a battery or other source of d-c potential there would be a momentary flow of current from the positive side of the battery to one plate and an equal flow of current from the other plate to the negative side of the battery. The flow of current would exist for only an instant, then would stop. No current could continue to flow because there is insulation between the metal plates.

If the battery were disconnected from the metal plates and then reconnected to them in the same manner as before there would be no momentary flow of current provided the plates had remained completely insulated from all electrical conductors while the battery was disconnected. It is evident that the first connection of the battery produced some change in the insulating material between the plates which enabled them to oppose flow of current during the second test.

When first studying electricity we learned that all substances consist of atoms which contain electrons, and that electrons are particles of negative electricity. When a potential difference is applied to conductors separated by insulation, as to the metal plates just discussed, the potential difference causes negative electrons to flow from one side of the potential source to one of the conductors or metal plates. These negative electrons pass to the side of the insulator in contact with the plate, and that side of the insulator becomes more negative. An equal quantity of electrons leaves the opposite side of the insulator and passes through the other metal plate to the other side of the potential source. This loss of negative electrons leaves this side of the insulator more positive than before.

When an insulating material is used in the manner described it is called a **dielectric.** The side of the dielectric connected to the positive terminal of the battery acquires a positive charge of electricity—meaning that it loses some negative electrons and becomes more positive. The side of the dielectric connected to the negative terminal of the source becomes negatively charged, meaning that it has more than the normal number of electrons. Since the dielectric is an insulator, through which electricity or electrons cannot flow, the unbalanced condition will persist on the surfaces of the dielectric when the battery or other source is disconnected, and would persist were the dielectric removed from between the plates so long as the dielectric comes in contact with no conductors.

An electric potential, or a difference of potential, means simply that there are more electrons at one place than at another, or that one place has more than its normal number of electrons, or that another has fewer than its normal number.

Any difference of potential is measured in volts. Connecting the battery to the plates and the dielectric produced a difference of potential on opposite sides of the dielectric, equal to the difference of potential furnished by the battery. Consequently, when you connect the battery to the plates a second time the battery potential is opposed by a potential equally great on the dielectric. The positive terminal of the battery is connected to the side of the dielectric having a positive charge and the negative terminal of the battery to the side having a negative charge. The potential difference of these charges is equal to that of the battery, so no current flows.

CAPACITANCE AND CAPACITORS

Conductors separated by insulation or a dielectric, and having a difference of potential, have the ability to produce electric charges on the dielectric. This ability to receive and hold electric charges is called **capacitance** or may be called **electrostatic capacity.** A device which contains conductive plates and insulating dielectric arranged especially for receiving electric charges is called a **capacitor** or an **electrostatic condenser.**

The capacitance of a capacitor is measured in accordance with the quantity of electricity (electrons) which may be added to one side and taken off the other side of the dielectric. If a potential difference of one volt causes one coulomb of electricity to flow into a capacitor the capacitance is one farad. If we made a capacitor with mica only as thick as the paper in this page, and used a single square sheet, our capacitor would have to measure more than a mile along each side to have a capacitance of one **farad.** A unit so large as the farad is impractical for ordinary capacitors, so we use the **microfarad** which is equal to one one-millionth of a farad.

The capacitance varies with the kind of dielectric, and the effect of the kind of dielectric on capacitance is called the **dielectric constant** of the material. The dielectric constant of air is 1.0, while that of waxed paper, as one example, is from 2.5 to 4.0. This means that a capacitor with waxed paper dielectric will have a capacitance 2.5 to 4.0 times as great as an otherwise similar one having air for its dielectric. Dielectric constants of most insulating materials range from 1.5 to 8.0.

With a given knid of dielectric, capacitance becomes less in direct proportion as the dielectric is made thicker, and becomes more in direct proportion as the area of dielectric in contact with the plates is made greater. Many capacitors which are to withstand voltages of only a few hundred have dielectrics of several sheets of thin waxed paper. For high voltages the dielectric usually is sheets of mica.

If a capacitor is connected in a direct-current circuit there will be a momentary flow of current as the capacitor takes its charge, then the current will stop because the dielectric is an insulator.

If a capacitor is connected in an alternating-current circuit the flow in amperes will be reduced but some current will continue to flow. The greater the capacitance of the capacitor the larger will be the remaining current. This rather peculiar action is due to the fact that alternating current merely surges back and forth in a circuit, moving first one direction and then the other. The alternating current may flow in one direction until it charges the capacitor in that direction, then may flow in the opposite direction as the capacitor discharges and is recharged in the opposite direction or opposite polarity.

ELECTROSTATIC FIELDS

Just as there is a magnetic field and magnetic lines of force around a magnet so there is an electrostatic field and electrostatic lines of force around an insulating material or dielectric material which is electrically charged. The electrostatic field may be represented by lines between electrostatic poles just as the magnetic field is represented by lines between magnetic poles. Electrostatic lines issue from the positive electrostatic pole and return to the negative electrostatic pole.

The positively charged end of a dielectric may be called its positive pole, and the negatively charged end its negative pole. Unlike electrostatic poles, one positive and the other negative, attract each other just as do unlike magnetic poles. Like electrostatic poles, or like charges, repel each other—which again is similar to the behavior of magnetic poles.

The greater the dielectric constant of a substance the more easily it carries electrostatic lines of force. Consequently, when a material of high dielectric constant is placed within an electrostatic field this material tends to draw into it some of the electrostatic lines which otherwise would travel through the surrounding air, which is of lower dielectric constant.

It is important to understand that the potential difference between opposite sides of a charged dielectric may be very high and yet the quantity of electricity which will flow to and from the dielectric may be very small. As an example, many of the capacitors used in radio have capacitances of only a fraction of a microfarad, which means they will charge with only a little electricity and then will discharge a similarly small quantity. But these capacitors may be charged to potentials of hundreds of volts, or even thousands in transmitting outfits. Many a radio man has received a stinging shock from the high potential discharge from a capacitor of fairly small physical size.

Electricity which exists as an excess or as a deficiency on charged bodies such as dielectrics is at rest or remains stationary except while the body is being charged or discharged. This electricity which is stationary is called **static electricity,** and when talking about its effects we use the word **electrostatic** to distinguish them from effects of moving electricity, which is the electric current.

ELECTRIC CHARGES PRODUCED BY FRICTION

If you rub a stick of sealing wax with wool, silk or cotton cloth you actually rub some electrons off the cloth and onto the wax. The sealing wax then has extra negative electrons, so is negatively charged. The cloth has lost negative electrons, so remains positively charged. Now there are electrostatic fields around both the wax and the cloth, and either will attract small bits of paper, thread and other insulating or dielectric materials—just as either pole of a magnet will attract pieces of iron and steel. This experiment shows that electric charges may result from friction when two insulating materials are rubbed together. Such frictional charges of static electricity are harmful more often than useful.

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, that may have a potential of over 6,000 volts. 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 of considerable 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.

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 that may reach a value of 100,000 volts. 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. The tires of many such trucks are covered with a conducting paint for the same purpose. 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.

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 having potentials of 50,000 volts 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.

A workman around such belts may get such a shock from the static, that it will cause him to fall

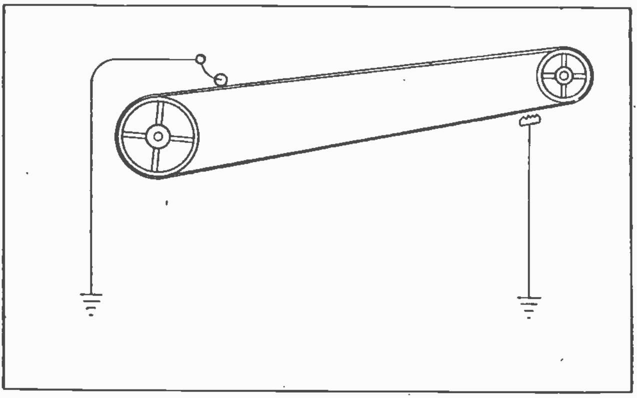


Fig. 120. Sketch showing how static can be removed from a belt, by use of either a metal comb or roller, and ground wire.

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 120 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.

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

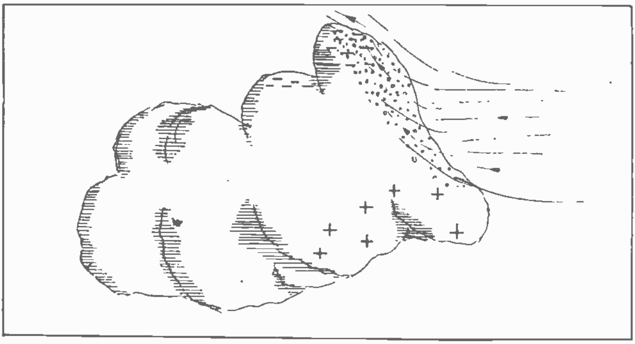


Fig. 121. Wind striking the face of a cloud, carries vapor and electrical charges to top of it.

particles of moisture are blown upward, carrying negative charges to the top of the cloud, and leaving the bottom positively charged. (See Figure 121.)

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.

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 122.

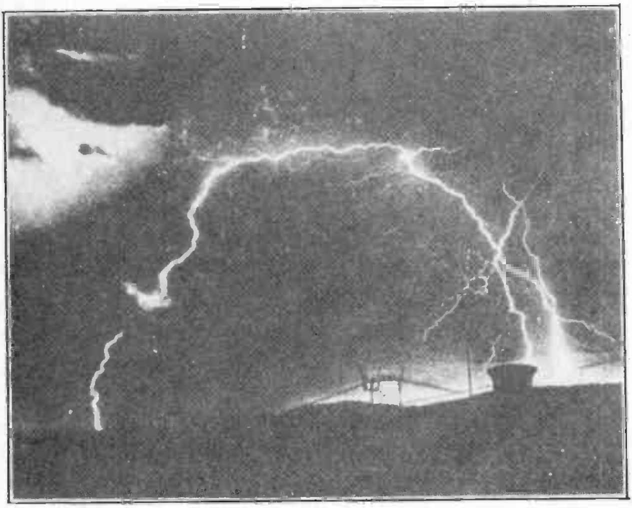


Fig. 122. Photo of a brilliant lighting flash at night.

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.

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 Figue 123.)

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.

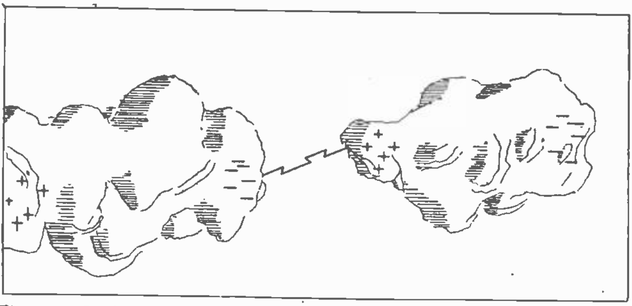


Fig. 123. Lighting flashing from one cloud to another, when clouds carry unlike charges.

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 Figue 125.

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.

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 a 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 ben 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.

Fig. 124. Large tree shattered by lightning, showing the force and power of heavy lightning discharges.

Tests also prove that rods of a given height, protect a certain cone shaped area around them as shown in Fig. 126. 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.

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.

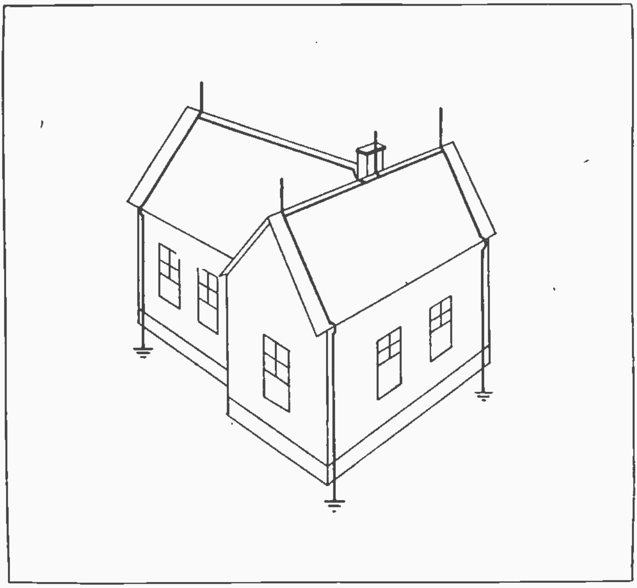


Fig. 125. Sketch of house equipped with lightning rods, to carry static and lightning safely to earth.

YOUR MENTAL TOOL KIT

Now we have arrived at the point where all the principles and rules that you have studied will commence working for you. The facts that you have learned are working tools of the electrical expert just as much as are his voltmeters, ammeters, wire cutters, screw drivers, and all the other things of more substantial form.

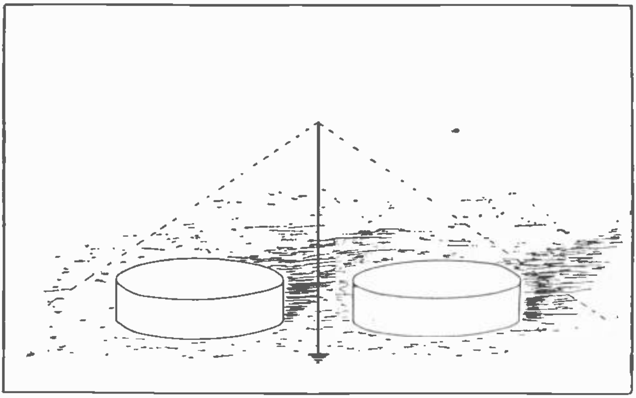


Fig. 126. Tall lightning rod used to protect oil tanks from lightning fires. The dotted lines show the area protected, and within which lightning will not strike.

The mental tools that have been given to you in all these pages—the tools that henceforth you will carry in your head—are more necessary and more useful than the ones made of steel and brass and bakelite that you use with your hands. The tools you carry in your head get sharper and do better work the more you use them. You never can lose these tools unless you forget to use them. They have stood up and proved their worth to electrical men over and over again, in many cases for a hundred years or more.

A man with an active mind and a good knowledge of basic principles is far better off than one with an empty mind and a trunk full of gadgets that he does not know how to use to best advantage. The man with the knowledge may start years behind the other one in practical experience, yet in an incredibly short time will catch and outstrip the other fellow in earnings. What's more, the greater your knowledge and understanding of what you are doing the greater will be the pleasure and excitement in doing electrical work.

If you feel that you have not remembered all of the dozens of facts that have been explained in preceding pages, don't let that worry you. Most, if not all, of them are stored away somewhere in the back of your mind. The day you need them on the job they will come popping out to help. And even though you don't remember every detail, at least you will remember that the point was covered in your Reference Set, and all you need do is look back to one of the sections and there you have it.

In our preliminary studies we have gone over many very simple things relating to electricity, and have encountered others which are not so simple. In the job instructions which follow we shall commence with the simplest kind of work—that of installing electric signals of various kinds. Such work is not only profitable and interesting, but it brings out many things with which it is essentail that you have experience before tackling some of the bigger jobs which come later.

ELECTRIC SIGNAL SYSTEMS

While Electric Signal and Alarm work is a field of tremendous importance, many of these installations operate on low voltages, and because of this, a student, in his eagerness to get into the more advanced work, is sometimes liable to overlook the opportunities in this field. Therefore, before we get into the actual study material on this Equipment and these installations, and to more fully appreciate the opportunities for both full and spare time work installing, repairing and servicing signal and alarm systems of all kinds, let us just look at a few facts to help us understand and appreciate the importance of this branch of Electricity, where hundreds of thousands of dollars are being spent each year.

OPPORTUNITIES IN THE SIGNAL FIELD

First, we must remember that there are many thousands of new homes being built every year. In addition to the regular electric wiring which must be done, there is also a great deal of low voltage work, such as the installation of door bells and buzzers, burglar alarms, fire alarm systems, etc. This one field alone requires the expenditure of hundreds of thousands of dollars every year, and as this work is very profitable, it offers the TRAINED MAN a wonderful chance to add to his income even while he is learning

Second, there are the millions of homes already built which now have door bell and buzzer systems, fire alarms, etc., which provide another field for spare time earnings in repairing and servicing of these installations in order to keep them in good operating condition.

Third, in addition to private homes and residences, there are many thousands of stores, office buildings, theaters, hospitals, hotels, banks, etc. that have signal systems, burglar alarms, fire

Door bell installations, buzzer systems and many other similar jobs present plentiful opportunities for profitable spare time work.

alarms and other low voltage equipment which must also be serviced and kept in good operating condition.

Fourth, besides the spare time earnings that are possible in installing and repairing these devices and systems, a good plan, and one that will provide you with a steady income is to make an arrangement with the owners of homes, stores, offices, etc. to keep their signal systems and low voltage equipment in good operating condition for a certain amount of money each year. The cost to the owner is small and the service he receives is well worth the small amount invested.
This is in reality a form of maintenance contract work, in which you agree to keep certain equipment in good operating condition for a certain amount of money each year. This means that you will have to make certain periodical inspections and answer all service calls that come from the owners of such equipment, during the terms of the contract.

Fifth, railways, with their block signal systems, train control equipment, etc., provide additional opportunities for the man who has the right kind of training to enable him to do this work.

Sixth, the signal field in electricity is one of the best ways in which a fellow can start an electrical business of his own. It requires very little money to start a business of installing alarm and signal equipment. The cost of apparatus and equipment is small, which means that most of the money that you will receive for these jobs will be for your time and labor.

Seventh, in addition to these opportunities for increasing your income and earning power, this instruction and training in electric signal work, alarm systems, etc., are valuable for another very important reason. The things that you will learn in these lessons will be of untold benefit to you later on, in studying such subjects as power plant work, etc. For example, a small bell-ringing transformer operates on exactly the same principles as a large power transformer, and is of course, much easier for the beginner to work on and to understand.

SIMPLE CALL BELL

One of the simplest of all signal systems, is the ordinary door bell or call bell.

Such an installation requires an ordinary bell, a dry cell, a switch, and a few pieces of wire as shown in Figure 1.

Note how the three devices are connected together in a single series circuit. One wire leads from the positive terminal of the cell to the right-hand bell terminal, one from the left bell terminal to the switch, and one returning from the switch to the negative cell terminal, thus completing the electrical circuit when the switch is closed.

In an actual installation, of course, these wires would be much longer, as the button would be located at the door, and the dry cell and bell probably near together somewhere in a rear room of the house.

This same system can be used for an office call with the button located on a certain desk, and the bell at another desk or office where a party is to be called. The battery can be located at either end of the circuit, equally well.

This circuit can also be used for a shop call, or a burglar alarm or fire alarm, by replacing the push button switch with a special door or window switch, or thermal switch, all of which will be explained later.

So we find that this very simple system has a variety of valuable uses.

USE OF PLANS AND SYMBOLS

When the equipment for any signal system is pictured as in Fig. 1, it is of course easy to recognize each part, and also to connect the wires as shown. But we must have some form of plan or sketch to do such work from, that can be made quicker and cheaper than photographs. So we have certain little marks or signs which we use to indicate the different pieces of equipment in blue prints or job plans and sketches. These marks are called **Symbols.**

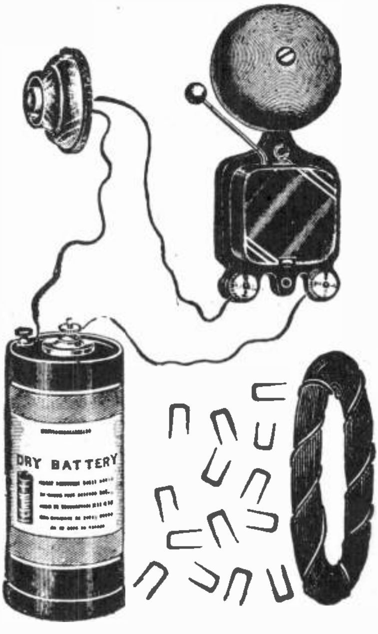


Fig. 1. Materials and parts for a simple doorbell or call system. Note how the dry cell, bell and button are connected.

As practically all new electrical installations now-a-days are made from prints or plans, the man who knows these symbols and can read prints has a great advantage over the untrained man who cannot.

In Fig. 2 is shown a simple sketch of the same door bell system as in Figure 1.

This sketch uses the symbols for the various parts, and can be quickly and easily made, and also easily understood, with a little practice.

The part marked "A" is the symbol for a cell, the long line representing the positive terminal at which the current leaves, and the short line the negative terminal. "B" is the symbol for the bell, and "C" for the switch.

The heavy top line of the switch represents the movable contact. The arrow underneath represents the stationary contact. Note that the arrow does not touch the upper part, showing that the switch is open as it should be normally. Imagine that you were to press down on this top part causing it to touch the arrow and close the circuit. Current would immediately start to flow from the positive cell terminal to the bell, and back through the switch to the negative side of the cell. The arrows along the straight lines, representing wires, show the direction of current flow.

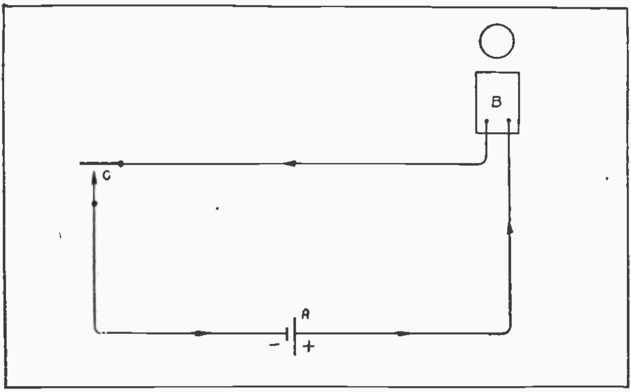


Fig. 2. Sketch showing the connections and circuit of simple doorbell system.

In **Reading** any electrical diagram from now on, practice **Tracing Out** the current flow in this manner. First locate and recognize all the parts by their symbols, and if there are any open switches, imagine that you close them. Then starting at the battery, trace the current flow along the wires and through the devices, always returning to the opposite side of the battery from the one at which you started. Remember that unless you have such a complete circuit no current will flow.

3. COMMON DEVICES IN SIGNAL CIRCUITS

Now let's find out more about each of the devices used in this simple system just covered, and also others.

We can readily see that the principal parts which we must have for any electric signal system are **a source of current supply, a means of control, and a device to transform the electric energy into a signal.**

Fig. 3. Two common dry cells such as used extensively in signal systems. One is cut away to show terminal strip attached to the zinc.

4. BATTERIES FOR CURRENT SUPPLY

Dry cells are very commonly used to supply current to ordinary door bell and call systems of the "open circuit" type, where current is only required for occasional short intervals. Figure 3 shows two dry cells. You are already familiar with the care and operation of these cells from a previous lesson. When two or more cells are used they can be connected series or parallel according to the voltage and current requirements of the signal device. These connections were also covered in a previous lesson on Series and Parallel Circuits. Figure 4, however, shows two groups of three cells each, one group connected series, and the other parallel.

Dry cells should not be used in closed circuit systems, except where the current requirements are exceedingly small.

Primary cells of the "gravity" type or the "Edison" type are often used in closed circuit systems

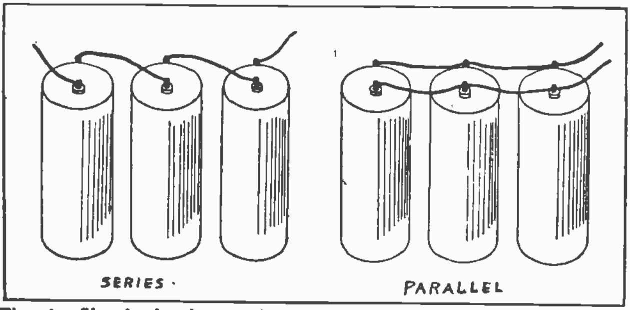


Fig. 4. Sketch showing method of connecting groups of dry cells in series or parallel, to obtain proper voltage or current for various Signals.

because they will stand the continuous current requirements much better than dry cells. The operations and care of these cells were also covered in a previous section.

Storage batteries are often used in signal systems where the current requirements are quite heavy.

Several complete lessons will be given on storage batteries later on in your course.

5. MOTOR GENERATORS FOR SIGNAL SYSTEMS

In very large signal systems **Motor-Generator** sets are often used to supply signal current.

They consist of a motor operated from the usual 110 or 220 volt current supply in a building, and driving a generator which supplies from 2 to 30 volts D.C. to operate the signals. (See Figure 5)

Storage batteries are often used with motor generators, to supply current for short periods when the motor-generator might be shut down.

Figure 6 shows a storage battery connected in parallel with a D.C. generator so that the generator, while operating, will keep the battery fully charged.

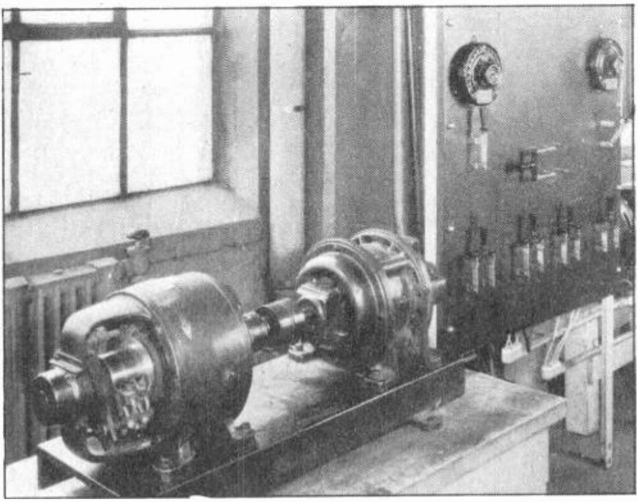


Fig. 5. Photo of low voltage motor generator set and switchboard, used for supplying energy to large signal systems.

Then, when the generator is stopped for any reason, the battery supplies the current to the signals. The generator should be disconnected from the battery when it is stopped, so the battery will not discharge through the generator winding.

6. BELL TRANSFORMERS

Bell Transformers are very commonly used to supply current to ordinary door bell and simple call systems. These transformers operate from the 110 volt A.C. lighting circuits and reduce the voltage to that required for the signal bells or lamps.

Figure 7 shows two common types of door bell transformers.

A number of these transformers have three secondary wires, or "leads," giving 6, 8, or 14 volts with different connections. Others give still higher voltages. Where higher voltage bells or lamps are used, or where the line is long, the higher voltage "leads" on the transformer should be used.

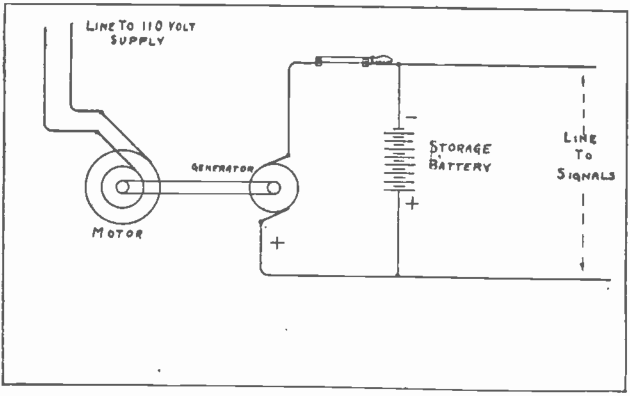


Fig. 6. Diagram of motor generator and storage battery connected together for dependable energy supply to large signal systems.

In Figure 8 is shown a sketch of the windings and connections of a very common type of bell transformer. The primary winding "P" consists of about 1800 turns of No. 36 wire. The secondary winding consists of 235 turns of No. 26 wire, and has a "tap" or connection at the 100th turn. The core legs are about ½ in. x ¾ in. in size and 2¼ in. long.

Transformers can only be used where there is electric supply in the building, and only on A.C. They will not operate on direct current supply, and in fact, will "burn out" quickly if connected to a D.C. line.

For special uses transformers are obtainable with taps and a switch to vary the voltage in a number of steps. One of this type is shown in Figure 9.

Several other types are shown in Figure 10. Two of these, on the left, are mounted right on covers of "outlet boxes" for convenience in installing and attaching them to the lighting circuits, which are run in conduit, or protective iron piping. The other is built in a box with fuses.

All of the various sources of current supply above mentioned are low voltage devices, usually furnishing from 6 to 20 volts, as most bells and signal lamps are made to operate at these low voltages. Special bells are made, however, for 110 volt operation. But a low voltage bell should never be connected directly to a lighting circuit, as it will immediately burn out, and possibly blow the fuses or do other damage.

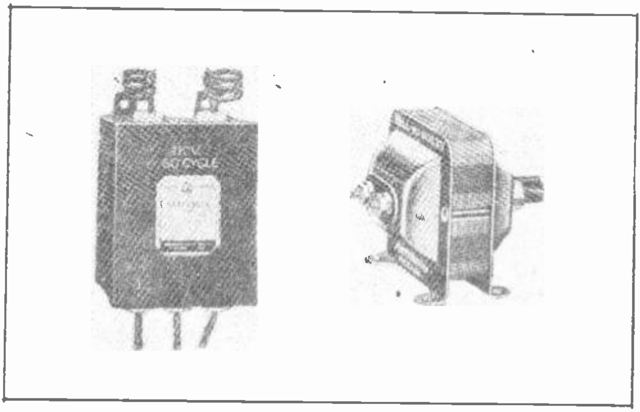


Fig. 7. Two different types of low voltage bell transformers. These reduce the voltage of an A. C. lighting circuit to low voltage required for bell operation.

Certain types of signal systems using relays cannot be operated satisfactorily with transformers, as they require the continuous pull of D. C. on the relay magnets. Batteries or motor generators are required for such systems.

7. CURRENT SUPPLY TROUBLES

When signal systems fail to operate, the trouble can very often be traced to a weak or dead battery, burned out transformer, or blown fuse in the lighting circuit to which the transformer primary is connected. Cells and batteries can be quickly and easily tested right at their terminals with a bell or buzzer, low reading voltmeter, or battery ammeter.

A transformer can be tested with a bell, buzzer or low voltage test lamp for the secondary test, or a 110 volt test lamp for the primary test.

When "shooting" trouble on any defective signal system, you should **never fail to check the source** of current supply first of all, because very often the trouble is merely a dead battery or blown fuse.

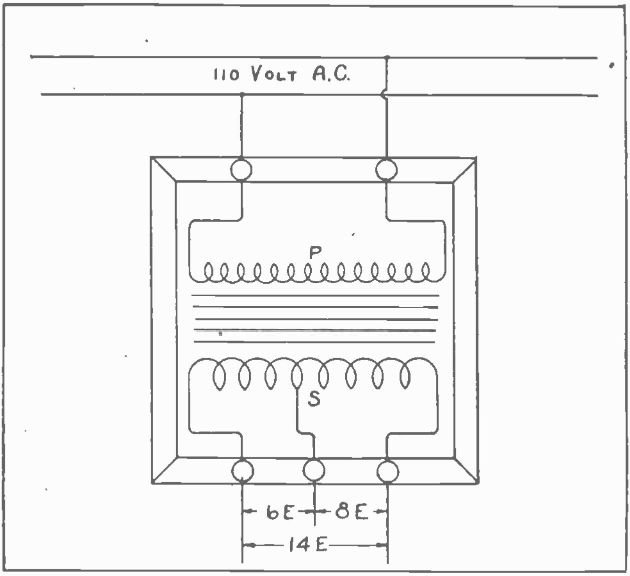


Fig. 8. Sketch showing windings and connections of a bell transformer.

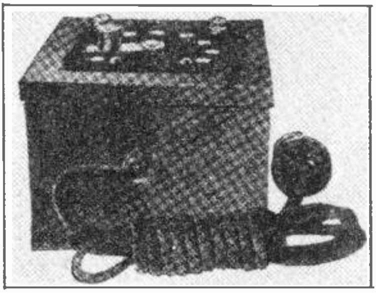
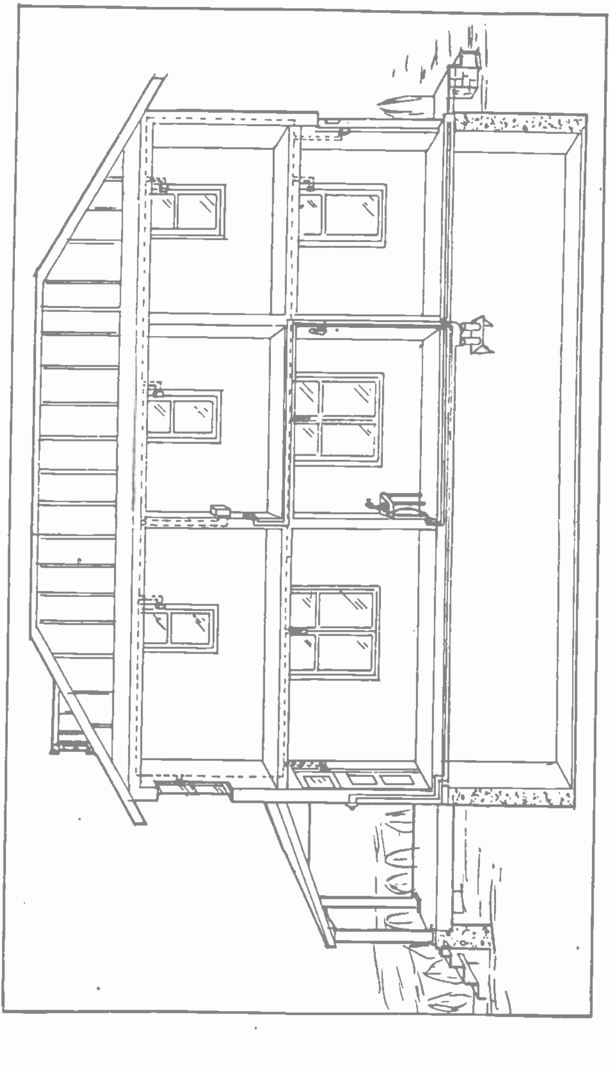


Fig. 9. Low voltage transformer with "taps" for obtaining various voltages.

8. SIGNAL SWITCHES

Now that we know something of the different sources of current supply for signal systems, let us consider the means of control or switches used.



Sectional view of a house showing the wiring for doorbells, burglar alarm and telephone. These are three of the most common signal conveniences in the home.

Referring again to Figure 2, the purpose of the switch, as we have already mentioned, is to close and open the circuit, and start or stop the current flow, thus causing the bell to ring when desired.

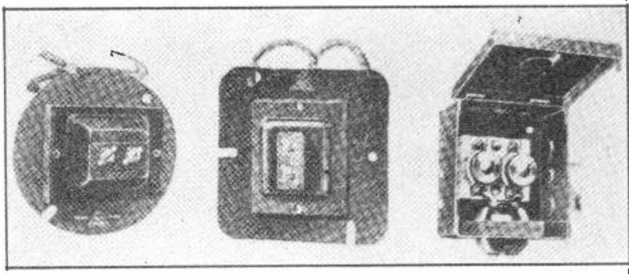


Fig. 10. Three types of bell transformers which are built in the covers of standard outlet boxes for conduit wiring.

This type of switch is called a **Push Button** switch. Figure 11 shows the operating parts of such a switch with the cover removed, and also the assembled switch. The upper left part shows the

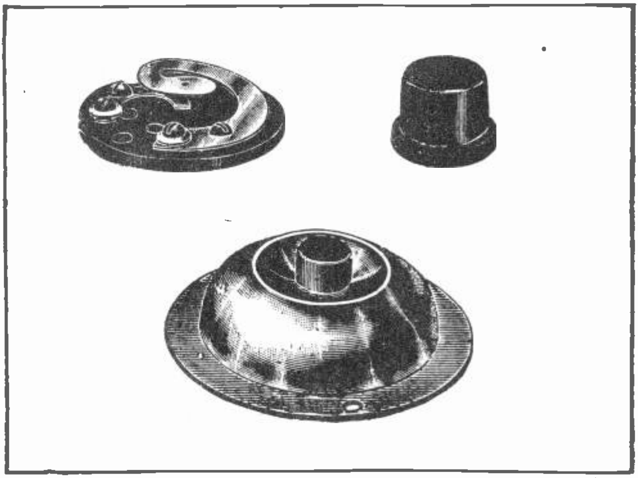


Fig. 11. View showing parts of a push button switch; also completely assembled button below.

contact springs, mounted on an insulating base of hard fibre. The short lower contact is called the stationary one, and the longer upper spring is called the movable contact.

When assembled, the button, which is also of insulating material, rests on the large springs and is held in place by the cover, as shown in the lower part of the figure. The springs are so shaped that they normally remain separated from 1/8 in. to 1/4 in., thus keeping the circuit open. But when the button is pressed it forces the movable spring down onto the stationary one, closing the circuit and allowing current to flow through the switch.

This type of push button switch is called an **Open Circuit Switch**, because it is normally open.

These switches are made for low voltages only, and should never be used for high voltage lighting circuits, or heavy currents, as they may arc and overheat badly.

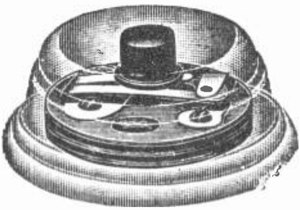


Fig. 12. Double circuit push button switch, showing clearly the arrangement of contacts and parts with respect to base and cover.

When connecting such a switch in a circuit, one wire is attached to each of the screws which have the washers under their heads. This fastens one wire to each switch contact.

The two holes in the fibre base are for the wires to pass through, and the switch is held in place by the cover. The button is slipped in the hole in the cover before placing the cover on the switch. Some switches have metal covers that snap on, while others have wood covers that screw on. In addition to this common open circuit switch, we have "closed circuit" and "double circuit" push button switches.

A **Closed Circuit** switch is one that has its contacts normally closed, and some current flowing through it all the time except when it is pressed open.

9. DOUBLE CIRCUIT SWITCHES

A **Double Circuit** switch is one that has both a closed contact and on open contact, and when pressed it breaks the closed circuit and closes the open circuit.

In Figure 12 is shown a double circuit switch. This switch is used in certain types of signal and alarm systems, where we wish to open one circuit and close another at the same time.

Referring to the figure, you will see that it has a large movable contact, and one open contact underneath, and also a closed contact above the movable spring.

The top spring is called the closed contact because it is normally touching the movable strip, keeping a circuit closed through them until the button is pressed. Then the movable spring leaves the top one and touches the bottom one, opening one circuit and closing the other.

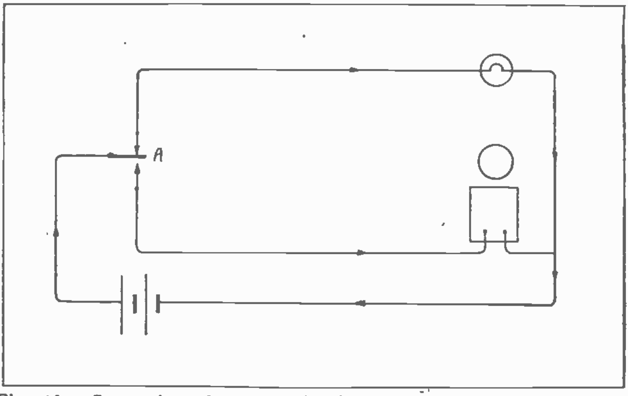


Fig. 13. Connections for a double circuit switch to operate a signal lamp and bell.

Figure 13 shows a double contact switch in use in a signal circuit. Normally the lamp burns continually and the bell is silent until the switch is pressed. Then the lamp goes out and the bell rings. Trace the circuit to note carefully this operation, and notice the symbol used to represent the double circuit switch at "A".

It is quite important, in making a drawing of these switches, to have the top contact closed or touching the movable strip, and the bottom contact or arrow should not be touching, in normal position.

Also remember that in all these switches the movable part is a spring, so it goes back to normal as soon as released.

In Figure 14 is another type of double circuit switch, that has no cover, and is used for indoor work such as desk call systems.

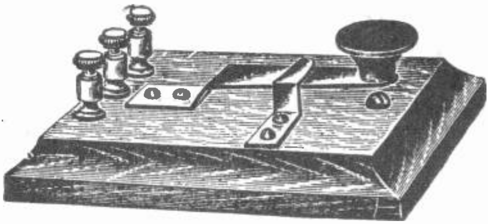


Fig. 14. Different type of double circuit switch, very convenient for code signally because of its "key-like" construction.

Because of the shape of its spring and button, it is very convenient to use as a signalling key for certain code calls.

With either of the double contact buttons shown, we can remove the bottom contact or leave it unused, and then this switch will serve as a closed circuit switch.

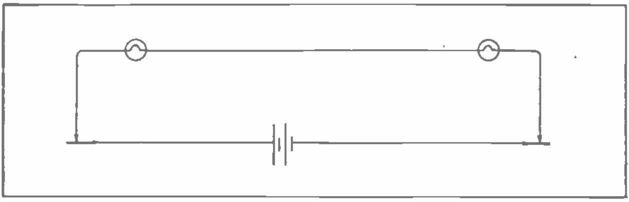


Fig. 15. Two closed circuit switches connected with lamps for a return call signal.

Figure 15 shows a sketch of two such switches used with two lamps, as a signal system for two parties to signal each other at a distance, by blinking the lamps.

Such a circuit should use a transformer, storage battery or gravity battery, because the continual current flow through the lamps would soon exhaust a dry cell.

One definite advantage of such a closed circuit signal system is the fact that any failure or defect, due to a dead battery or broken wire, is more likely to be noticed at once, than it is with an open circuit system. This is often of great enough importance to more than make up for the slight extra current cost.

10. DESK BLOCKS AND SPECIAL PUSH BUTTON SWITCHES

For desk call systems a smaller push button switch is often required, so a number of them can be located in one small block or panel.

Figure 17-A shows a desk block with five of these small buttons, and marker plates to indicate which call each button operates. Figure 17-B shows a

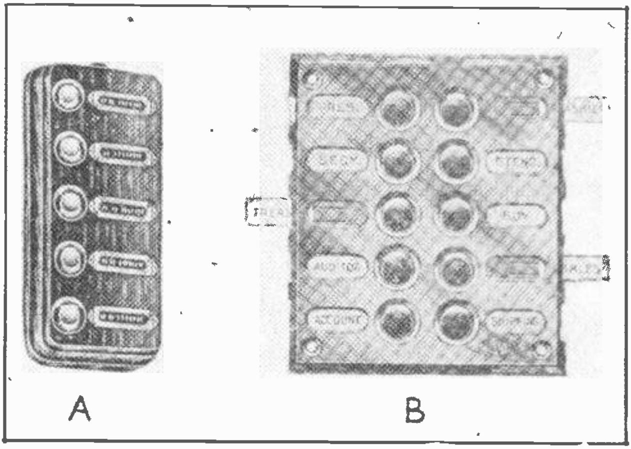


Fig. 17-A. Push buttons arranged in a desk block for office signal systems.

Fig. 17-B. Ten small push buttons with indicator tags, on a panel that can be used for wall or desk mounting.

metal panel assembly of 10 switches, such as quite commonly used in office call systems.

In Figure 18 are shown several types of small push buttons that can be mounted in desk blocks, or in round holes drilled in a board or desk.

For hospitals, and certain other uses, a very convenient push button can be arranged on the end of a flexible wire, so it can be laid on the pillow, or moved around somewhat. A button of this type, and also one to be clamped onto a bed or chair are shown in Figure 19.

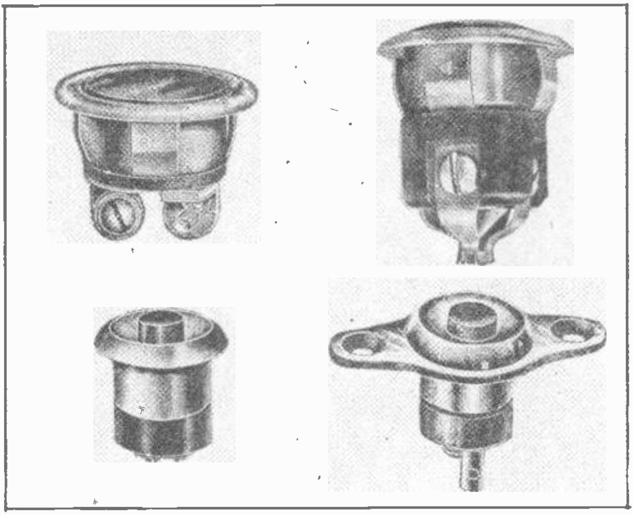


Fig. 18. Four different types of small push buttons for use in desk blocks or panels.

11. BURGLAR ALARM SWITCHES. DOOR AND WINDOW SPRINGS

In burglar alarm work we have special types of switches called **"Window Springs"** and **"Door Springs."** Figure 20 shows three views of common types of window springs which are made to fit in the window casing. These switches can be obtained in either open circuit or closed circuit types. They are mounted in the window casing in such a manner that when the window is closed, its frame rubs on the projecting slide of the switch and holds the switch open, so the bell does not operate. When the window is opened and its frame slides off the switch, the spring closes the circuit and causes the bell to operate. Or the reverse operation takes place where open circuit switches are used.

Figure 21 shows two door spring switches. The one at the left is a closed circuit switch, and the one at the right is an open circuit type.

These switches are installed in the door casing, so that when the door is closed it holds the button compressed, and when the door is opened, the spring pushes the button out and closes or opens the circuit as desired, causing alarm to operate. Window and door springs can be obtained in both closed and open circuit types.

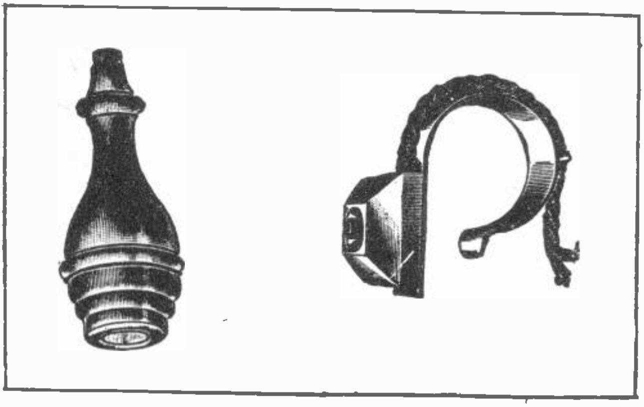


Fig. 19. Two types of push buttons commonly used in hospitals. The one on the left for attachment to pillow cord; the one on the right to be clamped to bed rail or chair arm.

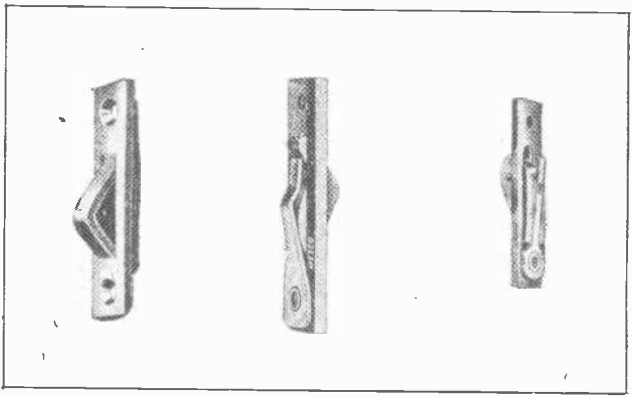


Fig. 20. Three different views of open and closed circuit window springs used in burglar alarm systems.

Two types of **Door Trips** are shown in Figure 22. This type of switch is to be mounted above the door so that as it opens, the top of the door will strike the suspended lever, causing the bell to operate momentarily.

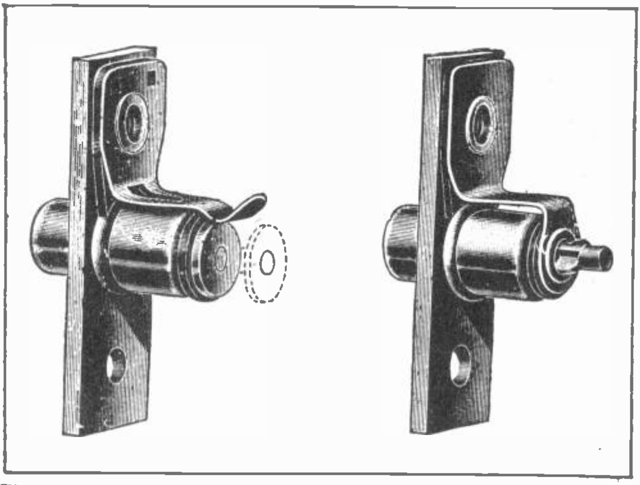


Fig. 21. Door springs of open circuit and closed circuit types to be mounted in door casings for burglar alarms.

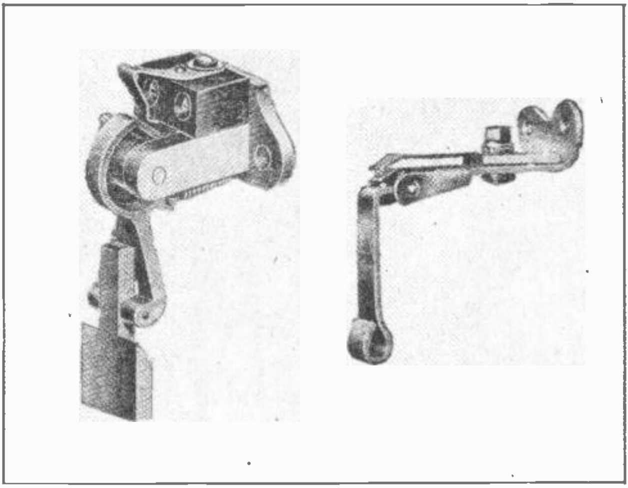


Fig. 22. Door trips to be mounted above a door, and ring a bell as the door is opened.

12. KEY OR LOCK SWITCHES

In burglar alarm systems a lock switch is often used so the owner can turn the system on at night and off during the day, or enter the building without tripping the alarm if he desires. These switches can only be operated with a special key. Figure 23 shows two switches of this type.

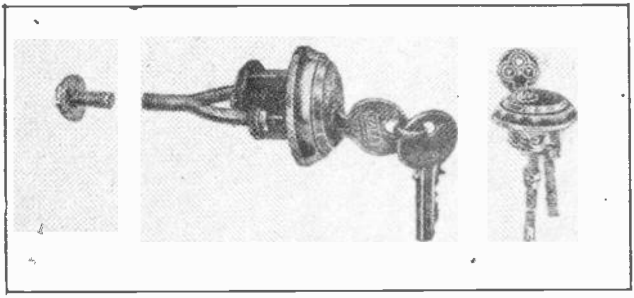


Fig. 23. Burglar alarm lock switches, used to turn the system off during the day, or when the owner wishes to enter the building without sounding alarm.

13. BURGLAR ALARM "TRAPS"

Another type of switch, often called a burglar alarm "Trap" is shown in Figure 24. This switch is arranged to be operated by a string attached to the door, window, or device to be protected.

Some of these "traps" will cause the alarm to operate if the lever is moved in either direction from the "set" position.

If the string is pulled it moves the lever in one direction, making contact on that side. If the string is cut, it releases the lever and a spring moves it in the opposite direction, making a contact on that side.

14. FLOOR SWITCHES

Often it is desired to have a signal system that can be operated from a concealed floor switch, under a carpet or rug. A switch of this type is shown in Figure 25-A. Pressure on any part of this switch will close a circuit through it, and operate a bell or other signal. Figure 25-B shows a special burglar alarm matting which is equipped with wires and contacts, to cause a bell to ring when the mat is stepped on.

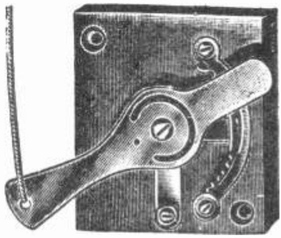


Fig. 24. Burglar alarm trap or switch to be operated by a string attached to door, window, or other object.

15. THERMAL OR HEAT SWITCHES

Another very interesting type of switch is the **Thermostat type.** One of these is shown in Figure 26. This switch is caused to operate by changes in temperature, and makes use of the different rates of expansion of different materials when they are heated. In the type shown here a strip of brass and one of hard rubber or composition are riveted together. When heated, the rubber or composition strip expands much faster than the brass, causing the whole strip to warp or bend downwards and close a circuit with the lower adjustable contact. When the strip is allowed to cool the contraction of the top strip causes the whole element to bend upwards again, and break the connection with the lower contact. If cooled beyond a certain point, it will bend upward still farther and close another circuit with the top adjustable contact.

These thermostatic switches are made in several different styles, and are used in fire alarm systems, or to indicate high or low temperature in ovens, refrigerators, storage rooms and various places, by operating a bell or signal when certain temperatures are reached. Some of their applications will be more fully described later.

So you see there are switches for almost every need in signal work, but all are simply devices to open or close a circuit.

Switches for special alarm or signal needs can often be easily and quickly made from two or more strips of light spring brass mounted on a piece of wood or other insulation, and bent to the proper shapes.

A few other types of switches are shown in Figure 27. Snap switches of the type used in lighting circuits are sometimes used in signal circuits also.

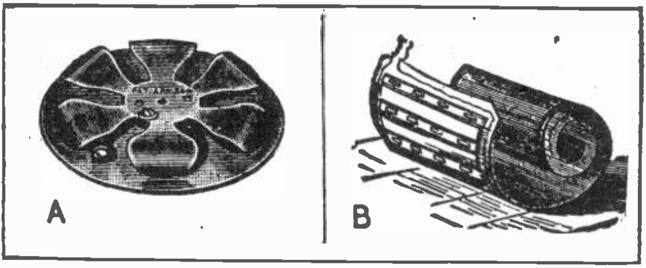


Fig. 25-A. Floor switch for use under carpets, near tables or desks.
Fig. 25-B. Burglar alarm mat to be placed under door mats or rugs, to close a circuit when stepped upon.

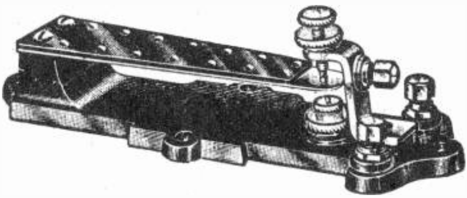


Fig. 26. Thermostatic switch which closes its contacts when heated, and is used in fire systems.

16. SWITCH TROUBLES AND TESTS

Some of the mysterious little troubles that cause failure of signal systems are often right at the switches, and nothing more than a loose connection, or dirty or burned contacts. Or possibly some small piece of insulating material such as a bit of string or fuzz from the wire insulation, or a bit of wood or sand, stuck to one of the contacts. A sure way to test any switch is to connect a dry cell and a buzzer, or low voltage lamp, directly across its terminals; and then press the switch a number of times. If it does not operate the lamp or buzzer every time it is pressed, its contacts should be thoroughly cleaned with sandpaper, knife, or fine file, and its terminals carefully tightened. Remember a very small object or amount of dirt offers enough resistance to prevent current flow in low voltage circuits.

Signal Switches

We have seen many an "old timer" or electrician with considerable experience sweat and worry over

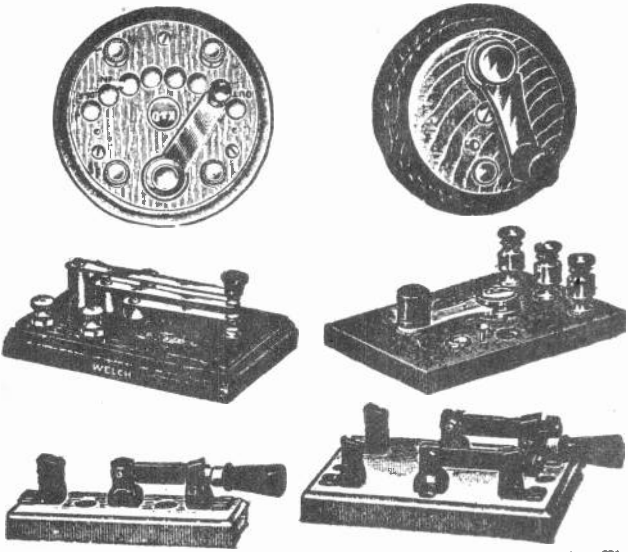


Fig. 27. Several different types of switches used in signal work. The two above are called Lever Switches. In the center on the left is a Multiple Key Switch; at the right double circuit Lever Switch. Below are two Knife Blade Switches.

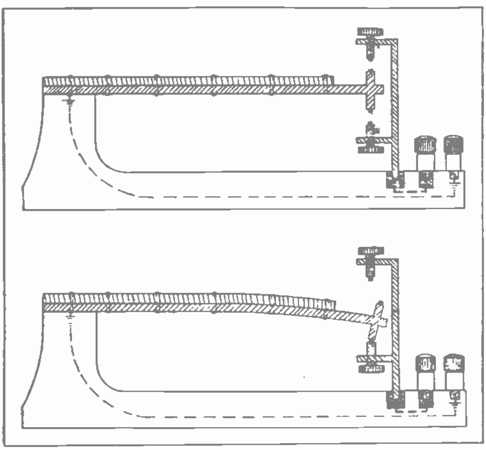


Fig. 28. Two sketches of thermostatic switch, showing the strip in normal position in the upper view, and warped to close the contacts in the lower view. Note how the circuit is completed through the metal frame of this device.

something of this same nature. But with a knowledge of circuit principles, Ohms Law, and these simple definite tests, such troubles can be "cornered" and need not be so mysterious to the man with training.

EXAMINATION QUESTIONS

1. Why are symbols used in wiring plans instead of actual pictures?

2. What are the principle parts needed for an electric signal system?

3. What kind of primary cells would you select for use on a closed circuit system?

4. What purpose does the bell transformer serve in door bell systems?

5. What purpose does the switch serve in a signal system?

6. Would you select an open or a closed circuit switch for use on a simple door bell circuit?

7. Are the contacts in a closed circuit switch normally open or closed?

8. Describe a double contact switch.

9. Name two uses for a thermostatic switch.

10. What are the most common troubles which cause push button switches to fail?

SIGNAL EQUIPMENT

1. SIGNAL BELLS AND LAMPS

The purpose of any signal or alarm system, is to call the attention of someone. To do this we can use either an "audible" or "visible" signal, or quite often a combination of both. By an audible signal, we mean one that creates sound loud enough to be heard by those whose attention is desired. Bells, buzzers, and horns are used for this purpose. Visible signals are those that are to attract the eye, such as lamps, or semaphores. The term "semaphore" means a sort of moving flag or shutter.

Visible signals as a rule can only be used where they are in front of, or in line with the vision of those whose attention is desired, and are most commonly used where an operator or attendant is watching for them continually.

Electric bells are very commonly used in all types of signal systems.

Their construction and operation is quite simple and yet very interesting, and important to know.

2. VIBRATING BELLS

There are several different types of bells, but the **Series Vibrating Bell** is the most commonly used of any. Figure 1 shows a good view of such a bell with the cover removed, showing the coils and parts.

Examine this carefully and compare it with Figure 2, which is a sketch of the same type of bell, and shows the electrical circuit and operating principle clearly. Note how easy it is to recognize each part in the photo, from the simple symbols in the sketch, and how the sketch really shows some things more clearly than the actual photograph. "A" and "A" are the bell terminals to which the wires are fastened. "B" "B" are the cores and coils or electro-magnets, which attract or operate the armature "C". "D" is a spring which supports the armature and also pulls it back every time the magnets release it. "E" is the end of the same spring, on which is mounted a piece of special alloy metal, which serves as a contact to close a circuit with the adjustable screw contact "F". These form the **Make and Break Contacts,** and are very neces-

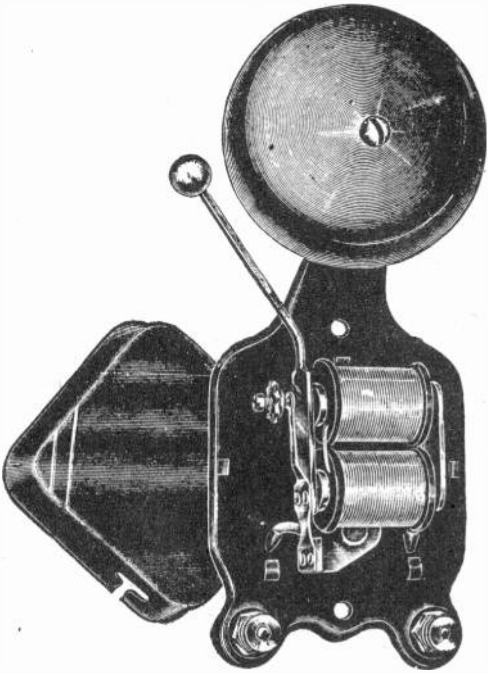


Fig. 1. View showing common vibrating bell with cover removed. Note carefully the construction and arrangement of coils, armature, and contacts.

sary in the operation of the bell. "G" is the frame of the bell, "H" is the hammer which is attached to the armature, and strikes the gong "I", when the magnets attract the armature.

When a battery is connected to terminals "A", "A", current at once starts to flow through the bell. If the positive battery wire was attached to the left terminal, current would flow up through the armature, which, of course, is insulated from the frame, then through the "make and break" contacts, through the coils and back to the right hand terminal and the battery. As soon as current flows through the coils, the magnets attract the armature, causing the hammer to strike the gong, and also opening the "make and break" contacts. This stops the flow of current, demagnetizing the coils and releasing the armature. As soon as the armature falls back and closes the contacts, the magnets pull

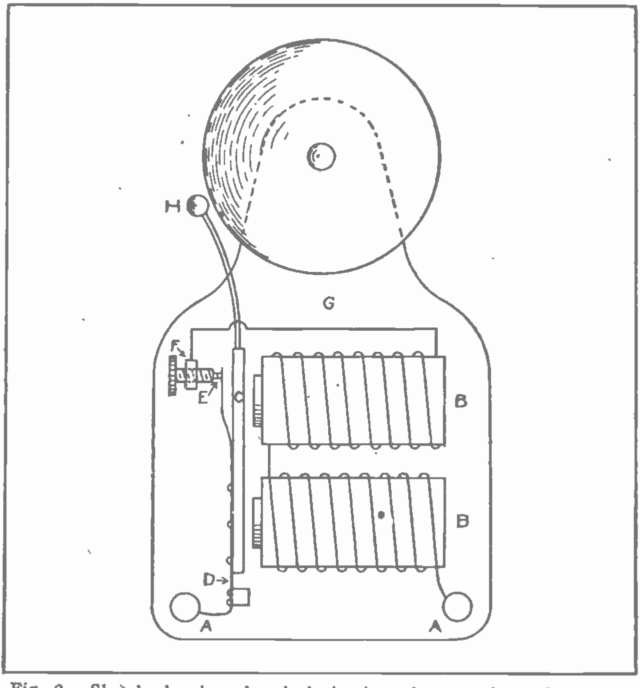


Fig. 2. Sketch showing electrical circuit and connections of common vibrating bell. Observe very carefully the parts of this diagram, and the explanation given.

it away again. This is repeated rapidly as long as current is supplied to the bell; thus it is called a **Vibrating Bell.**

3. BELL TROUBLES

Most of these bells have their coils wound for 6 to 10 volts, and should not be operated on much higher voltage or the coils will overheat and burn their insulation off, which destroys them.

Most vibrating bells are made for short periods of operation only, and should not be allowed to operate continuously for long periods, or the arc at the contacts will heat and burn them. If these contacts become badly burned or dirty, they should be cleaned and brightened with a thin file. When

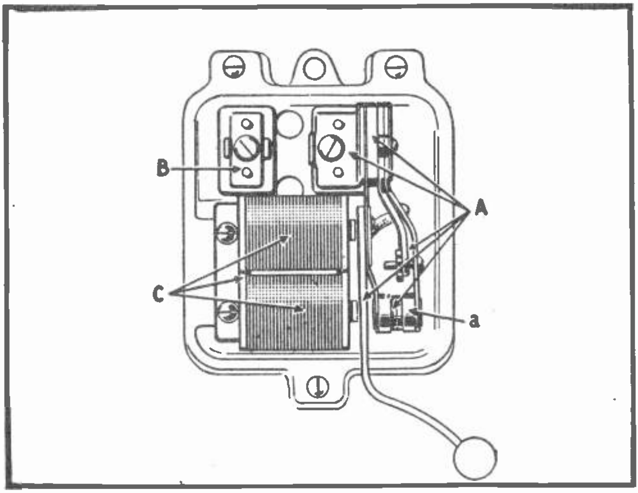


Fig. 3. Heavy duty bell frame and parts. Note the extra heavy carbon contacts for making and breaking the circuit at "a."

a vibrating bell refuses to operate the trouble can usually be found at the contacts, or a loose terminal nut, or poorly adjusted armature spring.

When the contacts are worn out, they can be replaced on the more expensive bells, but on the cheaper bells it is difficult to remove them and the bells can be discarded more economically, because of their very low cost.

In the more expensive bells, the contact points are faced with platinum, silver or special alloys that resist corrosion and burning, as **even a very small amount of burned metal or dirt in these contacts will prevent the operation of the bell.**

In some vibrating bells both terminals are insulated from the frame by little fibre sleeves and washers, and must be kept so.

If this insulation becomes defective the current is shorted through the frame and the bell will not operate. Other bells have only one terminal insulated, and the other is intentionally grounded to the frame, passing the current through the frame to the armature, which in this case is also grounded to the bell frame.

Sometimes the hammer of a bell becomes bent so it will not touch the gong, or rests too tightly against it, stopping the proper operation of the bell.

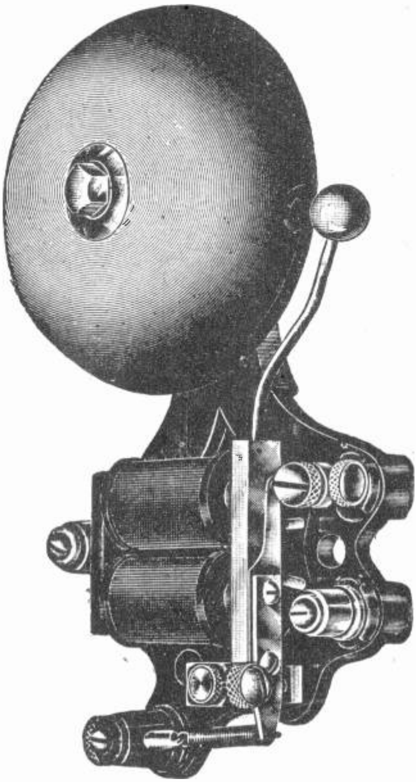


Fig. 4. Ruggedly constructed heavy duty bell. Bells of this type are often wound for 110-volt operation, and used where a very loud signal is desired.

A good understanding of the parts and operation of these bells will enable anyone with a little mechanical ability, to easily locate and repair their most common troubles.

In Figure 4 is shown one of the larger types of vibrating bells which are often wound for 110 volt operation.

Series vibrating bells **will operate on either D. C. or A. C.** as it does not matter which way current flows through them; the magnets will attract the armature just the same. For this same reason, it makes no difference which way a battery is connected to these bells, as far as polarity is concerned.

4. SINGLE STROKE BELLS

Sometimes it is desired to have a bell that will give single taps each time the button is pressed, instead of a continuous vibration.

Such a bell is called a **Single Stroke Bell.** Figure 5 shows a sketch of a bell of this type. The only

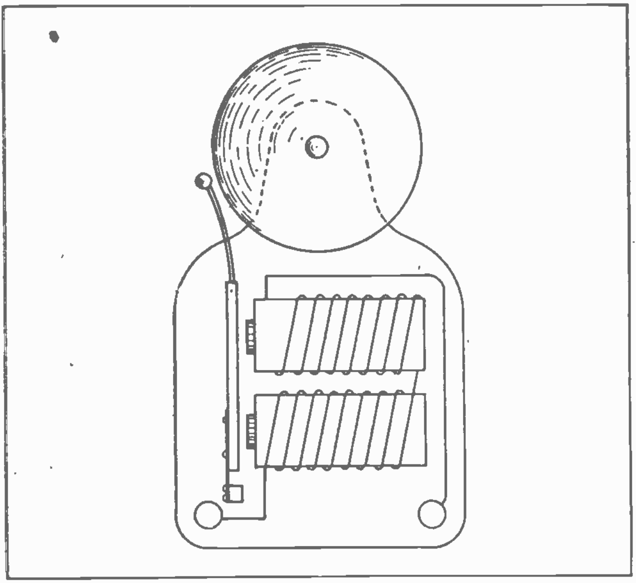


Fig. 5. Circuit diagram of a single stroke bell. Note that it does not have "make and break" contacts.

difference between this and a vibrating bell is that it has no make and break contacts, and therefore cannot vibrate. Each time the button is pressed and current supplied to this bell, its hammer strikes one tap of the gong. As long as the switch is kept closed the magnets hold the hammer quietly against the gong, after the first tap. When the switch is opened the hammer drops back ready for the next stroke.

These bells are very good for code calling, where a certain number of distinct strokes are used for each different call. They should be operated on D. C., as alternating current will cause the hammer to chatter slightly. This is due to the regular variations in value of alternating current.

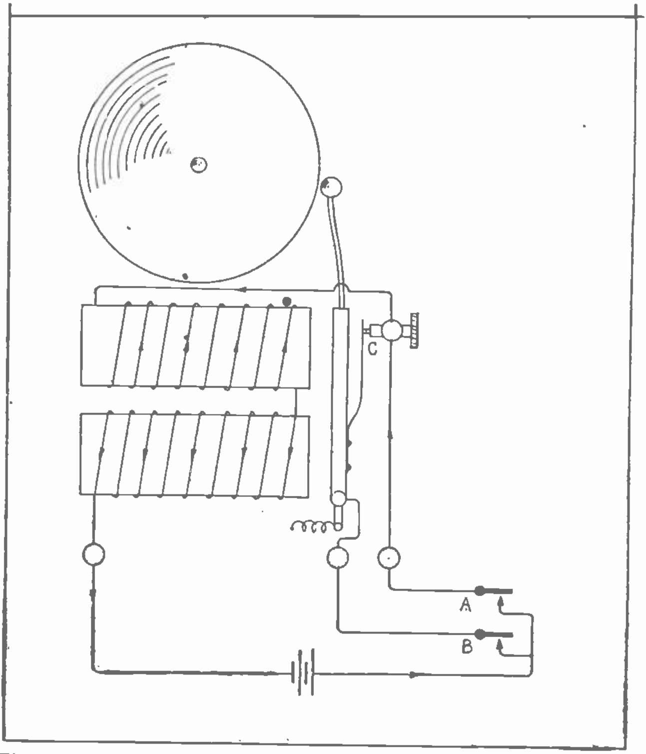


Fig. 6. Connections for a combination bell to be used either single stroke or vibrating. Trace this circuit carefully.

5. COMBINATION BELLS

There are also combination bells which are arranged to be used either vibrating or single stroke.

Figure 6 shows a sketch of such a bell connected to a battery and two switches, to be operated either as a single stroke or vibrating bell as desired.

If button "A" is pressed, the current will flow directly through the coils without having to pass through the make and break contacts at "C", and the bell will operate single stroke. The arrows show

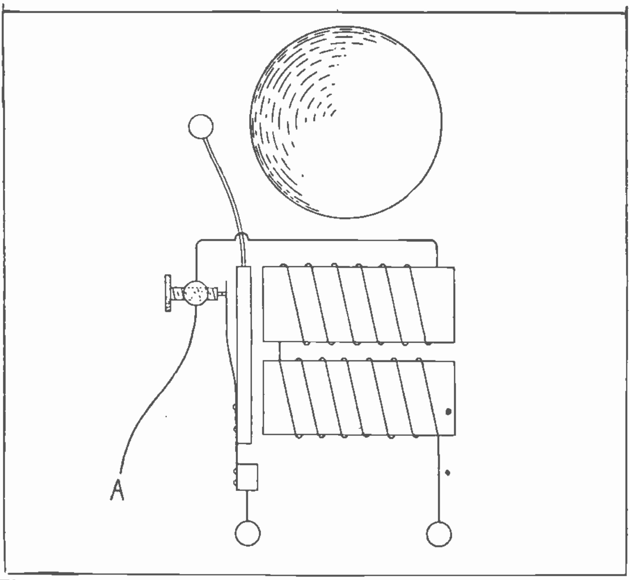


Fig. 7. Sketch showing method of attaching an extra wire to the stationary contact to convert an ordinary vibrating bell for single stroke or combination operation.

the path of current flow, during single stroke operation. If button "B" is pressed the current will flow through the armature and make and break contacts, and then to the coils, and the bell will vibrate because the magnets can now break the circuit rapidly as they pull the contacts apart at "C".

In emergencies or when a combination bell of this type cannot be obtained conveniently, you can easily convert an ordinary vibrating bell to single stroke or combination operation, by attaching an extra wire to the stationary contact of the breaker. See Figure 7, and the extra wire "A".

There are several other types of bells that are slightly different from the series vibrating type with principles very similar, but they are little used and can be easily understood with a little close observation and a knowledge of general principles covered here.

Another type of bell used extensively in telephone work, and operated on alternating current, will be taken up in a later section.

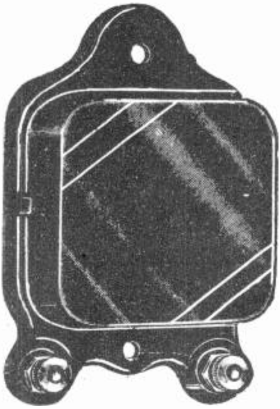


Fig. 8. Common office type buzzer, very similar to a vibrating bell, except that it has no hammer or gong.

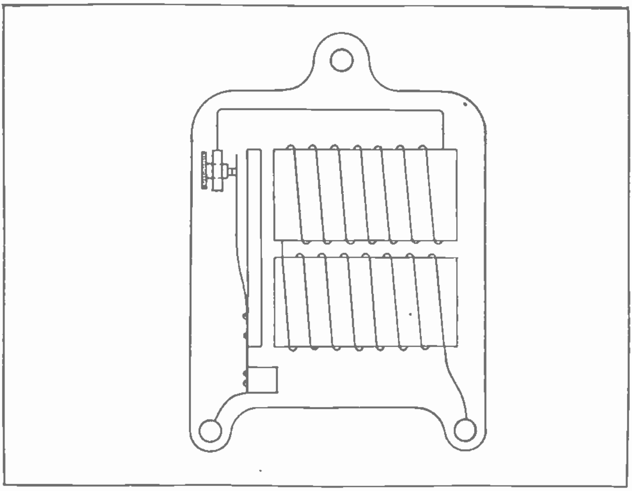


Fig. 9. Sketch showing coils and circuit of a buzzer of the type shown in Fig. 8.

6. SIGNAL BUZZERS

In certain places such as hospitals and offices where noise is undesirable, a bell is too loud, and some device to give a softer note is needed.

For this purpose we have buzzers. These buzzers are almost exactly the same in construction and operation as the bells, except that the hammer and gong are left off entirely. The vibration of the smaller and lighter armature makes a sort of low buzzing sound which is sufficient to attract the attention of anyone near it. Figure 8 shows a common type of office buzzer enclosed in its metal case, and Figure 9 shows a sketch of the electrical circuit and parts of this buzzer. Buzzers can be obtained in different sizes, and some have an adjustment screw on them to change the tone and volume of sound. Figure 10 shows four buzzers of different sizes.

7. "MUFFLING" OF BELLS

Sometimes when a buzzer is not available it is desirable to partly silence a bell, without putting it out of service entirely. This can be done by plugging the back of the gong with paper, or by removing the hammer ball, or bending it back so it does not strike the gong.

8. CARE AND TESTS OF BELLS AND BUZZERS

When any bell or buzzer fails to operate, a quick test to find out whether the trouble is in the bell or some other part of the circuit, can be made by connecting a cell or battery of proper voltage directly to the bell terminals.

If the bell does not operate then, be sure its terminals are tight, and its armature free to move. Clean the make and break contacts carefully with a thin file, or fine sand paper, and you will probably cure the trouble. If it still does not operate, examine the coils and the wires leading to them and, if necessary, test the coils as explained

Usually, however, the trouble will be found at the contacts, loose terminals, or armature adjustment.

9. SILENT SIGNALS

In some places an entirely silent signal is desired, and a visual indication is used instead of a bell or buzzer.

For this purpose we have low voltage signal lamps of various types. These can be obtained in voltages from two to twenty, and with colored bulbs, in white, red, blue, green, amber, etc. The different colors can be used to indicate different signals or to call different parties.

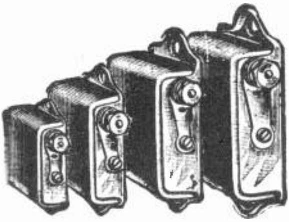


Fig. 10. Four office buzzers of different sizes. Each size gives a signal of a different tone and volume.

Some of these lamps can be obtained with miniature threaded bases, to screw into small porcelain sockets, and can be conveniently located most anywhere desired. Others are made in special sizes and types, such as those used in telephone switchboards, etc.

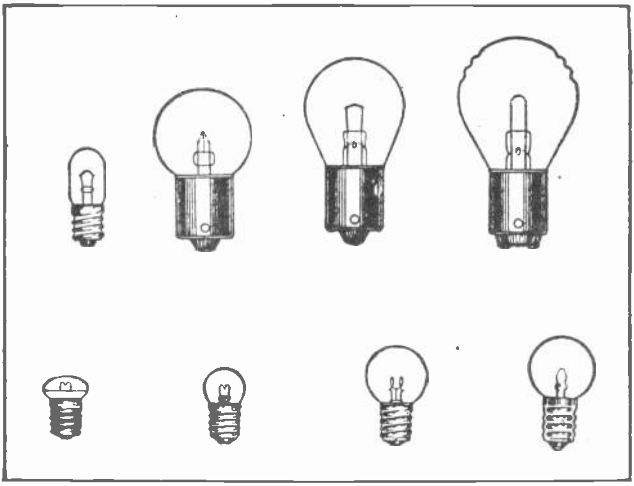


Fig. 11. Several types of low voltage lamps which can be used for signal circuits.

When regular signal lamps are not available, automobile lamps and flashlight lamps can often be used to good advantage.

In many cases both a lamp and bell are used, or a lamp in the daytime, and a bell at night to arouse a sleeping person.

Danger signals often use both a red lamp and a bell. Railway crossing alarms are good examples of this.

Lamps of proper size and voltage rating can often be connected in parallel with a bell as in Figure 13A, or in series as in Figure 13B.

Fig. 14 shows a circuit which enables the caller to use either the lamp or bell as desired.

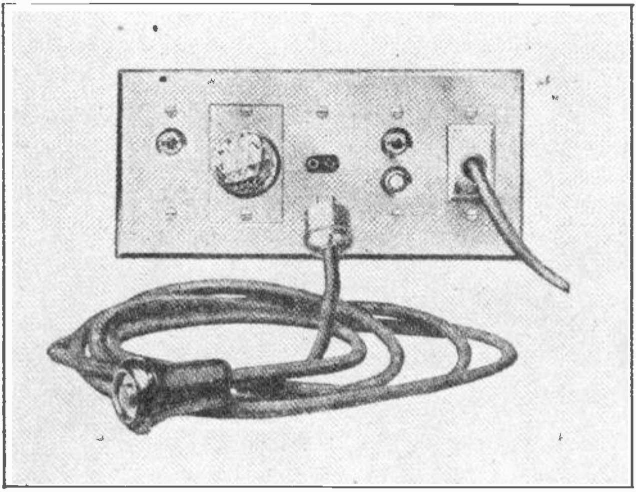


Fig. 12. Panel and cord for silent hospital signal. The lamp is located behind the glass "bulls-eye" at the left.

10. MAGNETIC DOOR OPENERS

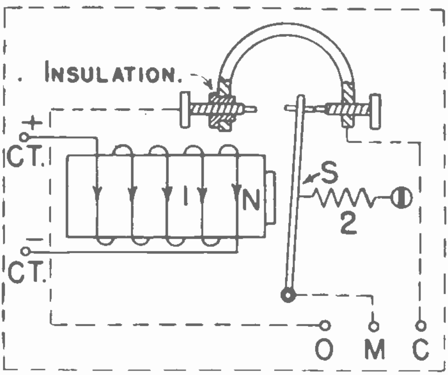
A device quite commonly used in connection with door bells is a **Magnetic Door Opener**, shown in Figure 15. These devices will unlock the door by use of magnets, when a button inside is pressed. They are particularly popular and useful in apartment buildings where the door bell may call someone several floors above. Such buildings usually have speaking tubes or telephones in connection with the door bells, and after the bell is rung and the party in the house finds out who is calling, they can unlock the door if they wish to by merely pressing a button in their apartment. Thus they are a great convenience and time saver. Figure 16 shows a sketch of a magnetic door lock in connection with a door bell system. Note how the same battery and the center wire are used for both circuits. Many worth while economies can be effected in wiring signal systems, by such simple combinations of circuits. A number of these will be shown a little later in this section.

RELAYS

A RELAY IS A **MAGNETICALLY OPERATED SWITCH** that can be used to:

1. Control circuits distant from the operating point.
2. Control a relatively high voltage or high wattage circuit by means of a low power, low voltage circuit.
3. Obtain a variety of control operations not possible with ordinary switches.

Whether the circuits controlled will be closed or opened when the relay coil is energized will depend upon the arrangement and connection of the relay contacts.

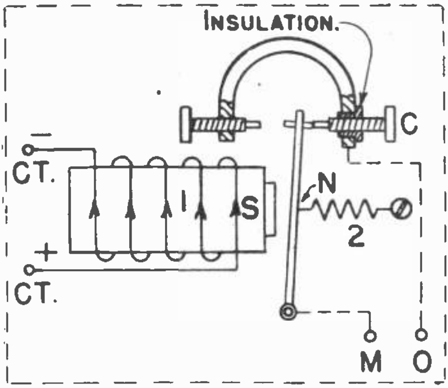


WESTERN UNION RELAY.

ACTION

When current flows through the relay coil, it magnetizes the iron core with a polarity that depends upon the connection of the coil to the source. This pole induces in the iron section of the movable assembly a pole of opposite sign, and the attraction between these operates the relay switch. If the

C = Normally closed contact.
O = " open "
M = Moving contact.
1 = Magnet coil with terminals CT.
2 = Spring.



Pony Relay.

current through the coil is reversed, both poles are reversed; therefore **attraction always occurs.** From above it is obvious that relays can be designed to operate on either direct or alternating current.

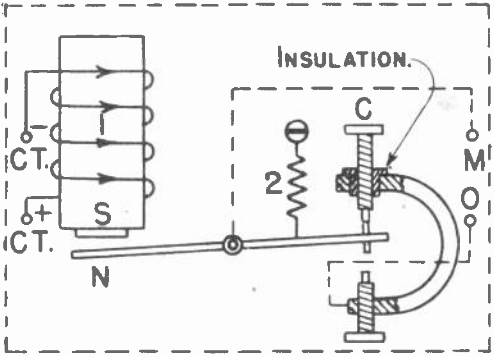
It is important to note that while relays may vary widely in mechanical construction, they all operate on the same principle. The sketches on this sheet show some of the differences in design.

TESTING

Before any attempt is made to connect a relay in a circuit:

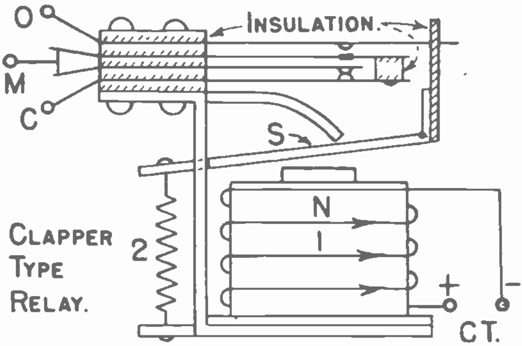
1. Make a sketch of the terminal locations
2. Test and identify all terminals
3. Make sure the relay is operating.

Using an ordinary test lamp circuit, first find the pair of terminals that, when the test leads are placed on them, causes the relay to operate. These are the **coil terminals.** Identify them on the terminal sketch with the symbols CT. Next locate by test, inspection, or both, the **open, moving,** and **closed** contact terminals. Mark them on the terminal sketch with the symbols O, M, and C respectively.



DIXIE RELAY.

After the terminals have been identified, check the operation. The relay should pull the movable section up as soon as the coil is energized, and drop



it out as soon as the coil is deenergized. The moving section should not touch the core, and the tension on the spring should not be too low or too high. The relay switch contacts must be clean.

Connecting a relay in a circuit without first making the above tests is, in the general case, an inefficient and time wasting procedure.

RELAY CIRCUITS

Diagram A shows an application in which a relay and a low voltage control circuit are used to operate

a circuit carrying more power at a higher voltage.
To wire this circuit:

1. Make a note of the apparatus required. 2 **open circuit** switches; 1 relay; 1 lamp; 2 batteries.
2. Test all apparatus involved and select and use only that equipment that is in operating condition.
3. Wire each circuit one step at a time, and check each step before wiring the next.
4. Trace the circuits according to the method previously outlined.

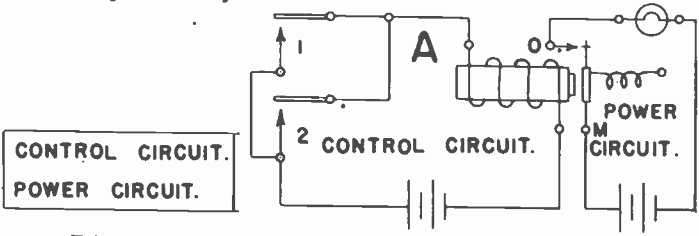


Diagram B shows a relay application similar to that indicated in A. In this case, however, the control circuit is normally **closed,** whereas in A the control circuit is normally **open.** The switches used are the **closed circuit** type. Note also that in diagram A the **open** contact of the relay switch is used in the power circuit, but that in B the **closed** contact is employed. The list of apparatus for this circuit will therefore be somewhat different than in the previous case. The procedure for wiring will be the same as before.

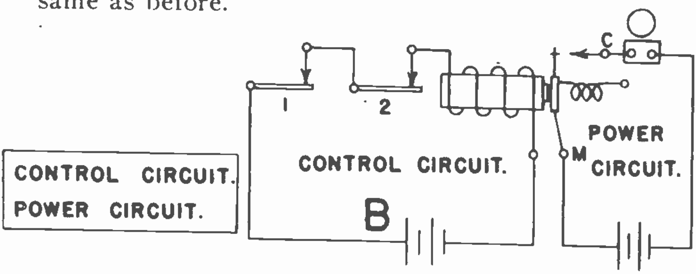
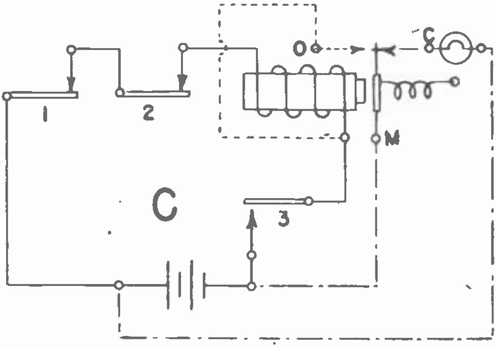
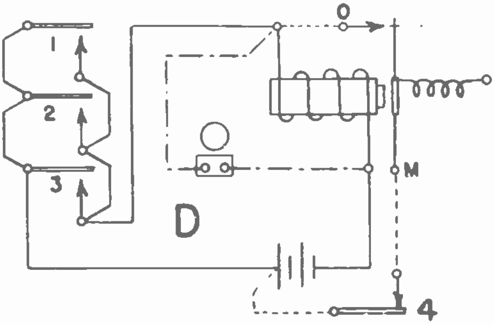


Diagram C shows relay applications in which a type of control not obtainable with ordinary switches is achieved. When switch 1 or 2 is pressed the relay switch closes the indicating circuit and the lamp lights and remains alight until switch 3 is pressed, when the relay is energized and stays that way until some other switch is operated.



FIRST STEP	CONTROL CIRCUIT.
SECOND STEP	ALARM CIRCUIT.
THIRD STEP	HOLDING CIRCUIT.

Wire the circuit in 3 **steps** and **test each** before going on to the next. The **first** step is shown in **solid** lines, the **second** in **dashed** lines, and the **third** in **dotted** lines.



FIRST STEP	CONTROL CIRCUIT.
SECOND STEP	ALARM CIRCUIT.
THIRD STEP	HOLDING CIRCUIT.

Diagram D shows another relay being used to obtain a special type of control. Switches 1, 2, or 3 energize the relay and close the bell circuit through the relay switch. The bell rings continuously until switch 4 is pressed to reset the relay.

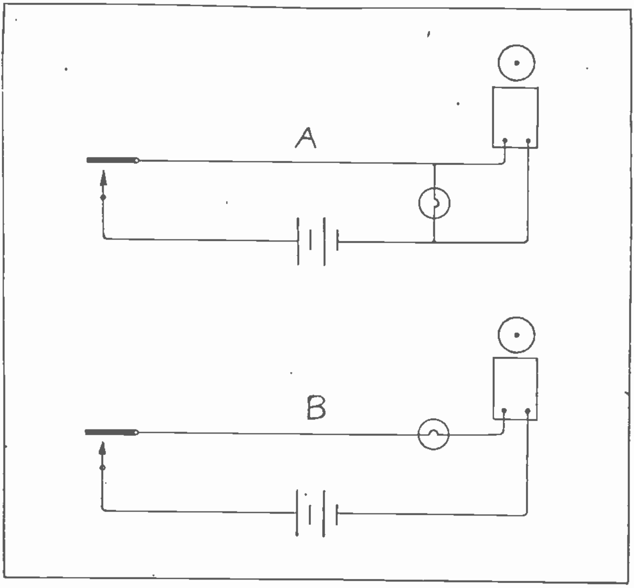


Fig. 13A. Signal lamp connected in parallel with a bell so they both operate at once.
Fig. 13B. Signal lamps can also be connected in series with bells if they are of the proper resistance.

11. DROP RELAYS FOR CONSTANT RINGING SIGNALS

In certain alarm and signal systems it is often an advantage to have the bell continue to ring until it is shut off by the person it is to call. For example a burglar alarm in order to give a sure warning, should not stop ringing if the burglar stepped in through the window and then closed it quickly. To provide continuous ringing of a bell once the switch is closed, we use a device called a **drop relay.** Figure 17 shows one of these devices, and Figure

18 shows a sketch of the connections of a drop relay with a bell, battery, and switch, ready to operate. Trace each part of this circuit and examine

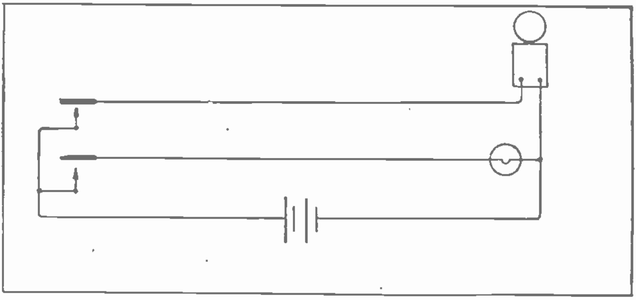


Fig. 14. Connections for operating either a bell call or silent lamp signal, as desired.

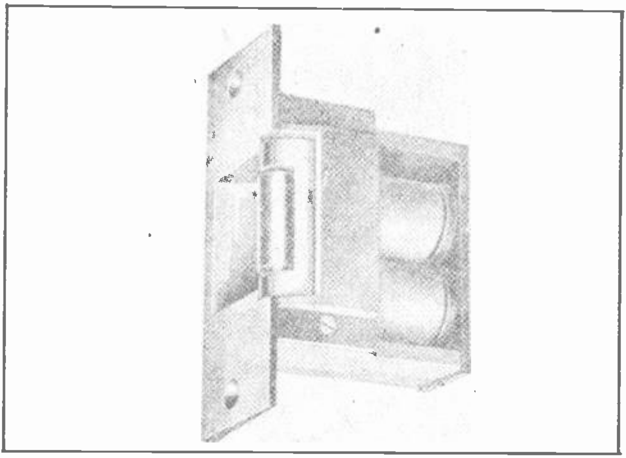


Fig. 15. Magnetic door opener, used to unlock doors in apartment houses or buildings from a distance, by the use of a push button and low voltage circuit.

the parts of the device carefully, and its operation will be easily understood.

When the switch is closed, current first flows through the circuit as shown by the small arrows, causing the coils to become magnetized and attract the armature. This releases the contact spring which flies up and closes the circuit with the stationary contact to the bell. Before being tripped, the contact spring is held down by a hook on the armature, which projects through a slot in the spring. The button "B" extends through the cover of the relay, and is used to push the contact spring back in place, or reset it, and stop the bell ringing.

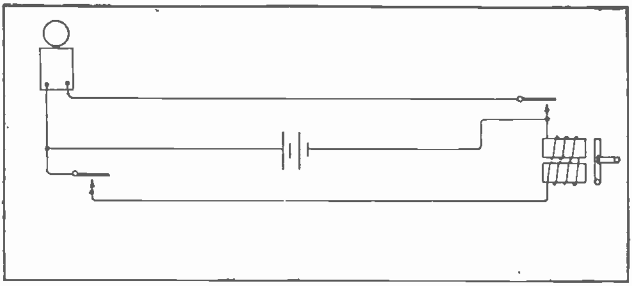


Fig. 16. Sketch showing connections for a door bell and magnetic door opener.

In tracing the bell operating circuit shown by the large black arrows, we find the current flows through the frame of the device from "C" to "D."

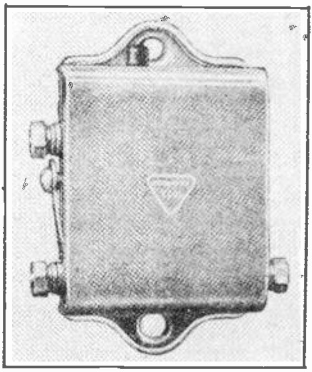


Fig. 17. Common type of drop-relay to provide constant ringing in alarm or signal circuits.

The marks or little group of tapered lines at "C" and "D" are symbols for **Ground** connections. From this we see that a ground connection as used in electrical work does not always have to be to the earth. But instead a wire can be **Grounded** to the metal frame of any electrical device, allowing the current to flow through the frame, saving one or more pieces of wire and simplifying connections in many cases. It is a very common practice in low voltage systems, and extensively used in telephone and automobile wiring. So remember what that symbol means whenever you see it from now on. Another type of drop relay is shown in Figure 19, and its circuit and connections with a bell and battery are shown in Fig. 20.

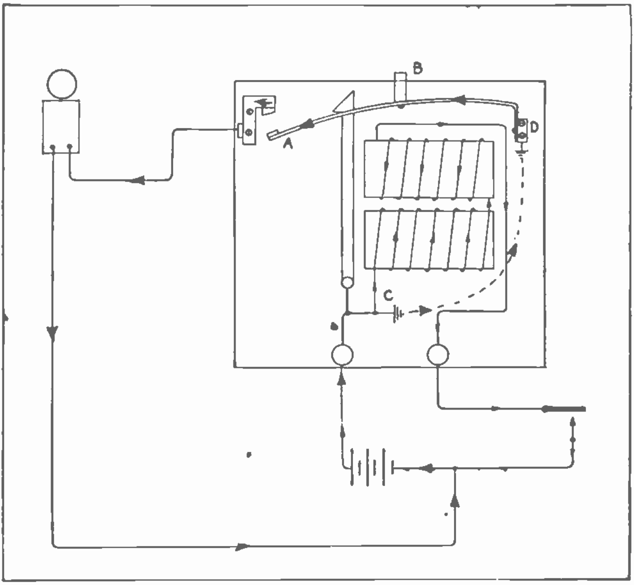


Fig. 18. Sketch showing complete circuit and connection of drop-relay of the type shown in Fig. 17. Examine this sketch and trace the circuit very carefully.

This relay is a little different in construction than the one in Figure 17, but it performs the same function of causing the bell to ring constantly when the relay is tripped. Trace this circuit carefully and compare the terminals "C," "D" and "E" with their position on the relay in Figure 19, and this will show you how to properly connect the device in a circuit.

Drop relays are used very extensively in burglar alarms, and also in other forms of signals. Some special bells are made with an extra release spring and switch to make them ring constantly until re-set. This is a sort of drop relay built right into the bell.

12. RELAYS

In your last lesson it was mentioned that a closed circuit system is much more reliable than an open circuit system, because any fault such as a broken wire or dead battery would make itself known at once by causing the signal to operate. So closed circuit systems are much better for burglar alarms, fire alarms, etc., where it is very important not to have a fault in the system go unnoticed until just when the signal is most needed.

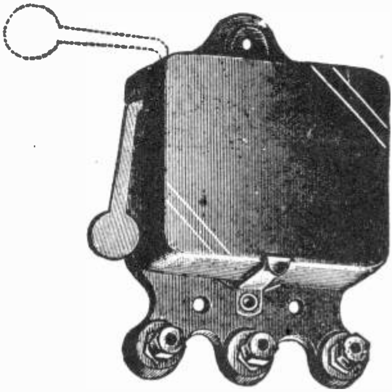


Fig. 19. Another type of drop-relay of slightly different construction, but also providing constant ringing.

We cannot, of course, connect a bell directly in a closed circuit, or it would ring continually. So we have an interesting device which can be connected in the closed circuit, using very little current, and making no noise until its circuit is disturbed. Then it immediately gets busy and closes a second circuit to the bell, causing it to ring.

This device is called a **Relay**. Its name gives a good idea of its function. When it receives an impulse or has its current interrupted, it passes on an impulse of current to a bell or other device, similar to the man in a relay race who passes his stick to the next man to carry on.

A relay is in reality a **Magnetically Operated Switch.** Figure 21 shows a common type of Pony Relay, which is used extensively in alarm, signal, and telegraph work.

Examine this relay very closely. You will note the **Coils** or electro magnets, which are to attract the **Armature** or movable part of the switch. The armature is the vertical metal piece set in pivot hinges at the left end of the magnets. Then there is a coil spring attached to it and having its other

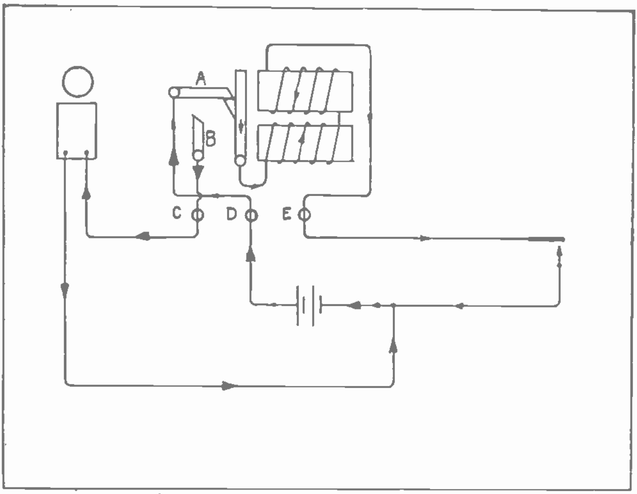


Fig. 20. This sketch shows the method of connecting a drop-relay such as shown in Fig. 19 to a bell battery and push button for constant ringing signals.

end fastened to an adjusting screw to vary the spring tension on the armature. This spring is to pull the armature back each time the magnets release it. The large piece of brass with the curved arch above the armature is called the **Bridge**, and supports two adjustable bridge contacts. These screw contacts have hollow tips, in which we can place plugs of metal, hard rubber, or wood, according to which contact we wish to use in the circuit. Note that the armature tip also has small points of good contact metal on each side where it touches the bridge contacts.

13. RELAY TERMINALS AND CONNECTIONS

The two connection posts or terminals on the right end of the base in Fig. 21 connect to the coils. And of the two on the upper left corner, the right-hand one nearest the armature is connected to the armature, and the left one connects to the bridge. These connections are made under the relay base. It is very important to remember which of these terminals are for the coils, armature, and bridge.

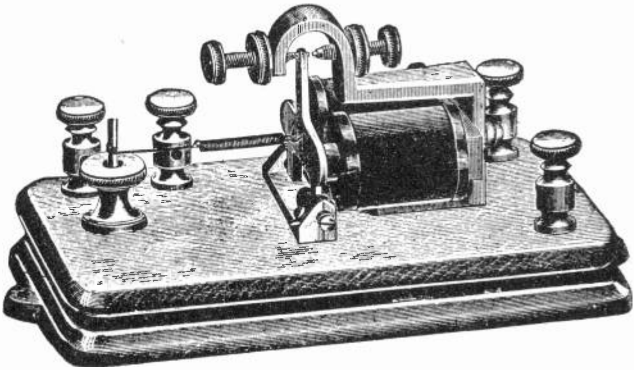


Fig. 21. Common Pony Relay such as used in burglar alarm and telegraph systems. Examine the construction and parts, and compare with description given.

Figure 22 is a sketch of this relay showing its electrical parts and circuits from the opposite side to the one shown in Figure 21. Compare this very closely with the picture in Figure 21, and locate the coils, armature, bridge, contacts, and terminals,

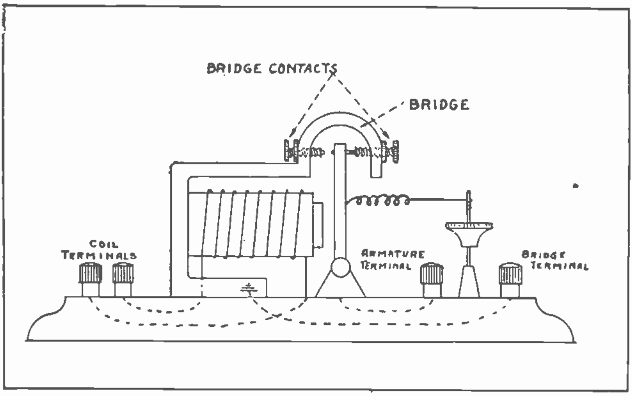


Fig. 22. Diagram showing the arrangement of the electrical circuits and terminals of a Pony Relay.

so you know the location of each and the operating principle of the relay. Figure 23 shows another relay of slightly different construction but same general principle as Figure 21.

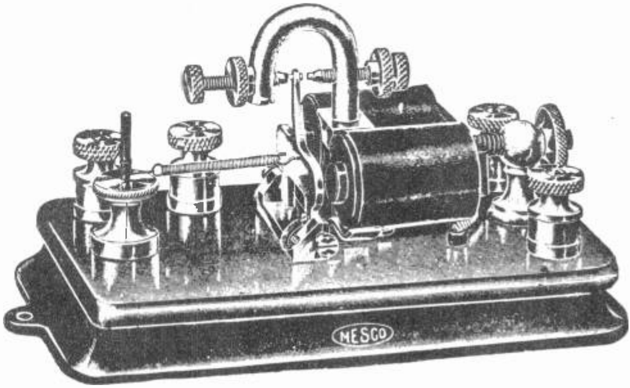


Fig. 23. Another type of Pony Relay similar to the one in Fig. 21, but of slightly different mechanical construction.

14. OPEN, CLOSED, AND DOUBLE CIRCUIT RELAYS

Relays can be used in several different ways in circuits, and according to their use they are called **Open Circuit, Closed Circuit, and Double Circuit Relays.**

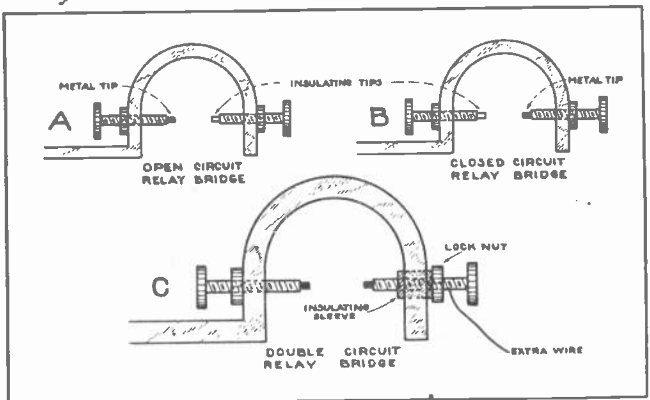


Fig. 24. This sketch shows in detail the manner of arranging and insulating relay bridges for open circuit, closed circuit, and double circuit operation.

To use a relay as an open circuit device, we place the metal tipped bridge contact screw on the left side of the bridge arch, and the insulated contact on the right, or the side away from the coils, as in Fig. 24A.

For closed circuit operation we reverse them. For double circuit use we fit both bridge screws with metal tips, but remove one screw and insulate it from the bridge arch, by enlarging the hole and fitting it with an insulating sleeve, then replacing the screw in this sleeve. Then we attach an extra wire to this screw for the extra circuit. See Figs. 24A, B, and C. With a drill to enlarge the hole in the bridge, and piece of fibre or hard rubber, or even hard wood, for the insulating sleeve, any ordinary pony relay can be easily changed to a double circuit relay in this manner in a few minutes. This is a very important thing to remember, because some time you may not be able to get a double circuit relay, and it may be very handy to know how to change over a single circuit relay in this manner.

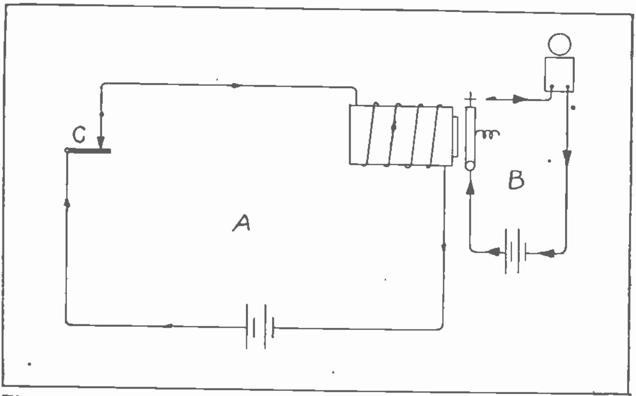


Fig. 25. Connections for a closed circuit relay used to operate a bell in a simple burglar alarm system.

15. RELAYS USED IN BURGLAR ALARMS

Figure 25 shows a closed circuit relay connected up for operating a simple closed circuit burglar alarm. Here we have used just the symbol for the relay instead of a complete sketch. Note what a time saver this symbol is, and practice making a sketch of it until you are sure you can make it any time, when laying out a plan for a system using relays.

Trace out the circuit in Figure 25 until you understand its operation thoroughly. Note that current will normally be flowing all the time in the closed circuit "A". For this reason most relays of this type have high resistance coils, wound with many turns of very fine wire, so they will not use much current from the battery. Many of these common relays have coils of 75 ohms, and they can be obtained with higher or lower resistance for various uses. Recalling the use of Ohms law formula, we find that if a 75 ohm relay is used in a circuit with a 3 volt battery, only .04 ampere will flow. Or as $E \div R = I$, then $3 \div 75 = .04$.

Many relays are made so sensitive and with such high resistance coils, that .001 ampere or less will operate them. But even with the small current flow of .04 ampere, it will be best to use a gravity cell, Edison cell, or storage battery, for the closed circuit "A", so the continuous current flow will not exhaust the battery too quickly.

As long as this system is not disturbed, the current flowing in the closed circuit "A" and through the relay coils, will hold the armature away from the bridge contact, and the bell will remain silent.

But if a burglar disturbs the window or door to which the closed circuit switch "C" is attached, this will open the circuit and stop the current through the relay coils, and they will release the armature. Its spring will pull it against the bridge contact and close the circuit to the bell giving the alarm.

16. PROPER LOCATIONS OF PARTS FOR DEPENDABLE CLOSED CIRCUIT SYSTEMS

In installing such a system, the relay, bell, and batteries would usually all be grouped close together, possibly all on one shelf, so the wires between them and in circuit "B," would be short and have little chance of being damaged. The wires of circuit "A" would be the long ones running through the building to the part to be protected.

If these wires should be cut or damaged, or this battery go dead, the relay would immediately cause the bell to operate, calling attention to the fault.

While with an open circuit system the wire could be cut, or the battery dead, and the system out of order, without any one knowing it, and thus fail to operate when needed the most.

The battery in circuit "B" is not likely to go dead so often, as there is very seldom any current required from it. But it should be tested occasionally to make sure it is in good condition. Any important alarm system should be tested daily, or every evening, before being switched on for the night.

In Figure 25, in the relay symbol, we only show the one bridge contact which is in use.

When we desire to operate a bell or signal sounder at a considerable distance, an open circuit relay can be used to good advantage to save sending the heavier current required by the bell over the long line.

If we were to send the heavy current over the long line, it would cause considerable voltage drop and we would have to use larger, more expensive wires, or higher voltage supply. But the relay current being very small can be sent over the line more economically, and the relay will act as a switch at the far end of the line, to close a **Local** circuit to the bell. See Figure 26.

This circuit uses an open circuit relay, and the bridge contact on the side opposite to the one used in Figure 25. This method of using a relay to operate on a feeble impulse of current, and close a circuit to a larger device requiring more current, is one of their most common applications.

17. USE OF RELAYS IN TELEGRAPH SYSTEMS. GROUND CIRCUITS

Figure 27 shows two relays at opposite ends of a line, and operating **Sounders** in local circuits, in a simple telegraph system. The primary circuit includes two line batteries, two key switches, and two high resistance relay coils. The secondary circuits each consist of a local battery and sounder, and include the relay armature and bridge contacts as their switches. You will note that only one line wire is used in the primary circuit, and the earth is used for the other side of the circuit, by grounding the batteries at each end as shown. This saves considerable expense in line wire, and is quite commonly done in telegraph, telephone, and certain classes of signal work.

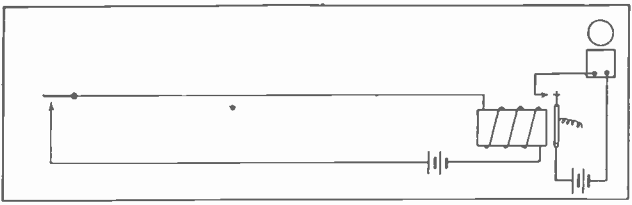


Fig. 26. Connection diagram for an open circuit relay used to operate a bell at a considerable distance from the push button.

If the ground connections are well made of buried metal plates, or rods driven deep into moist soil, the resistance of the earth is low enough so the losses are not very high with such small currents. Such ground circuits are not used to transmit electric power in large amounts, however.

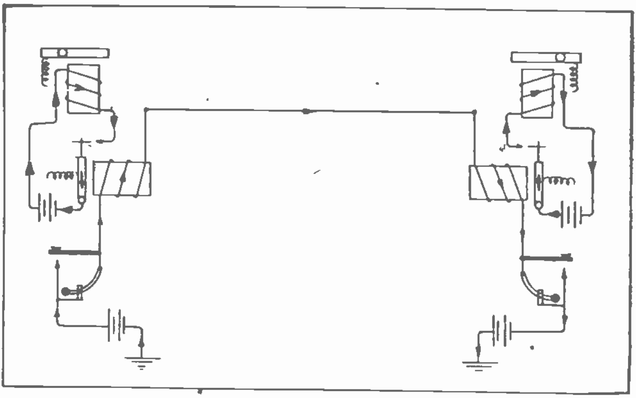


Fig. 27. Sketch of simple telegraph system showing line and ground circuit for the relays and keys, and local battery circuits for the sounders.

Both of the telegraph keys in this system have extra switches that are normally kept closed when the keys are idle. This allows a very small amount of current to flow through the line and relay coils continually, when the system is not in use.

This keeps the relays energized, and the local sounder circuits closed also, through the relay armatures and bridges. This may seem like a waste of current, but the batteries, being of the closed circuit type, stand this current drain very well and do not cost much to renew when exhausted.

When an operator wishes to send a message, he opens the auxiliary switch on his key, thus opening all circuits. Then each tap of his key sends a feeble impulse or very small current over the line, causing the relays to operate and give similar impulses, but of much heavier current, to the sounders from their own local batteries.

The operator at the other end of course hears the signals from his sounder. When the sending operator finishes, he closes his key switch, and waits for an answer. Then the other operator opens his switch and uses his key to signal back. Sometimes a number of such relays at various stations are all connected to one line, so they all operate at once, when any key is used.

Figure 28 shows a double circuit relay. In this system, as long as the switch "A" is closed the relay armature is attracted and closes a circuit through the lamp, showing that the circuit is in normal condition. But when switch "A" is opened the relay armature is released, allowing the lamp to go out and causing the bell to ring.

These double circuit relays have many uses, some of which will be shown a little later.

18. RELAY TERMINAL TEST

If you are ever in doubt as to the correct terminals on a relay, a quick test with a dry cell and two test wires will soon locate the coil terminals. When the cell is connected to the coil wires the armature will snap over toward the magnets. Connecting a cell and buzzer or small low voltage test lamp, to the armature and bridge terminals, and then moving the armature back and forth by hand, will soon show which terminal connects to the closed bridge contact and which to the open one.

19. ADJUSTMENT AND CARE OF RELAYS

Relays require careful adjustment to secure good operation. The pivot screws supporting the armature and acting as its hinges, should be tight enough to prevent excessive side play of the armature, but not too tight or they will interfere with its free movement. By turning one of these screws in, and the other one out, the contact points on the armature can be properly lined up with the bridge contacts. The bridge contacts should be adjusted to act also as stops for the armature. The contact on the magnet side should be adjusted to allow the armature to come very close to the core ends, to reduce the air gap and strengthen the pull as much as possible. **It should not, however, allow the armature to touch either core end, or it is likely to stick, due to slight residual magnetism,** even

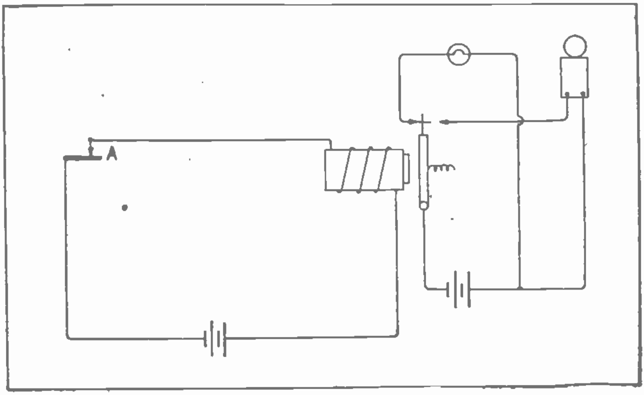


Fig. 28. Diagram and connections for a double circuit relay to operate a lamp when the system is undisturbed, and to ring a bell when the closed circuit is molested in any way.

after the coil current is turned off. Some relays have thin brass or copper caps over the iron core ends of the magnets, to prevent any possibility of this sticking. The contact on the side away from the magnets should be adjusted to allow the armature just enough swing to effectively break the circuit at the other contact; but not too far, or it will be very hard for the magnets to pull it back, due to the increased air gap between the armature and cores.

This would require more current to operate the relay. Usually the gap or travel of the armature contacts should be from 1/32 in. for breaking circuits at very low voltage and small current, to $\frac{1}{16}$ in. or ⅛ in. for slightly higher voltages and heavier

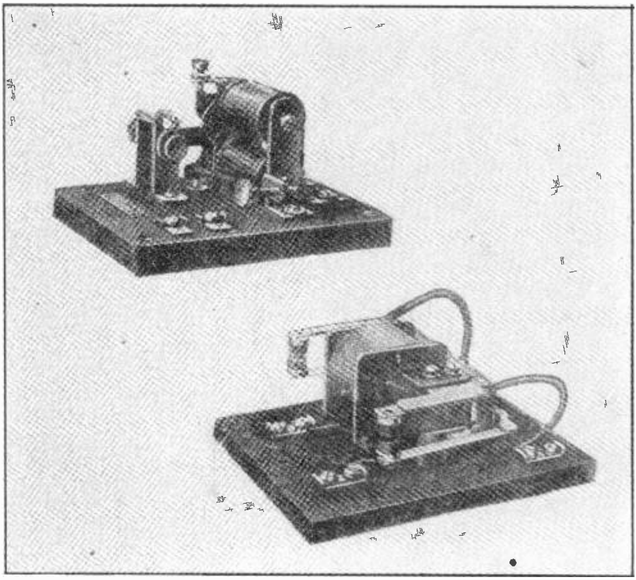


Fig. 29. Two additional types of relays used in various classes of signal circuits.

currents; as these have a tendency to arc more, when the circuit is opened and the points must separate farther to extinguish the arc quickly.

The armature spring should be adjusted just tight enough to pull the armature away from the magnets quickly when it is released, but not too tight, or the magnet will not be able to pull up the armature.

The contacts on both the armature and bridge should be kept clean and occasionally polished with a thin file or fine sandpaper, as the slight arcing often burns and blackens them, greatly increasing their resistance.

When contacts become too badly burned or damaged to repair, they can easily be replaced with new ones, obtained from the relay manufacturers.

Dust and dirt should be kept off from all parts, and all terminal nuts should be kept tight. Cores of magnets should be kept tight on keeper bar support.

Occasionally, but not often, a relay coil may become open, grounded, or shorted, or completely burned out. Simple tests as given in lesson number six on electro-magnets will locate any such fault. In addition to these pony relays, there are numerous other types used in telephones, railway signals, power plants, etc. Some of these differ in mechanical construction and shape, from the ones just described, but their general purpose and principle are very much the same. So if you have a good understanding of the relays in this section and always remember that **any relay is simply a magnetically operated switch**, you should be able to easily understand most any type.

Millions of relays are in use in plants throughout the country and every trained electrical man should be able to intelligently connect, test and maintain these important devices as they are used to control many electrical systems and machines.

EXAMINATION QUESTIONS

1. What is the difference between a single stroke bell and a vibrating bell?

2. What is a relay?

3. For what purpose is a Drop Relay used?

4. Draw a diagram showing a double circuit relay connected so as to make a lamp burn when the circuit is undisturbed, and so that it will cause a bell to ring when the relay coil circuit is molested.

5. How are relays classed according to their use?

6. What name has been given the movable part of a relay?

7. What name has been given to the curved arch above the movable part of the relay?

8. Will a series vibrating bell operate on alternating current?

9. Which gives a softer tone a buzzer or a bell?

10. What device would you select to give a silent signal?

X

ANNUNCIATORS

SIGNAL SYSTEMS

From our study of the electric signals we now know there are three important and necessary factors in the successful operation of any type of signal system. These are:

1. Source of current supply or power.
2. Some means of controlling this current supply or power.
3. Some type of equipment for converting the electrical energy into a signal.

The power, or current supply, can be obtained either from a battery or from the line which supplies the regular power for lights, motors, etc.

The control may be one of any of several types of switches, relays, etc.

The necessary equipment for converting the energy into an **audible** signal may be any device such as a bell, buzzer, or horn; or it may be a device that converts the electrical energy into a **visible** signal, such as light from a lamp.

In addition to using a visible electric light signal, we have another very important and widely used piece of equipment for furnishing visible signals, which has the advantage of indicating just where the signals originate or come from.

Such a visible signal device is known as an ANNUNCIATOR and is widely used in such places as hotels, offices, elevators, on trains, etc.

When we are in a large building and wish to make use of the elevator to transport us from one floor to another, we simply push a button switch at the elevator entrance, and the signal immediately flashes to the operator in the elevator. This signal then registers on an annunciator which shows the operator that someone desires to use the elevator and it also shows the operator on which floor you are located.

Or, when riding in a pullman car we may wish to summon the porter, in which case we simply push a button switch and again an annunciator, located in the porter's quarters, shows him which passenger desires service. We could go on and on describing many other different uses for the annunciator and visible signal equipment, but of more importance is the operating principle of equipment of this type, its adjustment, repair, and servicing.

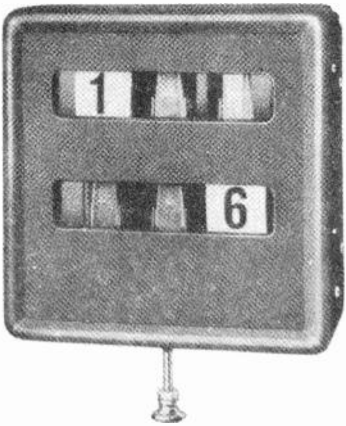


Fig. 1. A six-point annunciator with the reset arm shown extending through the bottom of the case.

1. ANNUNCIATOR PRINCIPLES

Annunciators consist of an electro magnet which when energized will cause indicating numbers to drop into view. Figure 1 shows a 6 point annunciator on which numbers 1 and 6 have been dropped into view showing that circuits 1 and 6 have been molested.

Fig. No. 2 shows the electrical circuit of a 4 point annunciator. Here for example, we have four switches that may be used, for office calls, burglar alarms. or hotel room calls. When any one of the switches is closed, current will flow through the respective annunciator magnet and on through the bell. When a magnet is energized the armature is attracted, allowing the weighted end of the arrow to fall off the catch, and the arrow to fly up, as on magnet 3.

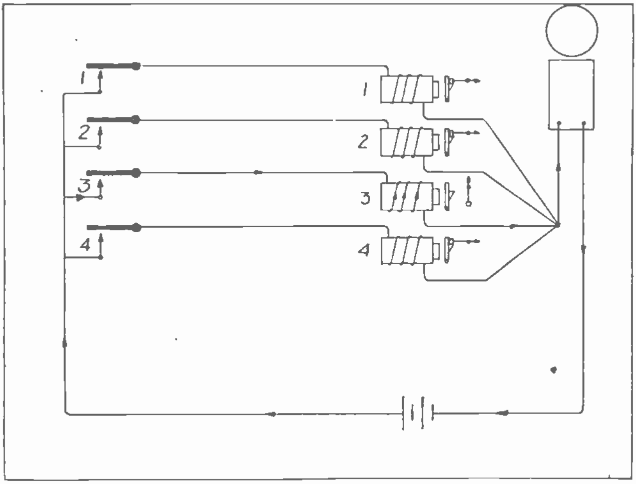


Fig. 2. Circuit diagram of the connections for a four-drop annunciator. Note that the drop number 3 has been operated.

Figure 3 shows one of the magnets and "number drops" of an annunciator. When this magnet is energized, the armature is attracted, thereby releasing the catch from the slot in the drop arm. Gravity then causes the drop number to fall. Annunciators usually have a system of rods and hooks, all attached to one lever, to push the drops back in place after any of them are tripped. Some are equipped with a strong electro-magnet to operate this "reset" lever.

Figure 4 shows a back view of an annunciator, and the magnets and reset mechanism.

Referring to Figure 2 again, note how one wire from each magnet attaches to a common terminal or wire leading to the bell. This is called a **Common Return Wire**, as it makes a common path for current from any magnet to return to the battery. This is the wire that should go to the bell, so all coil circuits will operate the bell when they are tripped. Some annunciators have the bell built in them, and others do not.

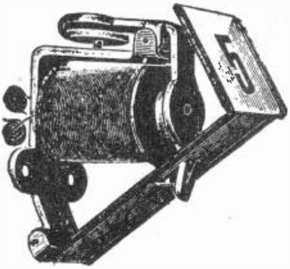


Fig. 3. This view shows the mechanical construction of one type of annunciator drop. Note how the drop is held up by a small hook on the end of the armature.

2. ANNUNCIATOR CONNECTIONS AND TERMINAL TESTS

When installing annunciators it is very important to connect the proper wires to the separate circuits, and to the bell. Sometimes the terminals are marked with numbers on the box where they enter, but when they are not marked, they can be found by a simple test. Using a dry cell or some other source of current supply, and two test wires, as in Figure 5-A, place one wire on one of the annunciator terminals at the end of the row or group, and hold it there while touching the other wire to the remaining terminals in rotation. If this causes the drops to operate in proper rotation then mark the wire to which your stationary test lead was connected, as the common lead, and the rest according to the numbers of the drops they each operate.

If touching the free test lead to certain of the terminals causes two or more drops to trip at once, the stationary lead is not on the common wire, and should be tried on the terminal at the opposite end of the row, because the common lead is usually at one end or the other. Sometimes, however, it may be somewhere else in the group.

By touching the test wires to adjacent terminals two at a time, when two are found that cause only one drop to operate, one of these leads should be the common return. In Figure 5-B, with the stationary test lead on wire No. 1, touching the other test lead to wires No. 2, 4, and 5, should cause two drops to fall each time, if they are reset before each test. But when No. 3 is touched only one drop should fall, as No. 3 is the common terminal. Then when the stationary lead is placed on wire No. 3, and the free lead touched to the others, each one should cause one drop to operate.

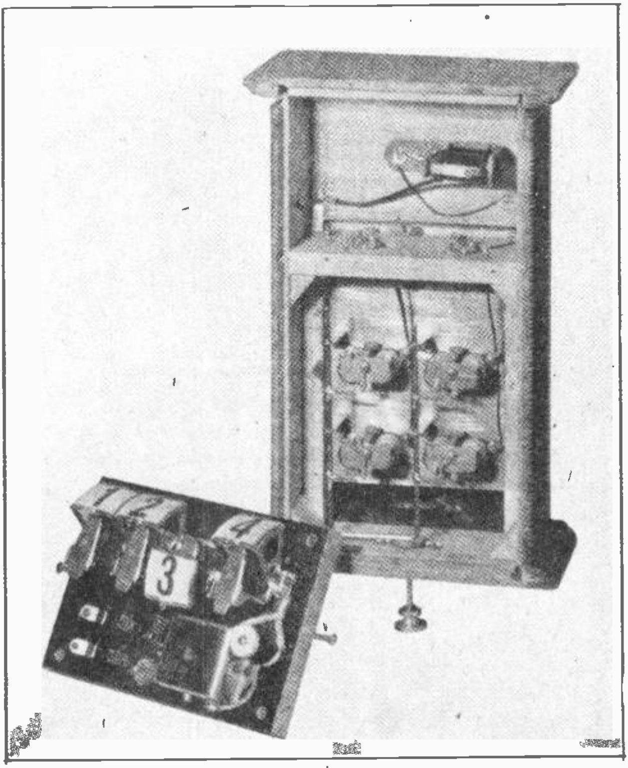


Fig. 4. Photograph showing the inside parts and construction of two common types of annunciators.

With annunciators that are equipped with a bell or buzzer permanently connected, it is easier to locate the common wire, as it is the only one that will cause the bell to operate when the test battery is applied. For example, when the test wires touch two terminals and cause the bell to ring, one of these terminals must be the common return lead. Trying each one with another wire will quickly show which one operates the bell.

Some annunciators have a ballast coil connected in parallel with the bell, as at "A" in Figure 6.

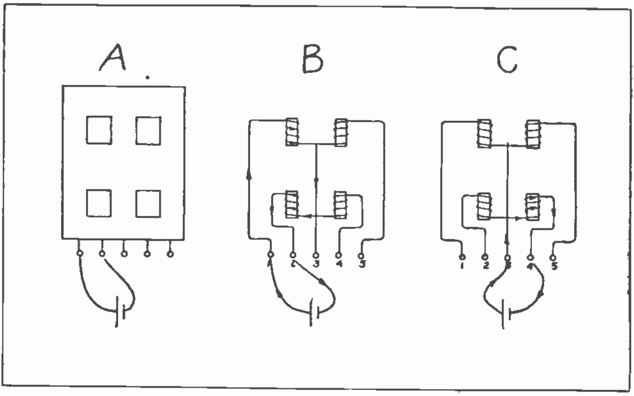


Fig. 5. Observe these test diagrams very carefully with the instructions given for locating annunciator terminals.

This coil carries part of the current when the bell is of high resistance and not able to carry quite all the current required to operate the drop magnets. Figure 6 also shows a different symbol which is often used for the annunciator in plans or diagrams.

Some large annunciators have a separate reset magnet for each drop magnet, as in Figure 7-A and B. In Figure "A" the reset coil has been operated, and has drawn the armature toward it, carrying the number on the disk out of view from the annunciator window. In Figure 7-B the trip coil has operated, drawing the armature toward it and bringing the number on the disk into view, in vertical position, in the annunciator window. (Window and case not shown in this sketch.)

Figure 8 shows both sets of coils for a four point annunciator and their connections. Each trip coil can of course be operated separately, but when the reset button is pressed all reset coils operate at once, resetting all numbers that have been tripped.

Hotels, hospitals, and steamships often have annunciators with several hundred numbers each. Elevators also make good use of annunciators.

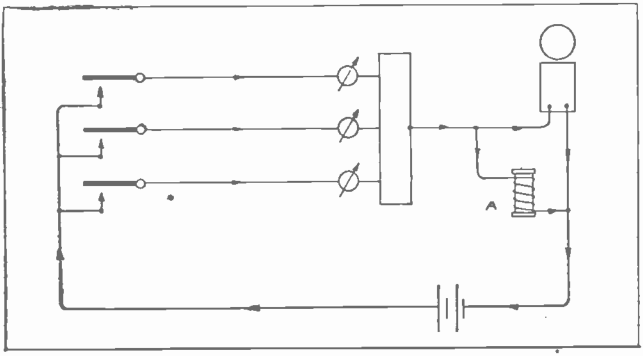


Fig. 6. Diagram showing connections of a three-drop annunciator in an open circuit signal system. This annunciator uses a ballast coil shown at "A," and connected in parallel with the bell to allow the proper amount of current to flow to operate the drops.

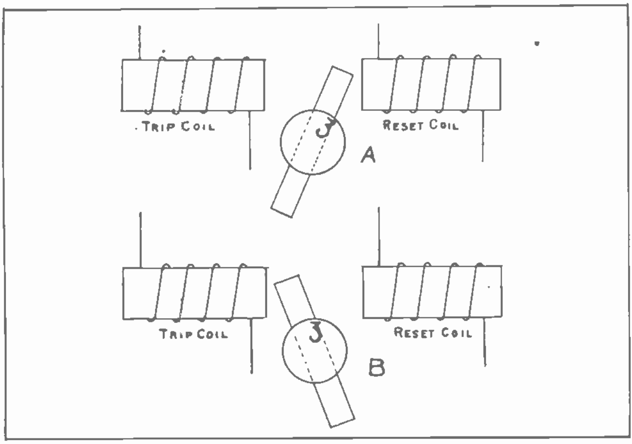


Fig. 7. Sketch illustrating arrangement of coils and number disks on an "electrical reset" annunciator.

3. LOCATING FAULTS IN ANNUNCIATORS

When annunciators fail to operate, careful checking and tightening of all terminals will usually locate the trouble. If none of the drops operate, and the supply battery to the system has been tested and found O.K., and all circuits are good up to the annunciator, then the trouble is almost sure to be in the common return wire, bell, or ballast coil, if one is used. If only one drop fails, then its own wire, coil, or mechanism is at fault, and careful checking and testing with a dry cell and buzzer should locate it.

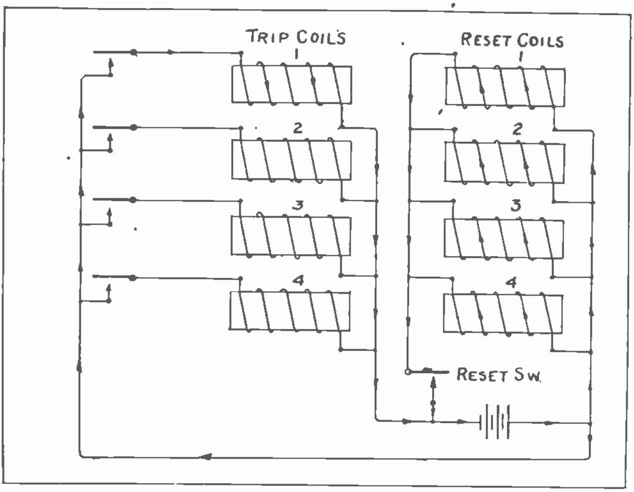


Fig. 8. Complete diagram of a four-drop annunciator using "electrical reset" magnets.

4. SYMBOLS USED IN SIGNAL DIAGRAMS.

The chart in Fig. 9 gives a review of the most common symbols used in the following diagrams and signal systems, and you should study these carefully, so you will be able to recognize them quickly when tracing any circuit. You will also want to be able to quickly select and use the proper symbol for any device, when laying out a plan for a job.

5. METHOD OF TRACING CIRCUITS, OR READING PRINTS.

In each of the following systems shown, make a practice of first examining the plan in general, locating and recognizing all of the devices by their symbols. Then get a general idea of the layout, number and arrangement of separate circuits which may be combined in the one system. Next start with the primary or first operating circuit, and trace it out carefully until you can imagine every step of its operation clearly, then the next circuit, or the

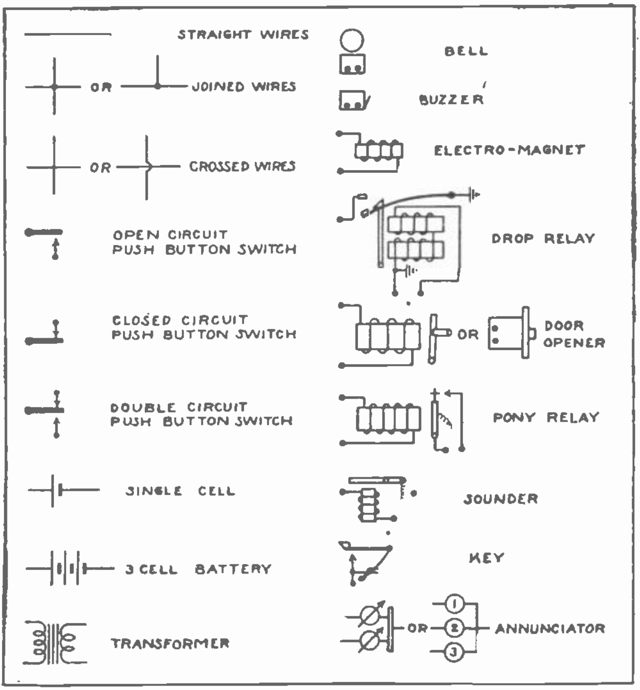


Fig. 9. These are some of the most important symbols used in signal diagrams and circuits. They should be memorized so you can easily recognize them when tracing any diagram in the future.

one which is operated by the first, tracing its operation and so on until you are sure you thoroughly understand the entire system.

At first this may seem like quite a job, but after a little persistent practice you get the trick or method of it, and then you can read most any plan almost at a glance. The ability to do this will be worth more in the field than any beginner can realize, until he finds out what a great help it is on the job, in any kind of electrical construction work or "trouble shooting" and maintenance.

Don't forget that every principle and bit of practice you get in tracing signal circuits will also apply to practically any other kind of electrical work.

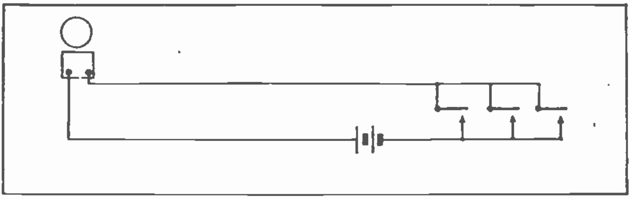


Fig. 10. Simple signal system using three buttons in parallel, any one of which will ring the bell.

Also remember that most electrical wiring nowadays is done from plans, and not by guesswork. And when we have a difficult trouble shooting problem in a large machine or system, looking over the plan furnished, or making a sketch of the wiring, will often speed up the location of the trouble more than anything else. The man who can do this and save the most time is the man who gets the best jobs.

Then too, as you carefully trace out and study each of the following systems you will also be gaining a knowledge of the principles and operation of common signal, alarm, and call systems.

6. OPEN CIRCUIT SYSTEMS

Fig. 10 shows an open circuit call or signal system, in which any one of three switches will operate the bell. Note that the switches are all connected in parallel. **Open Circuit Switches must always be connected in parallel, if each one is to be able to close the circuit.**

If open circuit switches were connected in series they would all have to be closed at once, in order to close the circuit. Make a sketch of this same circuit, but with the switches in series, and prove this out for yourself, because it is very important, and making a sketch will help you remember it.

Fig. 10. shows only three buttons in use, but any number can be connected in this manner to operate the same device. Such a circuit can be used for the

signals on street cars or busses, for an office call where several different parties are to be able to call one person, or for a simple burglar alarm system, by connecting the window and door contacts of open circuit type, to the bell and battery as shown.

7. SELECTIVE CALL CIRCUIT.

Fig. 11 shows a selective call system, in which switch number 1 rings bells 1 and 2, and switches 2 and 3 both operate bell number 3

Bells 1 and 2 are connected in parallel and both controlled by button 1. Button 2 and 3 are connected in parallel, and either one will operate bell number 3.

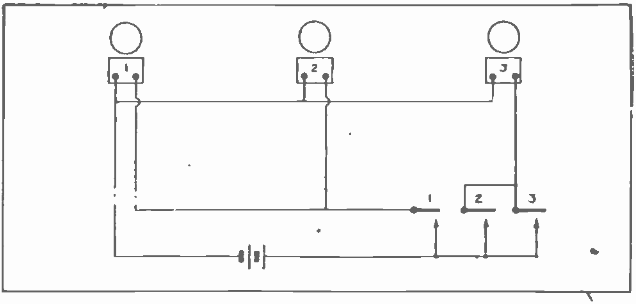


Fig. 11. Selective call system. Button No. 1 will ring bells 1 and 2; buttons Nos. 2 and 3 will ring bell No. 3.

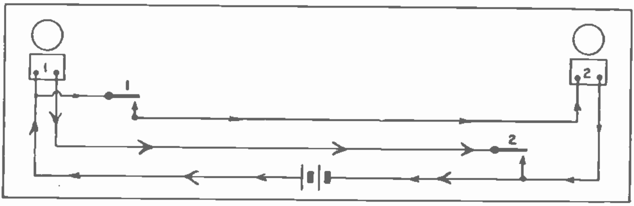


Fig. 12. Return call system. Button No. 1 will ring bell No. 2; button No. 2 rings bell No. 1.

The lower wire leading from the positive terminal of the battery to the stationary contacts of the switches, can be called a **Common Feeder Wire**, as it carries current to any of the buttons as they are closed.

Trace this circuit carefully. When switch number 1 is closed, current will flow from the battery through the switch, and then divide, part of it flowing through each bell. A good rule to remember in tracing such circuits is as follows: **Electric current will flow through all paths provided from positive to negative of the source of pressure. It also tends to follow the easiest path, or the greater amounts of current will flow over the lower resistance paths.**

In the case of Fig. 11, both bells being of equal resistance, and the circuits to them about the same length, the current will divide about equally.

The wire which leads from the left terminal of all three bells, back to the negative battery terminal, can be called a **common return wire,** as it serves to carry the current back to the battery, from any or all of the bells.

8. RETURN CALL SYSTEM.

Fig. 12 shows a return call system using two bells and two single contact buttons. This is called a return call system because either party can signal the other, or can answer a call by a return signal if desired.

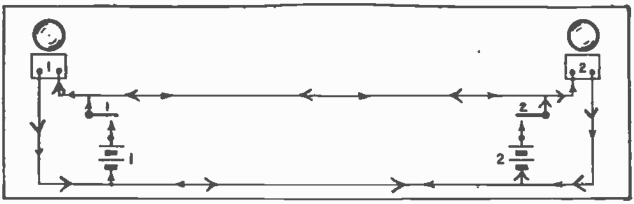


Fig. 13. Return call system using two batteries, thereby saving one wire.

Button number 1 rings bell number 2, and button number 2 rings bell number 1. When button number 1 is closed current flows as shown by the small arrows, and the large arrows show the path of current when button number 2 is pressed.

Note that three main wires or long wires are used in this system.

In Fig. 13 is shown another method of connecting a return call system, which causes both bells to ring when either button is pressed.

This system uses two batteries, one at each end, but it saves one main wire, using only two instead of three, as in Fig. 12.

When button number 1 is pressed current flows from battery number 1 as shown by the small arrows, dividing through both bells. When button number 2 is pressed, the current flows from battery number 2 as shown by the large arrows, also operating both bells.

In this system, if the line is very long the bell nearest the button pressed, may ring a little the

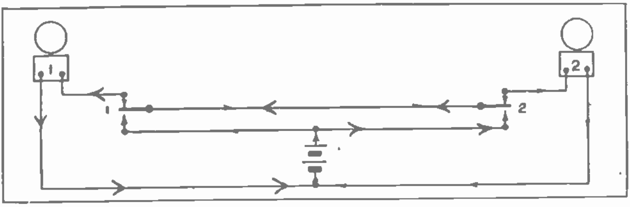


Fig. 14. Return call system using double circuit switches. Trace this circuit carefully.

loudest, because its circuit is shorter and lower resistance. Trace this carefully in the sketch.

If the far bell does not ring loud enough, then higher voltage batteries, or larger wires should be used.

Fig. 14 shows a return call system, using double circuit switches.

Here also, button number 1 rings bell number 2, and button number 2 rings bell number 1.

When button number 1 is pressed the current flow is shown by the small arrows, and the large arrows show the path of current when number 2 is pressed. If both buttons should be pressed at once neither bell would ring. Check this on the diagram.

This system also uses three main wires.

9. SAVING WIRES BY USE OF DOUBLE CIRCUIT SWITCHES OR "GROUNDS".

Fig. 15 shows how double circuit switches can be used to save considerable wire in connecting a return call system.

By using two separate batteries and the double circuit switches, one main wire can be eliminated and the system operated with only two wires as shown.

When button number 1 is pressed current (shown by small arrows) flows from battery number 1, and operates bell number 2. When button number 2 is pressed, current (shown by large arrows) flows from battery number 2, and operates bell number 1.

When such a return call system is to be installed where the bells are a long distance apart and it is convenient to make good ground connections at each end, we can eliminate still another wire, by the use of ground connections, as shown by dotted

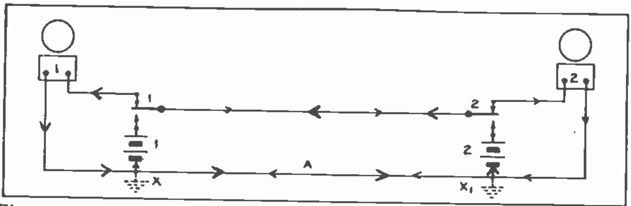


Fig. 15. Return call system showing how wires can be saved by the use of double circuit switches, two separate batteries, and a ground circuit.

lines at "X" and "X¹," in Fig. 15. Then we do not need wire "A", current flowing through the ground instead. Sometimes a piping system can be used for these grounds, and no connection to earth is needed.

Trace this circuit over very carefully, and be sure you understand its operation, as it is often very important to be able to save these extra wires, where the line between bells is long.

10. CALL SYSTEM WITHOUT SWITCHES.

Fig. 16 shows a system of signaling that is often very convenient for use on temporary construction jobs, where workmen need to signal each other; or in mines or mine shafts.

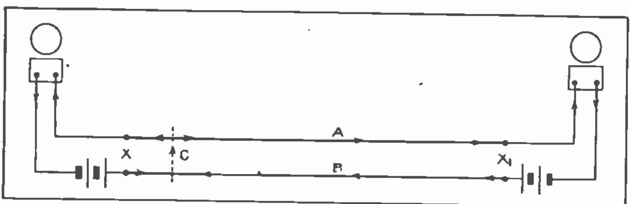


Fig. 16. Mine signal or alarm circuit which uses no switches. The bells are caused to ring by short circuiting wires "A" and "B".

No switches are used in this system, and instead wires "A" and "B" are bare or uninsulated, so any metal object can be used to "short" them or connect them together as shown by the dotted line at "C." Then if the wires "A" and "B" are strung tight and parallel to each other, a few inches apart and supported on insulators, a shovel, pick or piece of wire or metal touching both wires anywhere between points "X" and "X¹", will cause both bells to ring.

You may wonder at first why current does not flow all the time in this circuit, as it is always closed. Note how the batteries are connected positive to positive, or opposing each other, so if they are of equal voltage no current can flow normally. Of course if one battery was dead the other would cause both bells to ring continuously.

When a circuit is made between the two wires as at "C" the current starts to flow from both batteries as shown by the arrows, up through the connection "C" and then dividing through both bells, and returning to both battery negatives.

Such a system as this can also be operated from moving cars or elevators, by running the bare wires along close to the track or in the shaft.

11. SELECTIVE AND MASTER CALLS.

Fig. 17 shows a selective call system, with a master control, using one battery, three bells, and three single circuit switches.

Button number 1 operates bell number 1. Button number 2 operates bells number 2 and 3 in series. And button number 3, which is called the master button, operates all three bells in series. Trace each circuit carefully.

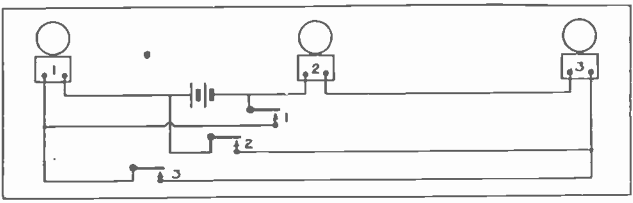


Fig. 17. Selective signal circuit. Check its operation carefully with the instructions.

Another method of arranging a selective call system with a **Master Switch,** is shown in Fig. 18. In this system any one of the double circuit switches 1, 2, 3 or 4, will operate its respective bell of the same number only, but the single circuit switch number 5, will operate all bells when all the other switches are in normal position.

When any one of the double switches is pressed, its movable contact is disconnected from the upper, or normally closed contact, so when the movable contact touches the lower one, current can only flow through its own bell. and not to any of the others.

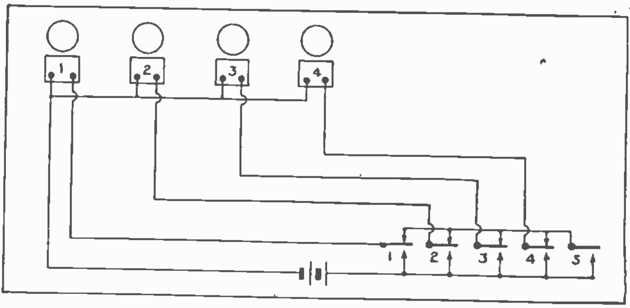


Fig. 18. Selective call system with Master Switch. This is a type of system very often used in executives' offices.

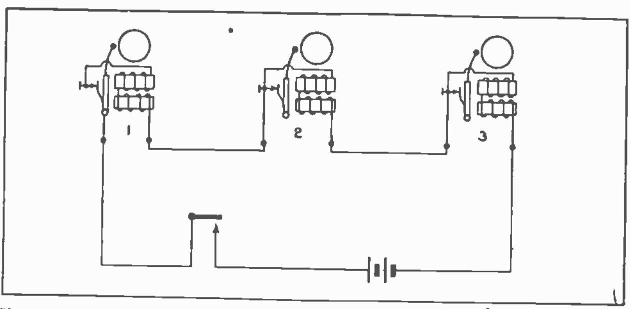


Fig. 19. This sketch shows the proper method of connecting vibrating bells in series, to secure best results.

When button number 5 is pressed current flows from the positive of the battery through this button, then divides through the closed contacts of all the other switches and to all bells. Trace this on the sketch until you can clearly imagine this operation.

Note how the wire from the positive of the battery is again used as a **Common Feeder** for all switches, and also the common return wire used for all bells. Of course one separate wire is required feeding from each switch to its bell, if we are to operate them separately at times, but a great amount of wire can be saved by proper use of **Common Feeder** and **Common Return** wires.

This is where a sketch or plan laid out in advance helps to save materials.

12. CONNECTING VIBRATING BELLS FOR SERIES OPERATION.

When several bells are to be operated in series as in Fig. 19, or other systems for which they are connected this way, they will usually not operate very loudly or steadily without a special connection. This is because they do not all vibrate evenly or in synchronism, and the make and break contacts of one bell will open the circuit just as another closes for its power impulse. This results in rather irregular and weak operation, and the greater the number of bells in series, the worse it usually is.

This can be overcome by arranging one bell only as a vibrator, and all the rest as single stroke bells. This is done by shunting out the make and break contacts of all bells except the one, as in Fig. 19. Here the current will flow through the make and break contacts of bell number 1 only, and on the others it flows directly through the coils. Number 1 bell then acts as a **Master Vibrator**, making and breaking the circuit for all the others, preventing them from interrupting the circuit, and forcing them to operate in synchronism.

A series connection of bells is often desirable where they are all to be rung at once and are located a long distance apart, as it saves considerable wire in many cases.

13. ECONOMICAL BARN OR GARAGE ALARM.

Fig. 20 shows a method of connecting a bell as a combination single stroke and vibrator, and obtaining a closed circuit call or alarm system.

When we recall that a closed circuit system usually requires a relay to operate the bell, we find that this connection effects quite an economy by saving the cost of a relay.

Tracing the circuits we find that as long as the switches are all closed, the current will flow continuously as shown by the small arrows, through the bell coils, then through the switches and back to the battery. This keeps the coils energized and holds the hammer quietly against the gong, after the first single stroke when it is connected.

Then when any one of the switches is opened, the circuit is momentarily broken, allowing the hammer to fall back and close the circuit again at

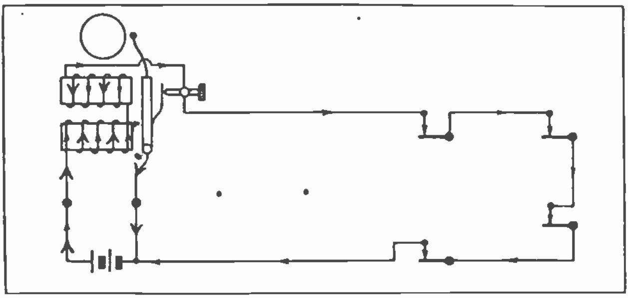


Fig. 20. Simple and economical barn or garage alarm of closed circuit type.

the make and break contacts of the bell.

The bell will then continue to vibrate, current flowing as shown by the large arrows, until the switch in the line is again closed. This is a very good circuit to keep in mind when the dependability of a closed circuit system is desired, but must be had at low cost.

A bell with high resistance coils should be used, to keep the amount of current flow small. A closed circuit battery should also be used, as dry cells would soon be exhausted by the constant current flow.

This system makes a very good barn or garage alarm, where long wires are to be run in the open, between the protected buildings and the house. Then if anyone attempts to cut these wires, the alarm will operate just as though the window or door switches of the building were disturbed and opened.

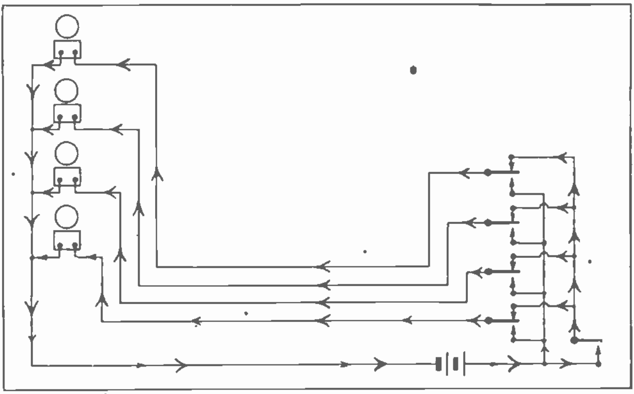


Fig. 21. Another type of selective call system with Master Control

14. OFFICE OR SHOP CALL SYSTEM.

Fig. 21 shows a selective master control call system that would be very convenient for an office executive or shop or power plant superintendent, to signal their various foremen or workmen. Any one at a time can be called, by pressing the proper double circuit switch, or all can be called at once by pressing the single circuit master switch.

The small arrows show the path of current flow when one of the double switches is operated, and the large ones show the current flow to all bells when the master switch is operated.

At first glance this circuit does not look much like the one in Fig. 18, does it? But look at it again and compare the two closely, and you will find they are exactly the same as far as parts and operation are concerned. The only difference is in the position or arrangement of these parts.

This comparison is made to show you that it does not matter how or where the bells or switches are to be located, as long as certain general principles of connection are followed.

Note that in each of these sketches a common feeder runs from the positive of the battery to all the lower or open contacts of the switches. Another common wire leads from the top of the master switch to the top or closed contacts of all double circuit switches. Then the individual bell wires are each attached to the movable contacts of the double switches in each case, and a common return from the bells back to the battery.

These are the principle points to note and follow in connecting up any such selective, master, call system.

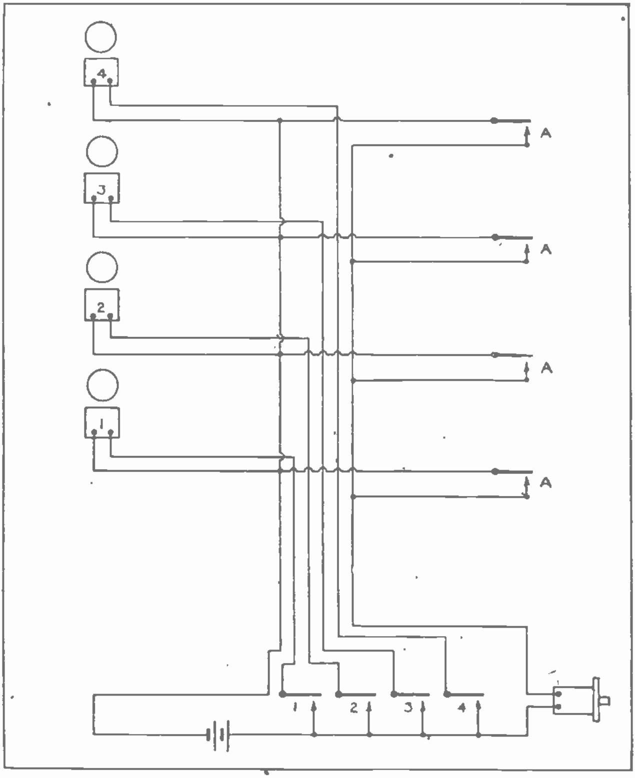


Fig. 22. Combination doorbell and magnetic door-opener system. Note the use of certain wires as common "Feeder" and "Return" wires.

15. APARTMENT DOOR BELL AND OPENER SYSTEMS.

Fig. 22 shows a door bell and magnetic door opener system for a three apartment building.

This sketch is arranged a little differently to show how the wires running up to the various floors can all be grouped together and run in one conduit or cable, and then branches taken off to each bell and switch.

Such a system is commonly used in connection with speaking tubes and telephones in apartment buildings, and could be extended to take in as many more floors or apartments as desired, just following the same scheme of connection as shown.

Any one of the buttons in the lower hall will ring its own bell of the same number. Then if the party is at home and wishes to admit the caller, any one of the apartment buttons marked "A" will operate the door lock.

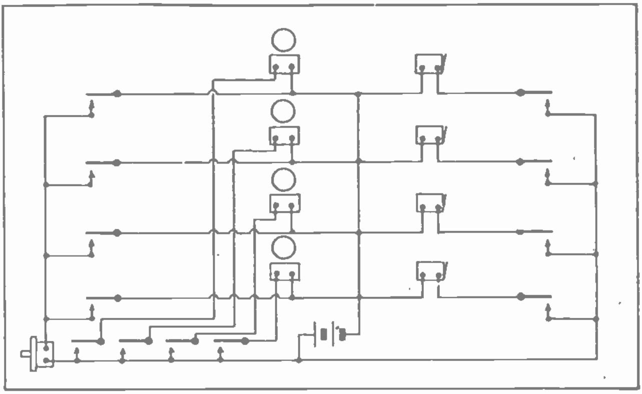


Fig. 23. Doorbell and door-opener system, including separate local buzzer circuits.

Fig. 23 shows a similar system of apartment building calls and door opener, including also a buzzer at each apartment door, for parties within the building to use when calling at any other apartment, and without going down to the front door. Trace the circuit and operation carefully.

16. HOTEL OR OFFICE CALL SYSTEM WITH ANNUNCIATOR.

Fig. 24 shows a selective, master call system that could be used very well in an office or hotel and many other places.

With this system a party at "A" can call any one of the parties "B", "C", or "D", by pressing the proper buttons; or he can call them all at once by pressing the master button.

The party called can also answer back or acknowledge the call with their button, and the annunciator and buzzer show the response to party "A".

Or if "B", "C", or "D", wish to signal "A" at any time, the annunciator shows which one is calling.

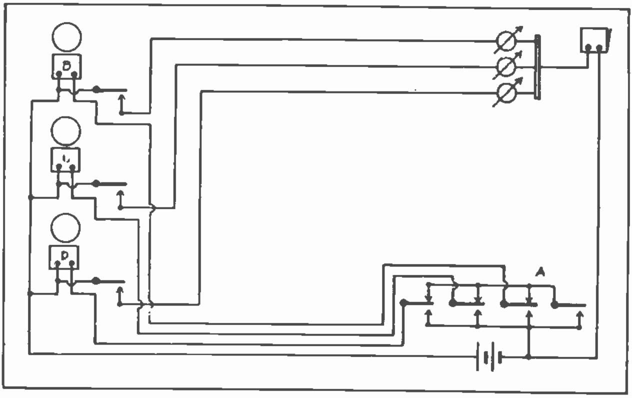


Fig. 24. Selective signal circuit with Master Control, return call and annunciator features. This is a very popular form of signal system.

17. SAVING WIRES BY SPECIAL GROUP CONNECTION, and SEPARATE BATTERIES.

Fig. 25 shows a method of connecting a large number of bells and switches in an extensive call system, and using separate batteries and a grouping system to reduce the number of main wires.

Any one of the buttons will ring its corresponding bell of the same letter. By the use of the three separate batteries and **Cross Grouping** connection of the bells and switches, this can be done with seven vertical line wires, while with one battery it would require thirteen wires.

18. CLOSED CIRCUIT BURGLAR ALARM FOR TWO FLOORS OR APARTMENTS.

Fig. 26 shows a closed circuit burglar alarm system for two apartments or floors of a building, using an annunciator to indicate which floor the intruder has entered, and also a drop relay to keep the bell ringing constantly until some one is aroused and shuts it off. This is a good alarm system to recommend to your customers.

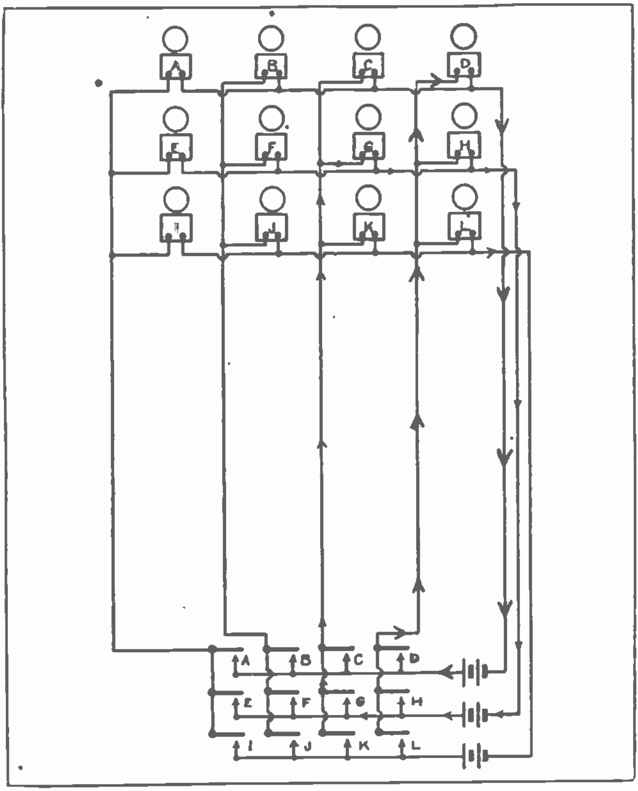


Fig. 25. "Group" method of connecting a large number of bells and switches to secure independent operation of each, with the least number of wires.

Normally, when the system is in operation, current flows continually in the two relay circuits as shown by the small arrows. This keeps both relay armatures attracted, and no current flows in the annunciator, drop relay, or bell circuits.

But as soon as any switch in either circuit "A" or "B", is disturbed, the relay current stops flowing, releasing the armature, and closing a circuit to the drop relay as shown by the dotted arrows. This trips the drop relay, starting the bell in operation The bell circuit is shown with large arrows.

A system of this type using several separate circuits gives one an excellent chance to practice step by step tracing of each circuit, and the operation of all parts of the system. Trace it carefully.

19. SPECIAL ARRANGEMENT OF VIBRATING BELL FOR CONSTANT RINGING.

Fig. 27 shows a rather novel method of arranging a vibrating bell for a constant ringing alarm, without the use of a drop switch or relay. This is done by placing a piece of hard cardboard, fibre or hard rubber, between the make and break contacts of

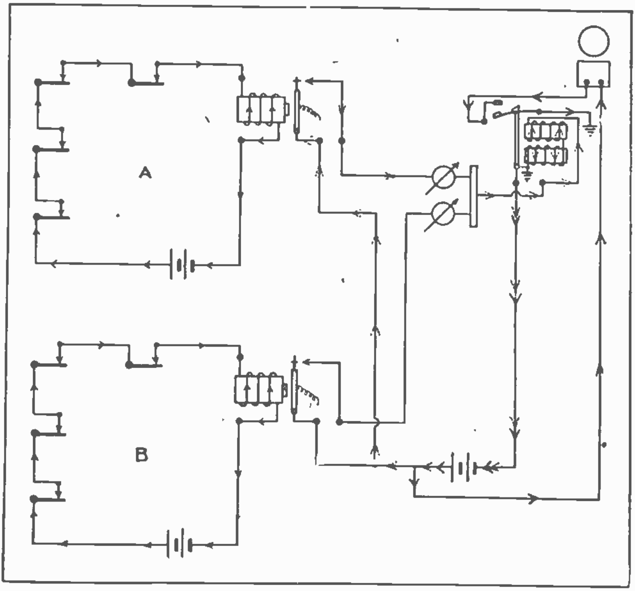


Fig. 26. Two section alarm system using a drop relay for constant ringing, also an annunciator to show which section of the building the alarm was disturbed in

the bell. The spring tension of the armature should hold it there normally, but if cardboard is used it should not be too soft, or it may stick in place when it is released.

When one of the three open circuit alarm switches is closed current will flow directly through the coils of the bell, attracting the armature and releasing the cardboard.

After the cardboard has been released the armature contact will be free to close the bell circuit through the vibrating contacts. This will allow the bell to ring continuously until switch "A" is opened. Switch "A" should be a lever switch or a snap switch.

However, if either one of the open circuit switches which are used to trip the alarm should be held closed then the bell would not ring because this would short out the breaker points and keep the circuit closed through the bell coils. The armature would be held by the electro magnets and could not open the circuit so as to allow the armature to vibrate.

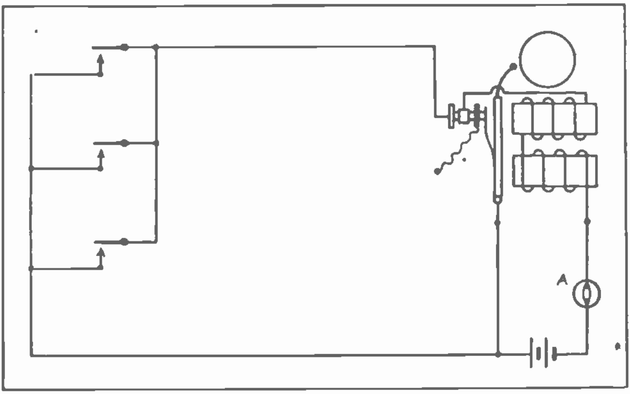


Fig. 27. Simple method of arranging an ordinary vibrating bell to secure constant ringing feature.

It is important when using this circuit as a burglar alarm to arrange the open circuit switches in such a way that they cannot be easily held closed. As an example, if the switches are to be mounted in a window so that a signal will be given when the window is opened a sliding contact switch could be used so that the switch will be closed only at a certain point. It would not be likely that a burglar would be able to replace the window on this exact point so as to stop the bell from ringing.

This system of course does not give the positive protection of a closed circuit system, or of one using a relay, but is very good for an emergency job, or one where the cost must be kept very low.

Now let us advise you to review the signal and alarm systems shown in this lesson and see how many places you can think of where some of these systems would save time or protect property for your friends and neighbors.

Then recommend the proper system and go after the job of installing it for experience and profit.

EXAMINATION QUESTIONS

1—Show the symbol used for each of the following: (a) bell, (b) buzzer, (c) double circuit switch, (d) open circuit switch.

2—What do we mean by the term Master Vibrator when two or more bells are connected in series?

3—For what purpose are annunciators used?

4—Are closed circuit switches connected in series or parallel with each other?

5—Are open circuit switches connected in series or parallel with each other?

6—Make a diagram showing how a bell may be connected so as to operate without a relay in a closed circuit alarm system.

7—Draw a sketch showing how a bell may be connected for constant ringing without the use of a relay or a drop switch.

8—What advantage does a closed circuit alarm have over an open circuit alarm?

9—Copy Fig. 11, and trace the circuits through which current would flow if switch No 1 is closed. Mark the circuit with little arrows.

10—Copy Fig. 17 and trace the circuit through which current would flow when switch No. 2 is closed.

HOLDING RELAY CIRCUITS

Fire alarms, burglar alarms, and many other signal and power circuits make unlimited use of magnetically operated switches known as relays. You have made a study of various types such as open circuit, closed circuit, double circuit, and drop relays. The importance of these various types has been fully explained. You are familiar with the operating principles of a drop relay and you understand how it may be used to cause constant operation of the signal once the circuit has been molested.

Now we will consider a relay **circuit** which will enable us to use an ordinary relay so that it will provide **constant ringing of the bell, without the use of a drop relay.** This is accomplished by connecting the relay to operate as a **holding relay.**

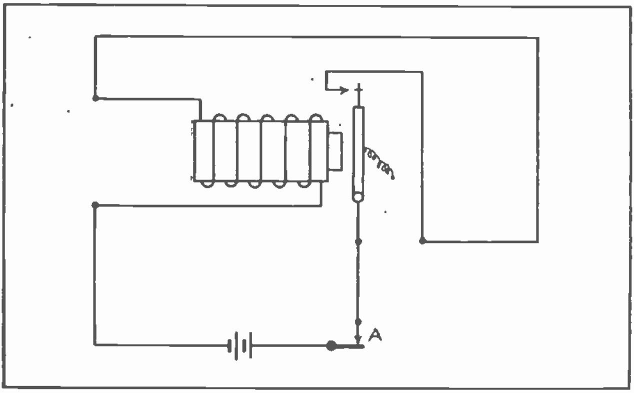


Fig. 1. Diagram illustrating the principle of a closed circuit holding relay.

The diagram shown on this page is the basic circuit around which are built all of the holding relay circuits shown on the following pages.

This term comes from the manner in which the relay armature closes a circuit to the coil, and causes the armature to continue to feed the coil until it is forced away, or its circuit broken by another switch. (See Figure 1.)

This relay has its armature and bridge connected in series with its coil and the battery. Imagine you were to push the armature to the left with your finger, until it touched the bridge contact. What would happen? The armature would stay there, because as soon as it touches the bridge contact, it closes a circuit for current to flow through the coil.

Then to get the armature to go back to its normal position it would be necessary, to force it away, in spite of the pull of the magnets, or to open the closed circuit switch at "A". This would stop the current flow through the coils, and allow the armature to release.

Remember that to connect up a "holding relay," its armature and bridge must be connected so they will close and hold a circuit through the coils when the armature is attracted.

2. OPEN CIRCUIT HOLDING RELAYS.

Now let's see how we connect this holding or stick relay in a simple open circuit, constant ringing alarm or call system, as in Fig. 2.

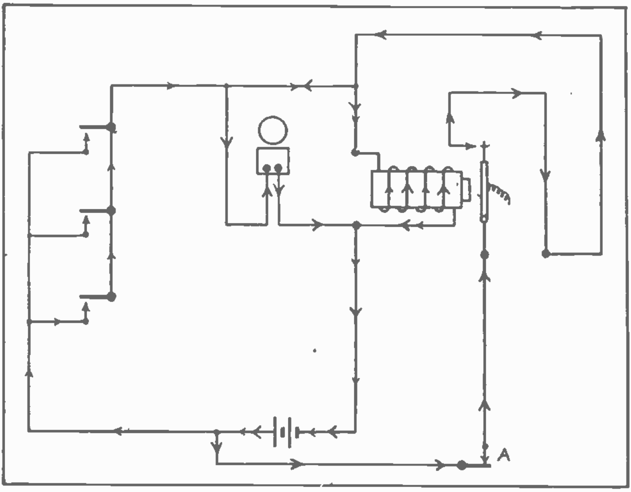


Fig. 2. Open circuit alarm system using a holding relay for constant ringing when alarm is tripped.

Here again we notice that the armature and bridge are in **Series** with the coils, and the bell is connected in **Parallel** with the coils. These are the

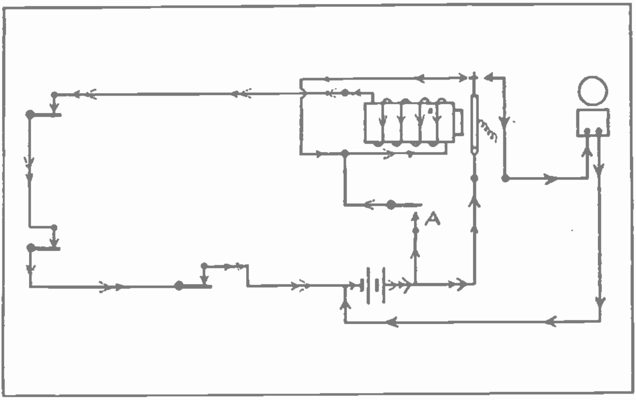


Fig. 3. Double circuit holding relay used in a closed circuit burglar alarm system. This is a very simple and efficient alarm circuit.

two principle rules to follow in arranging such a system.

The parallel group of open circuit switches is connected in series with the battery and relay coil.

Normally there is no current flowing in any part of this system, and the relay armature is not touching the bridge until the switches are disturbed. If any one of the open circuit switches is closed even for an instant, current will start to flow through the relay coils and bell in parallel, as shown by the small arrows.

This causes the armature to be attracted, and then it feeds current to both the coil and bell, even though the first switch is opened in case the burglar closes the window quickly.

The larger arrows show the path of current which keeps the relay coil energized and the bell ringing, after the system is tripped.

To stop the ringing of the bell and restore the system to normal "set" condition, we press the **Reset Switch "A"**.

This stops the current flow through the coils long enough to release the armature; then we allow switch "A" to close again, and if the open circuit switches are again normal or open, the system remains quiet until again tripped.

3. DOUBLE CIRCUIT HOLDING RELAY.

In Fig. 3 is shown a double circuit "holding relay" system, which gives both the advantages of constant ringing and closed circuit reliability.

Here we have the relay armature, bridge, coils, closed circuit alarm switches, and battery, all connected in series. An open circuit reset switch at "A" is used in this system. To set the system in order, this switch is pressed and current starts to flow at once, as shown by the dotted arrows. This energizes the relay coil and attracts the armature. Then the reset switch can be released, and the armature will stick in place, as it now feeds the coils, and a small current will flow continually as shown by the small solid arrows.

Now if any one of the closed circuit alarm switches is opened, the current stops flowing through the coil, releasing the armature, which closes a circuit to the bell, as shown by the large arrows.

This is a very simple and dependable alarm system, and one you may often have use for.

4. THREE SECTION ALARM SYSTEM.

Fig. 4 shows a system of this same type, with three separate sections for three different floors or apartments, and an annunciator to indicate which section is disturbed.

When an alarm switch in any one of the sections is opened, the relay sends current through the proper annunciator coil and keeps the bell ringing constantly until the reset button is pressed.

The relay armatures in this Figure and also the arrows, are shown as the system would be if sections 1 and 3 were normal, but section 2 has been disturbed causing the alarm to operate. Observe the armatures and arrows, and trace all circuits carefully to be sure you understand them.

At first glance such a diagram as Fig. 4 looks quite complicated and appears hard to understand, but you have probably found by now, that taking one section at a time, it can be traced out quite easily. This is true of even the largest circuit plans of telephone or power plant systems, and if you practice tracing each of these diagrams carefully, you will soon have confidence and ability to read any circuit plan.

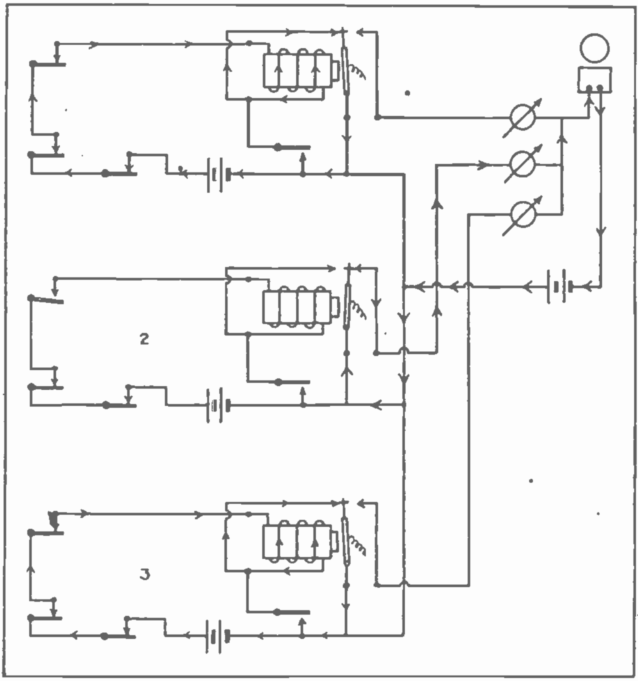


Fig. 4. Closed circuit burglar alarm system of three sections, each using holding relays for constant ringing; and an annunciator to indicate point of disturbance.

5. COMBINATION CLOSED AND OPEN CIRCUIT ALARMS.

Fig. 5 shows a method of using double circuit switches to operate both the relay and annunciator in a closed circuit constant ringing system.

When any one of the alarm switches is pressed, it opens the relay coil circuit and closes the annunciator circuit at the same time.

In this system the annunciator shows exactly which window or door is disturbed.

A number of such circuits could be arranged to protect separate floors or apartments in a building, and then all connected together through one annunciator and alarm bell as in Fig. 4. The additional annunciator would then indicate to the watchman, janitor or owner, which floor or apartment the alarm came from.

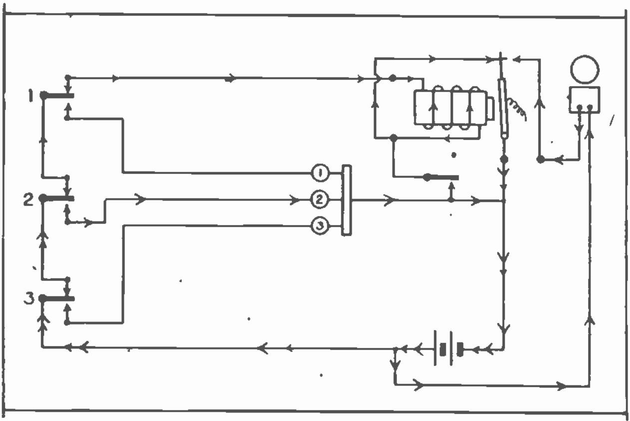


Fig. 5. Combination alarm system using double circuit switches to operate both the holding relay and the annunciator.

The small arrows in Fig. 5 show where current will normally flow when the system is "set". The large arrows show where current would flow through both the annunciator and bell circuits, if switch number 2 was disturbed.

After this system is tripped and the bell is ringing what would you do to stop the bell and reset the alarm?

6. BURGLAR ALARM FOIL FOR WINDOW PROTECTION.

In addition to window and door contacts, switches and alarm traps, some alarm systems use tinfoil strips for the protection of glass windows or thin wood panels that could be easily broken.

Tinfoil for this purpose can be bought in rolls, prepared for cementing to the inner surface of the glass or panel to be protected. It is then connected into the regular alarm circuit by attaching wires to its ends.

If the glass is broken it will crack the tinfoil and open the circuit, causing the alarm to operate.

Fig. 6 shows a large show window and small window above the door protected by burglar alarm foil, and the door and two small windows by door and window springs. **All are connected in series to form the closed circuit for the relay coil.**

Disturbance of any one will cause the bell to ring.

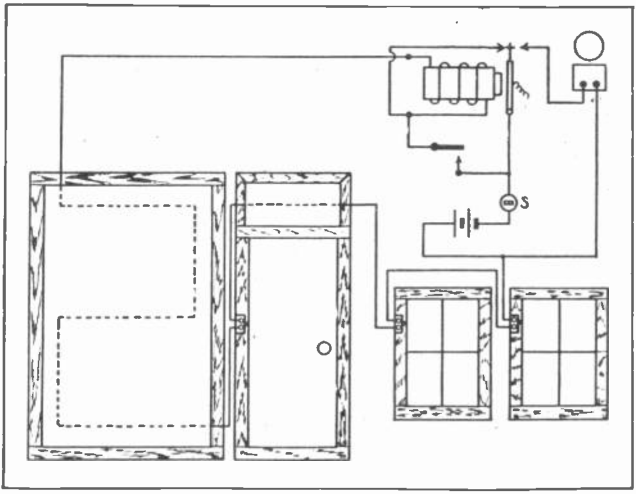


Fig. 6. This diagram shows the use and application of burglar alarm foil for the protection of glass windows and doors.

7. BALANCED ALARM SYSTEMS.

Burglar alarms can be arranged so that it is nearly impossible for even an expert to disturb or tamper with them without giving the alarm.

Fig. 7 shows a system using circuits of balanced resistance and a specially wound relay.

This relay has two coils wound in opposite directions on each core, so **when current flows through them equally they create opposing magnetic flux and do not attract the armature.**

The variable resistance at "A" is used to balance the current flow through coil "R", with that of coil "L", by being adjusted so that its resistance is equal to that of the entire alarm circuit. The alarm circuit includes the wire, switches, and the resistance unit "B" which is in series with the closed circuit switches.

As long as the alarm circuit remains of equal resistance to that of the balancing circuit, the current from the battery divides evenly through coils "L" and "R". But if any switch is opened or closed, or the wires are changed, the resistance of the alarm circuit will be changed and more current will flow through one coil or the other, and magnetize the relay core.

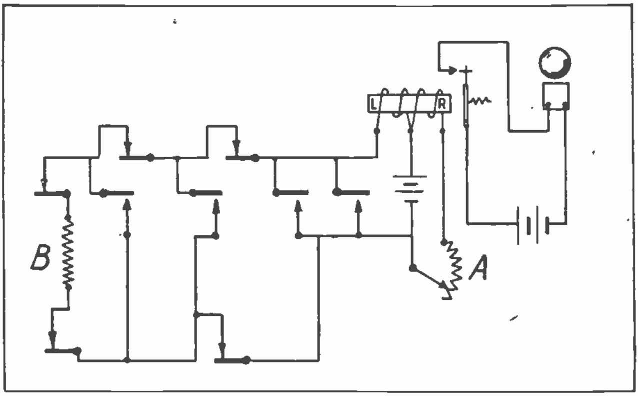


Fig. 7. Balanced resistance alarm circuit. This is a very dependable alarm system, as it is almost impossible to tamper with it without causing the larm to sound.

For example, if any closed circuit switch is opened, the current through coil "L" stops flowing, leaving the flux of coil "R" unopposed and strong enough to attract the armature and cause the bell to ring. Or, if any open circuit switch is closed, it affords a much easier path than the normal one through resistance "B", and more current at once flows through coil "L", overcoming the opposing flux of coil "R", and again attracting the armature and ringing the bell.

Variations of this principle can be used in several ways in different types of alarm circuits, making them very dependable and safe from intentional or accidental damage.

8. LOCK SWITCH CONNECTIONS.

Fig. 8-A shows how a lock switch can be connected in a burglar alarm system, to allow the owner or watchman to enter the building without

sounding the alarm, and also to turn off the system during the day.

This switch is connected in parallel with the entire line of switches here, and when it is locked closed, any of the others can be opened without tripping the alarm.

Or we can connect it to one switch only as in Fig. 8-B. In this case only the one door and

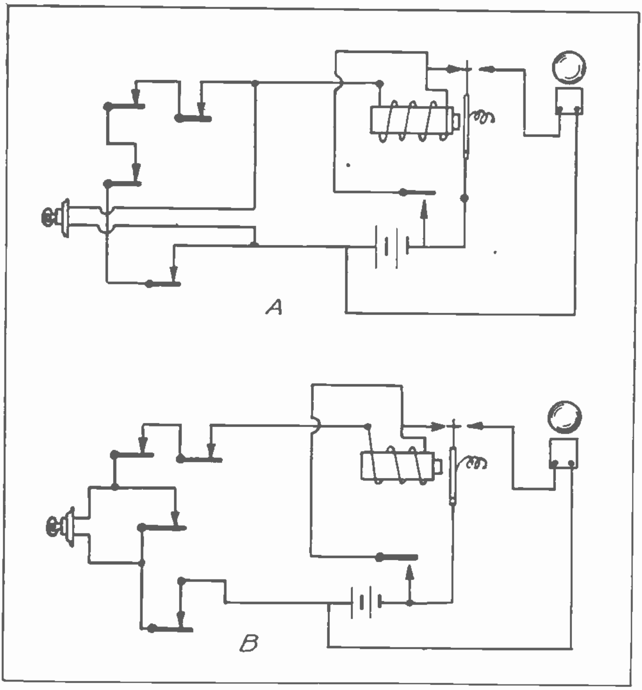


Fig. 8. These circuits "A" and "B" show two different methods of connecting a lock switch to a burglar alarm circuit.

switch can be opened without tripping the alarm. Then when the lock switch is again locked open, the alarm will operate if any other switch is opened.

9. FIRE ALARM EQUIPMENT AND CIRCUITS.

Fire alarms are very similar in many ways to burglar alarms, using many of the same parts such as relays and bells; and also many of the same types of circuits.

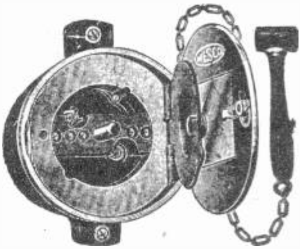
The principle difference is in the types of switches used.

There are manually operated fire alarms and automatic ones; the manual alarms being merely a signal system by which someone sends a warning of fire when he sees it. The automatic alarms are those that are operated by the heat of the fire, and send in the alarm without the aid of any person.

One simple type of manual fire alarm switch is the "break glass" type, in which the switch is held in a closed normal position by a small pane or window of glass. In case of fire the person sending the alarm merely breaks the glass, which allows the switch to open by spring action and give the alarm.

One of these devices is shown in Fig. 9. The illustration at the left, with the box closed, shows clearly how the glass holds the switch button compressed against a spring, and also the small iron hammer provided for convenience in breaking the glass. At the right the box is shown open and the switch button can be seen in the center.

Box Closed



Box Open

Fig. 9. Fire alarm box of the "break glass" type. Note the hammer used for breaking the glass, and the location of the push button in the box which has the cover open.

10. PULL BOXES AND CODE CALL DEVICES.

Figs. 10 and 11 show two different types of fire alarm "pull boxes". To send an alarm from this type of box, the operator opens the door and pulls the hook or crank down as far as it will go and then releases it.

When it is pulled down it winds a spring inside, and when released the spring operates a wheel or notched cam that opens and closes a switch several times very rapidly. These notches or cams can be arranged to send a certain number of impulses in the form of dots and dashes, or numbered groups of dots, to indicate the location of any particular pull box.

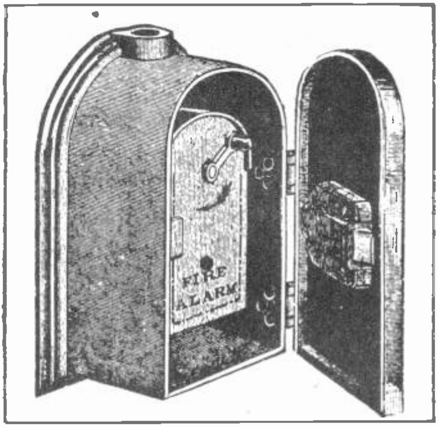


Fig. 10. This is a fire alarm "pull box" which sends in numerical or code signals to indicate its location.

This enables the fire department crews to proceed direct to the location of the fire.

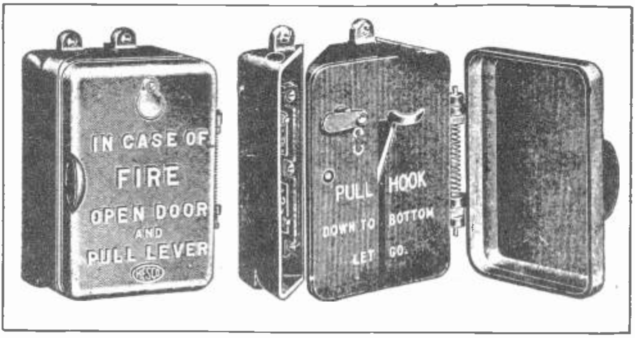


Fig. 11. Another type of fire alarm pull box which also sends code signals.

Fig. 12-A shows how a notched wheel can be arranged to open the contacts of a closed circuit

fire alarm, giving a series of short signals and sounding the number 241. Fig. 12-B shows a cam wheel arranged to close the contacts of an open circuit system and send call number 123.

From this we see that such boxes are merely mechanically operated switches or sending keys.

Certain types of industrial or shop "code call" systems use a mechanism similar to these to send

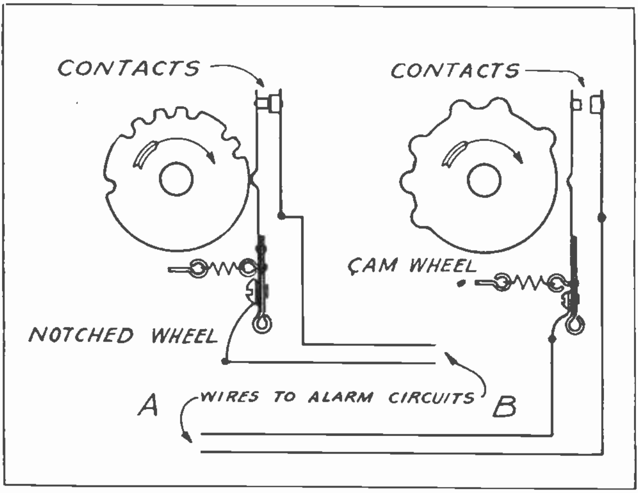


Fig. 12. This sketch shows the arrangement of the code wheel and contacts of closed and open circuit code call systems.

number calls for different parties in the plant. These will be explained later.

Fig. 14 shows a fire alarm control cabinet, which is used to control and check the condition of such systems. These cabinets are equipped with relays which receive the small impulses of current from the alarm box lines, and in turn close circuits sending heavier currents to the gongs or horns located near the cabinets.

Meters are also often provided for indicating the amount of current flow through closed circuit systems, and thereby show the condition of the circuits.

Note the diagram of connections which is in the cover of this cabinet, and is usually furnished by the manufacturer of such devices. So you can readily see what an advantage it is to know how to read these diagrams.

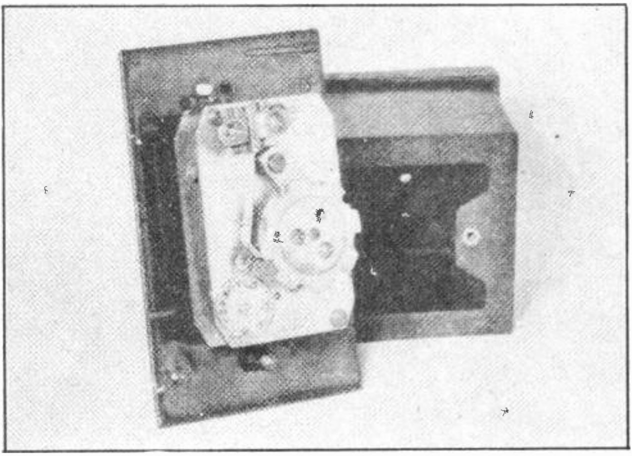


Fig. 13. Signal or alarm box of the code calling type, showing code wheel and contact springs.

11. SIGNAL RECORDERS

In fire alarm, bank burglar alarm, and police call systems, it is often desired to keep a record of the numerical code call sent in by the signal box, in addition to hearing the call sounded on the bell or horn. This helps to prevent mistakes in determining where the call comes from.

For this purpose we have recording machines which mark or punch the call on a moving paper type as the signal comes in, thus giving an accurate and permanent record of it. Such a device is shown in Fig. 15.

There is a spring and clockwork mechanism kept wound and ready to pull the tape through, at a definite speed. The first impulse of the signal operates a relay or magnetic trip that releases or starts the spring and tape.

Then another magnet operates a small pen arm, shown on the outside of the box in this case, and marks every impulse on the tape in the form of dots and dashes.

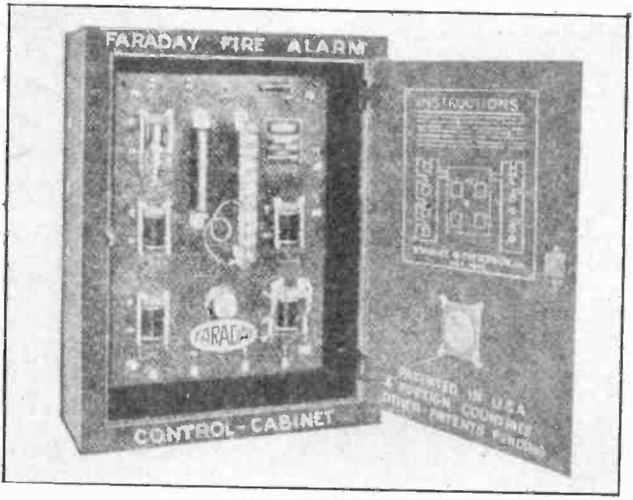


Fig. 14. Fire alarm control cabinet, showing relays, test meter, and connection diagram.

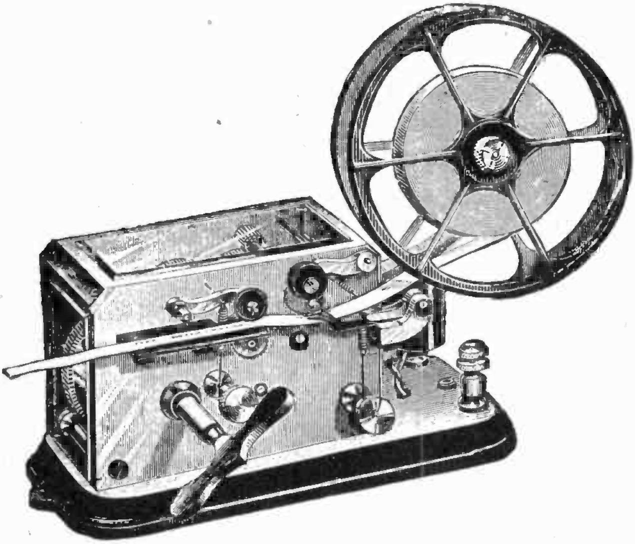


Fig. 15. Recording device for receiving code calls on paper tape. Fire and police departments use such recorders.

Alarm Circuits

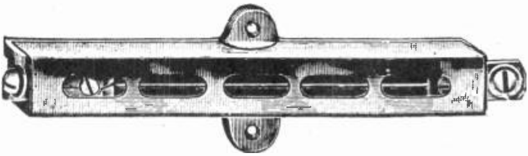
Automatic fire alarms use thermostatic switches or fusible links, to open or close circuits and send an alarm as soon as a certain temperature is reached. This type of system is very valuable in warehouses and buildings where no people or watchman are about to notice a fire immediately.

Thermostatic switches can be set or adjusted so a rise of even a few degrees above normal temperature will cause them to close a circuit almost immediately.

One switch of this type was explained.

Another type is shown in Fig. 16. There are various types in use but all are quite simple and merely use the expansion of metals when heated, to close or open the contacts.

Any number of such thermostats can be con-



Fil. 16. One type of thermostatic fire alarm switch, that can be adjusted to open or close an alarm circuit by expansion at temperatures above normal.

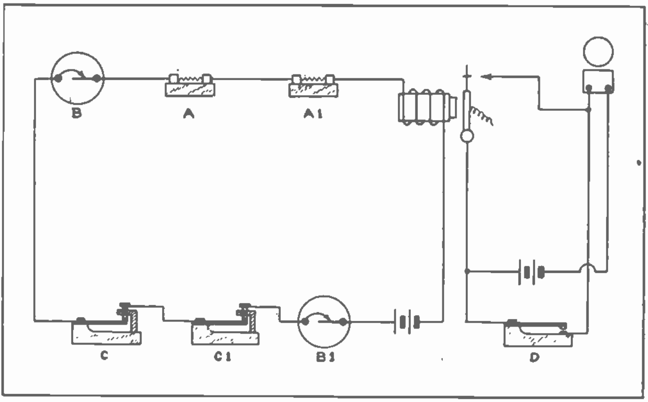


Fig. 17. This sketch shows the connection of several different types of fire alarm switches in one system.

nected on a fire alarm circuit to operate one general alarm, through the proper relays.

12. FUSIBLE LINKS FOR FIRE ALARMS.

The fusible link fire alarm is made of a soft metal alloy something like electrical fuse material. Some of these metals are made which will actually melt in warm water, or at temperature of 125 degrees and up. Such fusible links can be located at various points where fire might occur, and all connected in series in the alarm circuit. If any one is melted by fire or excessive heat near it, the circuit will be broken and the alarm operated.

Fig. 17 shows a fire alarm system in which all three types of switches are used. The "break glass" switches can be located where they are easily accessible to persons who might observe the fire, and the thermostats and links installed in other places in the building where no one is likely to be.

In this sketch, "A" and "A-1" are fusible link switches. "B" and "B-1" are "break glass" switches, and "C" and "C-1" are thermostatic switches. All of these are of the closed circuit type. In addition to these, an open circuit thermostat switch is shown at "D" to operate the bell direct in case of fire near the relay and alarm equipment. Fig. 18 shows a fire alarm fuse or link.

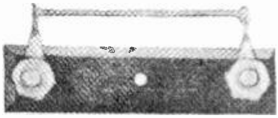


Fig. 18. Fire alarm fuse which melts when heated above normal temperature, opening the circuit and causing alarm to sound.

13. INDUSTRIAL SIGNALS AND HEAVY DUTY BELLS.

In factories, industrial plants and power plants, where signals are used to call department foremen and various employees, and where the noise would make ordinary small bells difficult to hear, large heavy duty bells or horns are used.

The bells used for such work are very similar to the smaller ones, but are much larger and are usually wound to operate on 110 volts. Instead of using the vibrating armature pivoted on one end, they often use a rod for the hammer. This rod is operated by the magnets in the case. Two bells of this type are shown in Fig. 19, and the hammer rod can be seen under the gong of the larger bell.

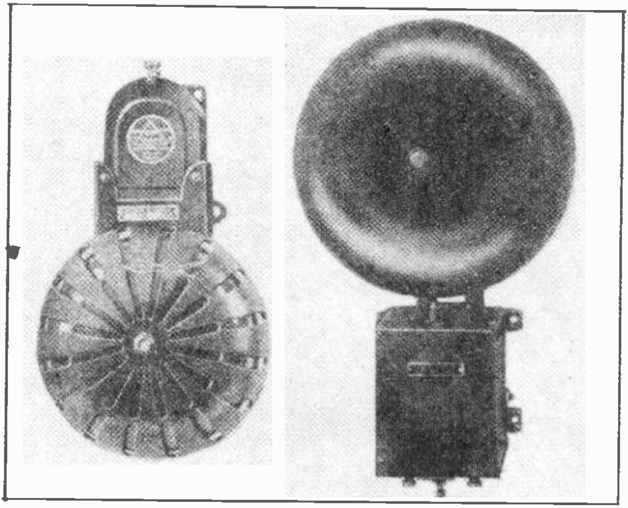


Fig. 19. Two types of large heavy duty bells for use in industrial plants or noisy places.

14. SIGNAL HORNS OR "HOWLERS".

Horns have a very penetrating note and for very noisy places are often preferred to bells. They are made to operate on either D. C. or A. C., and at 110 volts, or can be obtained for any voltage from 6 to 250.

Some such horns are made with a vibrator which strikes a thin metal diaphragm at the inner end of the horn. Others have small electric motors which rotate a notched wheel against a hard metal cam on the diaphragm, causing it to vibrate or "howl" loudly. Many of these horns are called "howlers".

Fig. 20 shows two horns of the vibrator type, and Fig. 21 shows one of the motor operated type.

Fig. 22 is a sectional view of a motor horn, showing all its parts.

Heavy duty bells and horns require more power to operate them, than can be handled by the ordinary small push button, and these **low voltage push buttons should not be used on 110 volts.**

So we usually connect the switches to a special relay which has heavy carbon contacts, to close the high voltage and heavier current circuit to the bells or horns.

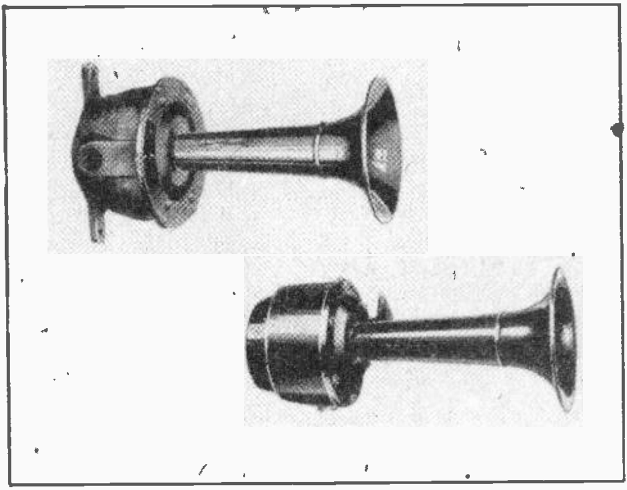


Fig. 20. Two styles of signal horns using magnetic vibrators to produce a loud note.

Fig. 23 shows the connection diagram for a group of horns with such a relay.

15. AUTOMATIC SIGNALING MACHINES.

In large plants where a great number of different numerical or code calls are used for signaling different parties, an automatic signaling machine is often used. With this device, the operator simply pushes a button for a certain call, and this releases or starts a spring or motor operated disk or code wheel, which sends the proper signal or number of impulses properly timed, in a manner similar to the fire alarm already explained.

A box with a number of these buttons and wheels can be used to conveniently call any one of a number of parties, by just pressing the proper button once, and this does not require the operator to

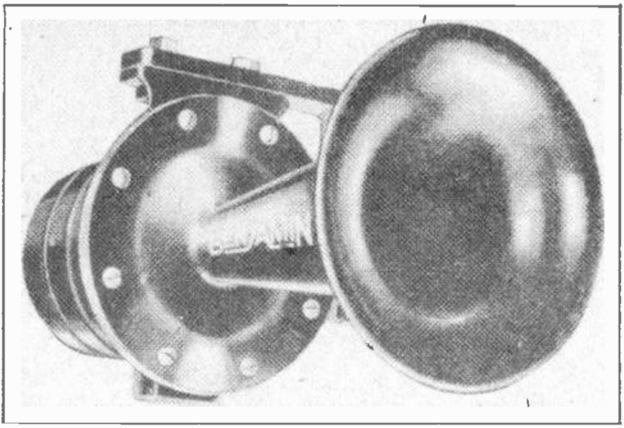


Fig. 21. Motor operated signal horn which produces a very penetrating note, and is excellent for industrial and power-plant use.

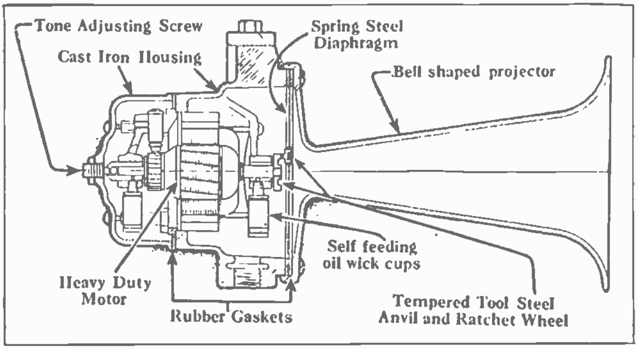


Fig. 22. Sectional view showing parts and construction of motor operated horn. (Sketch courtesy of Benjamin Electric Company.)

remember a number of code calls.

A diagram for connecting such a device to signal horns operated from a transformer is shown in Fig. 24.

Extra push buttons are also shown for sending special calls not included on the automatic signal box.

A time clock is also connected in this system to sound the horns at starting and quitting periods for the employees.

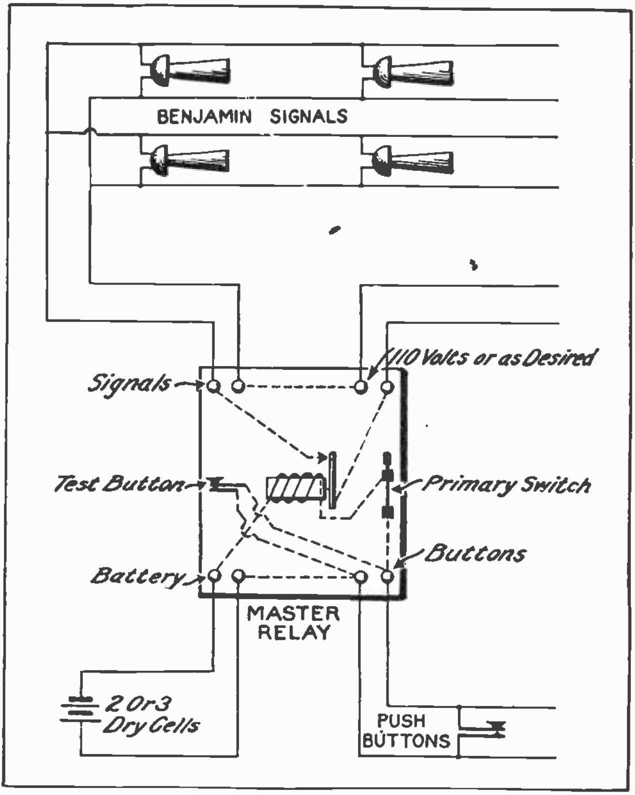


Fig. 23. Connection diagram for signal horns and Master relay. This relay operates on low voltage and very small current, and closes a high voltage, heavy current, circuit to the horns. (Courtesy Benjamin Electric Company.)

These clocks have two program wheels, one of which revolves with the hour hand, and one with the minute hand. These wheels carry adjustable lugs or projections which open or close electrical contacts as they come around.

Schools often use these program clocks with signal systems, to start and dismiss various classes.

16. AUTOMATIC PLUG-IN TYPE FIRE ALARMS.

Installing fire-alarm signal systems usually requires a separate wiring installation, or the use of existing signal equipment such as a door bell circuit, etc.

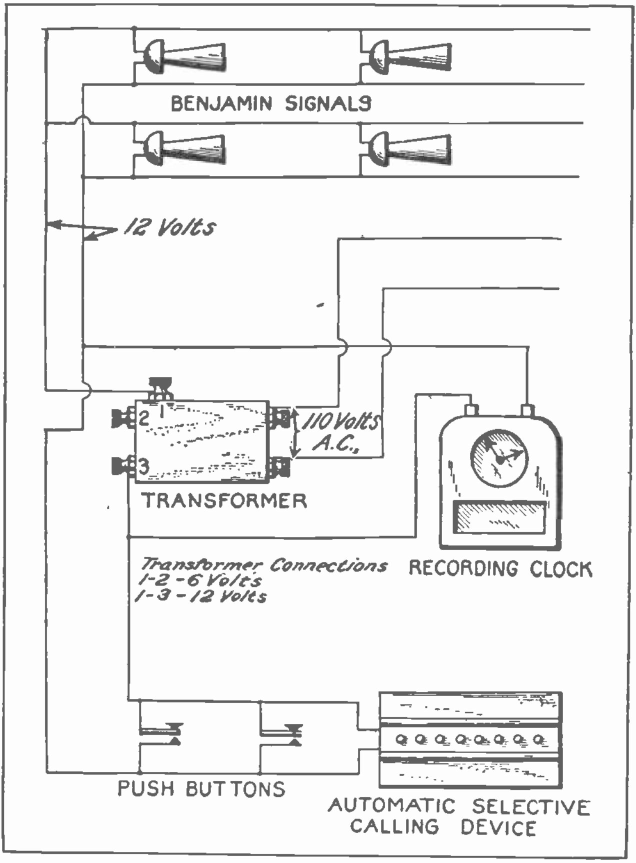


Fig. 24. This diagram shows the connections for signal horns operated from a transformer, and controlled either by a time clock or automatic signal device.

However, automatic fire-alarm equipment has been made available which does not require any special wiring for its installation, as each unit is self contained and is put in operation by merely "plugging in" to any regular electric convenience outlet or lamp socket.

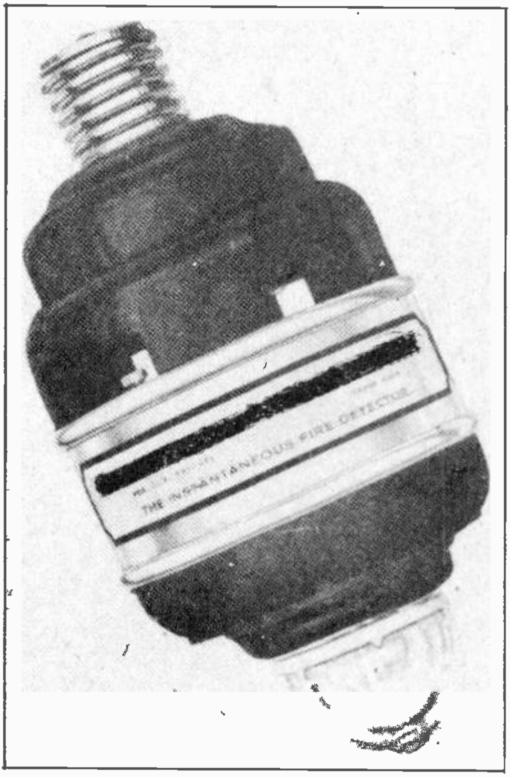


Fig. 25. A complete self-contained fire alarm unit that screws right into a lamp socket. See sectional drawing in Fig. 26.
(Courtesy H. Channon Co.)

In other words, this means that any home that is already wired for electricity can be provided with efficient, dependable fire-alarm service by merely "plugging in" one or several of these units.

Fig. No. 25 shows a very high grade alarm designed to be screwed into a regular electric light socket. This alarm consists of four important parts as follows:

1. A howler which operates directly off the 110 volt A. C. line after the circuit has been closed by one of the thermostats. See the sectional drawing shown in Fig. No. 26.

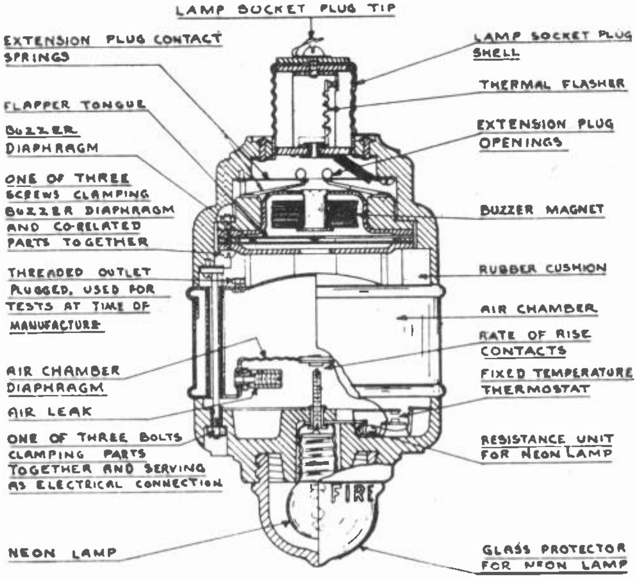


Fig. 26. A complete sectional drawing showing all of the parts used in the alarm unit shown in Fig. 25.

2. A low wattage neon lamp is located in the bottom of the unit to indicate that power is available at the unit.

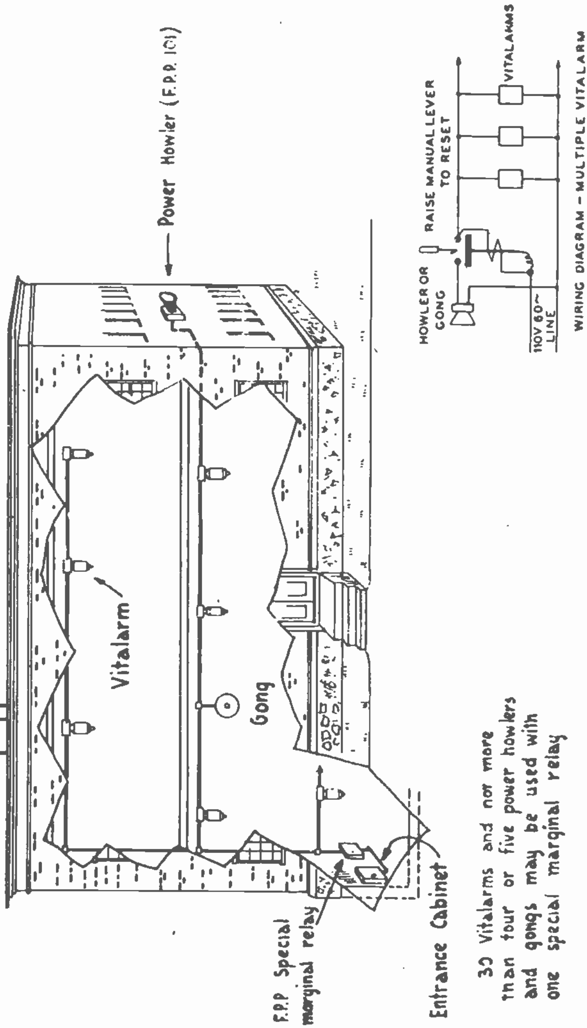
3. A "rate of rise" thermostat which is designed and adjusted to operate within one or two minutes when a sustained temperature rise of 15° to 20° Fahrenheit per minute is maintained. This thermostat will operate regardless of the prevailing room temperature at the start of the fire. As soon as the contacts close the howler is set in operation.

4. A "fixed" thermostat is used in connection with the more sensitive "rate of rise" thermostat and is set to operate at a temperature of 150° Fahrenheit.

This alarm unit is also designed so that an extension horn or howler, consuming not more than

15 watts, may be attached directly to the unit as shown by Fig. 28. If the extension unit consumes more than 15 watts then it will be necessary to connect a relay between the alarm unit and the extension unit.

FIG. 27. TYPICAL MULTIPLE INSTALLATION for INDUSTRIAL - COMMERCIAL OR INSTITUTIONAL USE



One or more of these fire alarm units may be installed in the home, factory or any other building where there is danger of fire.

Fig. No. 27 shows several alarm units installed in a commercial building and a power howler is connected to the system and mounted outside of the building. In this system separate power lines have been installed direct from the entrance cabinet to the alarms. The alarms are connected across the line parallel to each other the same as electric lights.

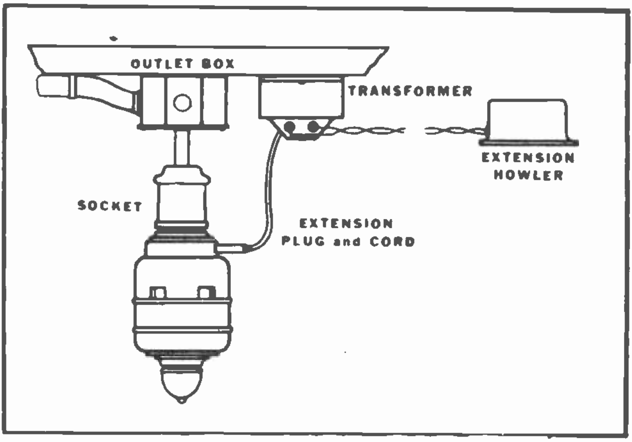


Fig. 28. A vitalarm fire detector installation showing an extension howler connected through a transformer.

This type of fire alarm makes an excellent and economical protective installation which you should be able to sell and install in many buildings.

EXAMINATION QUESTIONS

1—(a) What is the advantage of using a holding relay in an alarm circuit? (b) What rule should be followed in connecting up a holding relay?

2—(a) About what temperature is required to melt the metal used in a fusable link? (b) Is the metal soft or hard?

3—What advantage is there in using a lock switch in connection with a Burglar Alarm Circuit?

4—For what purpose is a glass used in a fire alarm box?

5—Copy diagram No. 17 and trace the circuit through which current would flow when thermostat "D" is closed.

6—What kind of a signal device would you select for use in noisy places?

7—Is it advisable to use ordinary small push button switches to control heavy duty bells and horns? Why?

8—How is tinfoil used in connection with a Burglar Alarm system?

9—Why doesn't the relay coil in Fig. 7, attract the armature, inasmuch as current is flowing through the coil?

10—Are the horns shown in Fig. 23, connected in series or parallel with each other?

INSTALLATION

OF CALL AND SIGNAL SYSTEMS

Now that you have learned the operating principles of signal equipment and circuits, and know how to trace the diagrams and plans, you will want to know more about how to install them.

In making any electrical installation, the first thing should be the plan or layout, and circuit diagram. So as soon as we have decided upon the type of system desired and how it should operate to give best service, we should decide on the location of the various parts, and then lay out the circuits accordingly.

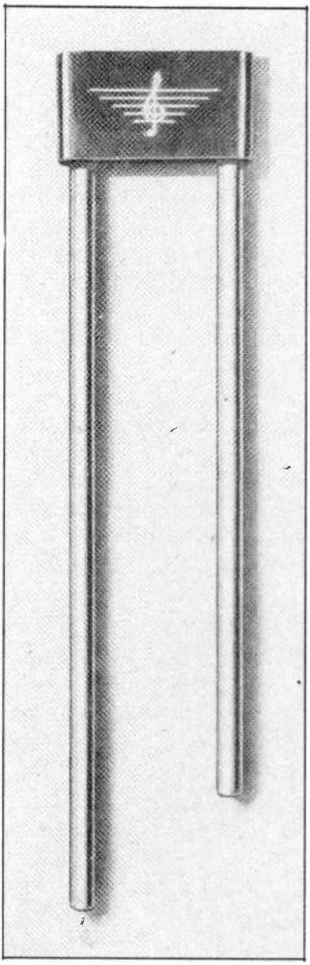
Complete wiring diagrams are usually supplied by the architects who draw up the plans for new buildings. In the case of large power or industrial plants the plans are generally drawn up by the Company Engineers. However, if such plans are not furnished, you should at least make up a rough layout before any work is started.

The plan can be drawn approximately to scale for the various distances between devices, or length of wire runs, and this will enable you to estimate and select the required materials with best economy.

Then, by following a circuit diagram, many mistakes and time losses can be avoided in making the final connections.

In drawing up plans, or in copying them from other prints, it is usually much easier to sketch the parts and devices on the paper first, in about the same location and proportional spacing as in the original plan, or as they are to be installed in the building. Then draw in the wires and circuits one at a time, keeping them as straight and simple as possible. Lay out the wires and connections first to get the desired operation and results. Then go over the plan again, and possibly redraw it to simplify it and shorten wires, making use of "common wires" eliminating unnecessary crossed wires, etc.

Signal System Installation



Large tubular chimes as shown above are very popular for use in modern door signal installations. They are new and easy to sell to many home owners.

LAYOUT OR LOCATION OF PARTS IN THE BUILDING

By going carefully over the building with the plans, and using good common sense in choosing the location for the various apparatus and wire runs, you can make a more satisfactory job and save additional time and labor on the installation.

For example, when installing a simple door bell system in a home, **the bell should be located in a rear room**, probably the kitchen, because both its noise and appearance would probably be objectionable in the parlor or dining room. Usually some "out of the way" place can be found in a corner or hall, or behind a door, and preferably quite high from the floor, so it is out of reach of children and safe from accidental damage. By considering where the wires can best enter the room and placing the bell on this side if possible. time and material may be saved.

The battery or transformer should usually be located in the basement or attic near to the bell or wires. However, the battery or transformer can sometimes be located on a small shelf or attached to the wall right with the bell, or in a small box.

The buttons of course must be located at the proper doors, and preferably on the door casing. Their height should be carefully chosen to be within convenient reach of grown-ups, but usually not low enough for small children to reach, unless a lower mounting is requested by the owner.

2. RUNNING THE WIRES

All wires should be run concealed whenever possible. Very often it is possible to drill two small holes in the door casing strip directly beneath the button and, by loosening the strip, run the wires under it to the basement or attic.

If it is not possible to get behind the strip, perhaps the holes can be drilled at an angle to get the wires into the edge of a hollow wall. Or, if necessary, they can be run in the corner at the edge of the door casing and covered with a strip of wood or metal moulding.

Where wires can be run through the basement or attic they can usually be stapled along the basement ceiling or attic floor. Care should be taken to run wires where they will be least likely to receive injury, and they should always be run as straight and neatly as possible.

Sometimes it is advisable to lay a narrow board to run the wires on across ceiling or floor joists in unfinished basements or attics.

When making long runs of wire always keep in mind the saving of time and material that can be made by using a common feeder wire to a number of switches, or a common return wire from bells to battery. This should also be carefully considered when laying out the diagram and plans.

Where it is desired to run wires vertically through walls, they can be **"Fished"** through by dropping a weight on a string from the upper opening to the lower one. This device is often called a **"Mouse"**. If the weight or "mouse" does not fall out of the lower hole, the string can be caught with a stiff wire hook and pulled out of the hole. See Fig. 1-C.

Then the wires can be pulled through with this string, or if necessary another heavier cord can be pulled through first, providing the wires are too long and numerous to be drawn in by the light cord on the "mouse".

In horizontal runs through walls a steel **"Fish Tape"** (a heavy steel wire) can be pushed through first, and hooked or snared at the outlet opening, then drawn through with the signal wires attached.

A little "kink" that often comes in very handy in either signal or light wiring is as follows:

A magnetized file may be used to good advantage in locating the proper place to drill through a floor or partition. Stick the file in one side of the floor or partition, and the point directly opposite on the other side of the partition, may be determined by using a magnetic compass.

The compass needle will be attracted by the file tip. Moving the compass around will locate the center of attraction, which should be the point directly opposite the file tip. Then measure the distance between the spot located by the compass and to the edge of the partition, and add one-half the thickness of the partition. Measure off this distance in the same direction from the file and you should have a point about in the center of the partition.

In other cases measurements in two directions from certain outside walls may be accurate enough.

Sometimes an exact spot can be located best by drilling through the wall or floor with a long thin feeler drill, ⅛ or 3/16 in diameter.

If the hole does not come near the exact spot desired, it will serve as an accurate point to measure from, and can be easily plugged and concealed afterward.

Fig. 1-A shows how to use the magnetized file and compass and make the measurements to locate the center of a partition. Fig. 1-B shows by the dotted lines how the small "feeler" holes can be drilled for the same purpose. The first hole should be drilled down at the proper angle and the second one drilled up, to try to strike the center of the partition. Or, the first one can be drilled straight down and then the proper distance measured over to partition.

Figs. 1-C and 1-D show the method of dropping a "mouse" through the holes and pulling the wires in.

3. RUNNING SIGNAL WIRES IN CONDUIT

In some cases, especially in modern fireproof office or factory buildings, signal wires are run in conduit. Conduit, as previously mentioned, is iron pipe in which the wires are run for protection from injury and to provide greater safety.

Signal wires should always be run in separate conduit of their own, and never with wires of the

higher voltage lighting system.

A fish tape is usually pushed through the conduit first, and used to pull the wires in.

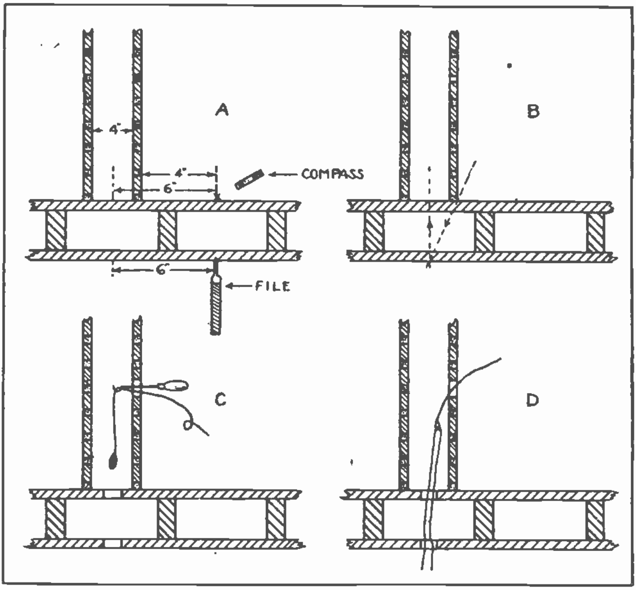


Fig. 1-A. Sketch showing uses of magnetized file and compass to locate spot to drill for wires. "B," dotted lines show how the "feeler drill" can be used. "C," dropping a "mouse" on a string, through holes in wall and floor. "D," pulling the wires in with the cord which was attached to the "mouse."

4. TESTING TO LOCATE PROPER WIRES FOR CONNECTIONS

When a number of wires all alike and without color markings are run in one conduit, cable or group, it is easy to find the two ends of each wire by a simple test with a battery and bell, or test lamp.

Simply connect one wire to the conduit at one end, and then attach the bell and battery to the conduit at the other end, and try each of the wires on the bell, until the one that rings it is found. This is the same wire attached to the conduit at the other end. (See Fig. 2-A.) Mark or tag these ends both No. 1 or both "A", and proceed to locate and mark the others in the same manner.

When testing or "ringing out" wires in a cable or open group with no conduit in use, very often some other ground to earth or some piping system, can be obtained at each end, making it easy to test the wires. (See Fig. 2-B.)

5. TROUBLE TESTS

When troubles such as grounds, opens or shorts occur in wires in conduit, the fault can be located as follows:

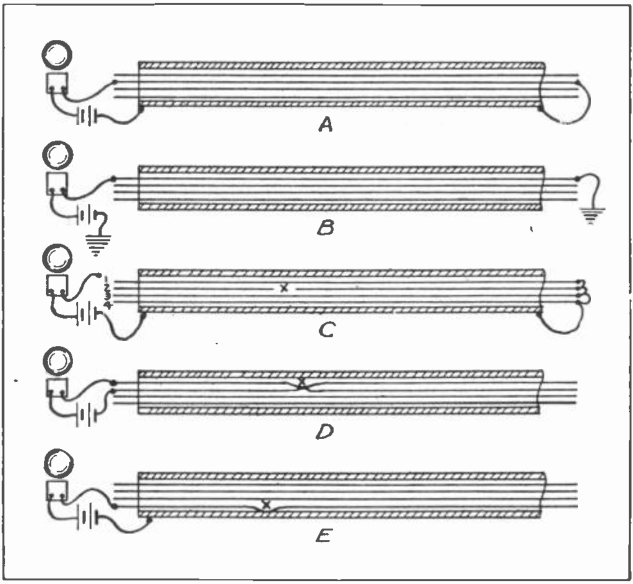


Fig. 2. Sketches showing methods of testing for various faults in wires run in conduit. Compare carefully with test instructions given.

Suppose one wire is suspected of being broken or "open." Connect all the wire ends to the conduit at one end of the line, as in Fig. 2-C. Then test with the bell and battery at the other end, from the conduit to each wire. The good wires will each cause the bell to ring, but No. 2, which is broken at "X" will not cause the bell to ring, unless its broken end happens to touch the conduit.

When testing for short-circuits between wires, disconnect all wires from the devices at each end of the line and test as in Fig. 2-D.

When the bell is connected to wires Nos. 1 and 2 it will ring, as they are shorted or touching each other at "X", through damaged insulation. Connecting the bell to any other pair will not cause it to ring.

Sometimes one wire becomes grounded to the conduit because of defective insulation as in Fig. 2-E.

For this test we again disconnect the devices from the wires, and connect the test bell and battery as shown.

With one test lead on the conduit, try the other lead on each wire. It will not ring on Nos. 1, 2, or 3, but will ring on No. 4 which is touching the pipe at "X", thus making a closed circuit for the test bell.

6. EMERGENCY WIRES, AND PULLING IN REPLACEMENTS

Where long runs of wires are installed in conduit or signal cables, it is common practice to include one or more extra wires for use in case any of the others become damaged.

This is especially good practice with cables, because it is difficult to remove or repair the broken wire. In a conduit system, where no extra wires are provided and a new wire must be run in to replace a broken or grounded one, it is sometimes easier to pull out all wires, and pull a new one back in with them.

Where this is not practical or possible, it sometimes saves time and money to pull out the broken or bad wire, and then attach two good wires to the end of one of the remaining wires, and pull it out, pulling in the two good ones with it. This replaces both the bad wire and the one good wire pulled out.

If the bad wire was not broken but only grounded, it can be used to pull in the new wire; but, of course, a broken wire cannot be used for this purpose. Therefore, it is often advisable to sacrifice one good wire, to pull in two new ones.

The several tests and methods just explained are very valuable and should be thoroughly understood, for use on other wiring systems as well as on signal systems.

While some of these tests were explained for wires in conduit, they can be also used on groups of open wires or cabled wires, by using in place of the conduit, some other ground or an extra wire, run temporarily for the tests.

7. SIGNAL WIRING MATERIALS

Now for the materials. In addition to the bell, battery or transformer, and push button switches, we will need the proper amount of wire, and in case of open wiring, staples to fasten the wire in place.

Ordinary bell or annunciator wire as it is called, is usually No. 16 or No. 18, B. & S. gauge, and is insulated with waxed cotton covering. It can be bought in small rolls of 1/4 lb. and up, or on spools of 1 lb., 5 lbs. or more. It can also be bought in single wires, or twisted pairs, and with various colored insulation.

Where several wires are to be run together, the use of different colors helps to easily locate the proper ends for final connection.

For damp locations, where the cotton insulation might not be sufficient, wire can be obtained with a light rubber insulation and cotton braid over it.

As ordinary door bells use only very low voltage, it is not necessary that the wires be so heavily insulated. **In most cases they may be run with no other protection,** such as conduit or mouldings.

To fasten the wires **we use staples which have paper insulation to prevent them from cutting into insulation of the wire.** However, these staples should not be driven too tightly down on the wires, and never over crossed wires, or they may cut through the insulation, causing a short circuit. Such a "short" under a staple is often hard to locate, and great care should always be used in placing and driving the staples.

Small cleats with grooves for each wire, and holes for screws to fasten them, are sometimes used. In other cases where twisted pairs of wires are run, a small nail with a broad insulating head is driven between the two wires, so the head holds them in place. Fig. 3 shows several sizes of insulated staples, and Fig. 4 shows the nail and cleats mentioned above.

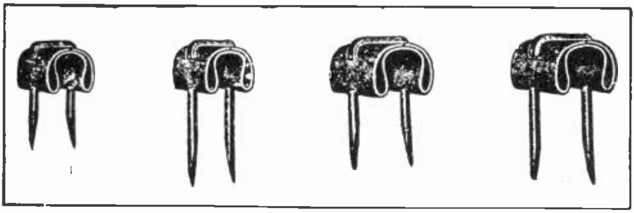


Fig. 3. Several different sizes and styles of insulated staples used in bell wiring.

On installations where a large number of wires are to be run in a group, cables with the desired number of wires can be obtained. These wires are usually marked by different colored insulation, so that the ends of any certain wire can be quickly and easily located at each end of the cable. Such cables simplify the running of the wires, save space and time, and make a much neater job in offices and places where numerous separate wires would be undesirable.

In large signal installations terminal blocks are used on some of the equipment, and all wires are brought to numbered terminals on these blocks. Then with the plans, on which the wires can also be numbered, it is very simple to make proper connections of cables with dozens or even hundreds of wires.

This is common practice with telephone installations and elevator signals, and also on modern radio sets, as well as for office and industrial call systems.

8. CAUTION NECESSARY FOR SAFE AND RELIABLE WIRING

Considerable care should be used when drawing bell wires through holes and openings, or the insulation may be damaged. Where the wires are left against the edge of a hole they should be protected from damage by vibration and wear, by means of a piece of hollow "loom" or insulating tubing slipped over the wires, and taped in place. Also, where wires cross pipes or other wires, they should be well protected with such extra insulation.

Even though signal and bell wires carry low voltage and small current, they are capable of creating sparks and starting fires if carelessly installed.

So, for this reason and also that the finished system will give good service, all signal work should be done with proper care.

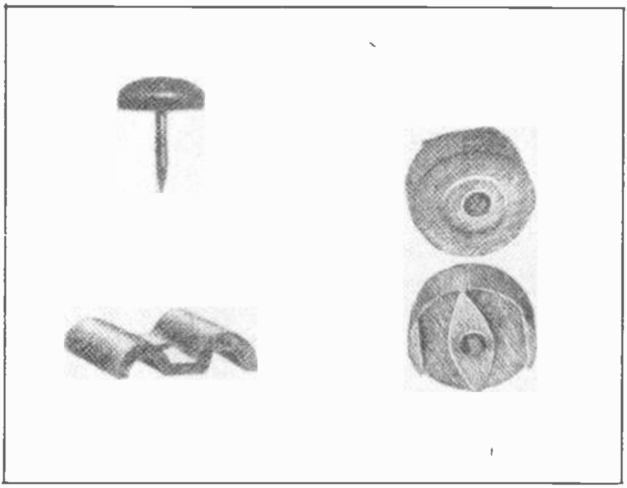


Fig. 4. Bell wires can also be fastened with the large headed nails and cleats shown here.

Low voltage signal wires must never be run in the same conduit with higher voltage lighting or power wires as it is very dangerous, and is also a violation of the National Electric Code, which will be explained in later lessons.

If such wires were run with high voltage ones, and a defect should occur in the high voltage wires and allow them to touch the signal wires with their thinner insulation, it would create a serious fire and shock hazard.

When installing bell transformers, **the wires from the lighting circuit to the transformer primary must be regular No. 14 rubber covered lighting wire, and** must run in conduit, armored cable, or approved fashion for 110 volt wiring, according to the code of that particular town or territory.

When making splices or connections to devices all wires should be well cleaned of insulation and all connections carefully made and well tightened. Splices in wires should be carefully soldered and well taped, to make secure and well insulated joints.

Any bell or signal system should be thoroughly tested before leaving it as a finished job. Pride in your work and neatness and thoroughness in every job should be your rule in all electrical work. That will be the surest way to make satisfied customers and success, in your job or business.

9. TROUBLE SHOOTING

In each section of this work on signal devices and circuits, common troubles and methods of locating them have been covered. In order to apply your knowledge of these things to solve any troubles in signal systems, your first step should be to get a good mental picture of the system, either from the plan or by looking over the system and making a rough sketch of the devices and connections.

Then go over it one part at a time **Coolly** and **Carefully,** and try to determine from the faulty action or symptoms of the system where the trouble may be.

10. KEEP COOL AND USE A PLAN AND A SYSTEM

A great mistake made by many untrained men in trouble shooting, is that they get rattled and worried as soon as they encounter a difficult problem of this nature. They forget that a plan or rough sketch of the wiring will usually be of the greatest help, and they make a few wild guesses as to what the trouble is. If these don't hit it, they often get still more rattled and indefinite in their efforts, and as a result sometimes mess up the system making it worse instead of improving it.

Remember that **Every Trouble Can Be Found,** and **Someone Is Going to Find It.** If you can do it, it will be to your credit and often put money in your pocket, or get you a promotion.

You can find any fault, by thoughtful systematic testing of each circuit and device and applying the knowledge you have of this work.

In general, a good rule to follow is to first **test the source of current supply.** See that it is alive and at proper voltage. A test lamp or voltmeter will do this nicely.

Then test the devices that fail to operate, using a portable battery and test wires to make sure the device itself is not at fault, or has no loose terminals.

If the power supply and all bells, relays, and switches are tested and O. K., then start testing the main wires and circuits with the proper switches closed to energize them. Use a test lamp of the proper voltage, or a voltmeter, to make sure the current can get through the lines.

No one can remember all these things perfectly the first time, but referring back to them and trying them out on the job at every opportunity is the quickest and surest way to fix them in your mind.

Never be ashamed to refer to a plan or notes when you have a problem of connection or other trouble. The most successful electricians and engineers always follow plans.

When a system has several separate circuits, test them one at a time and mark them off on the plan or sketch as each is proven O. K. In this manner you know at all times how far you have gone,

Fig. 5. This photo shows a view of the more common parts and materials used in signal and alarm wiring.

and where to look next, and can feel sure of cornering the trouble in one of the circuits or devices.

Remember a portable battery and bell, buzzer, or test lamp, and a few pieces of test wire, used with a knowledge of the purpose and principles of the circuits and devices, and plain common sense, will locate almost any signal trouble.

If at any time you have trouble in testing any piece of equipment, remember that you may refer back in your lessons for helpful information on that particular item.

Welcome every "trouble shooting" job as a chance to get some excellent experience.

11. PUTTING YOUR TRAINING INTO PRACTICE

Now, if you have made a careful study of your lessons so far, and have properly completed your experiments, you should be able to install almost any ordinary call or signal system

You may doubt your ability to do this, but that is natural at first, as most of us have felt this way on our first jobs. But the thing to do is to get out and try it as soon as you qualify. Follow your job sheets closely.

Fig. 6 shows a floor plan of a house equipped with a modern bell call system, that affords great convenience in any home. Here are shown front and back door buttons, and buttons to call a maid from the parlor, bedroom, or dining room. An annunciator indicates which door or which room any call comes from. The switch in the dining room can be a floor switch under the table for foot operation, while those in the other rooms can be neat push buttons in convenient locations on the walls.

In homes where no maid is kept several of these buttons may not be necessary, but practically every home should have a door bell.

They are becoming quite popular in many rural and farm homes. In these homes a call bell from the house to the barn or garage is often a great convenience.

In Fig. 6 the wires are shown in a simple layout to be easily traced, but they should be run through the basement or attic, or through the walls where necessary.

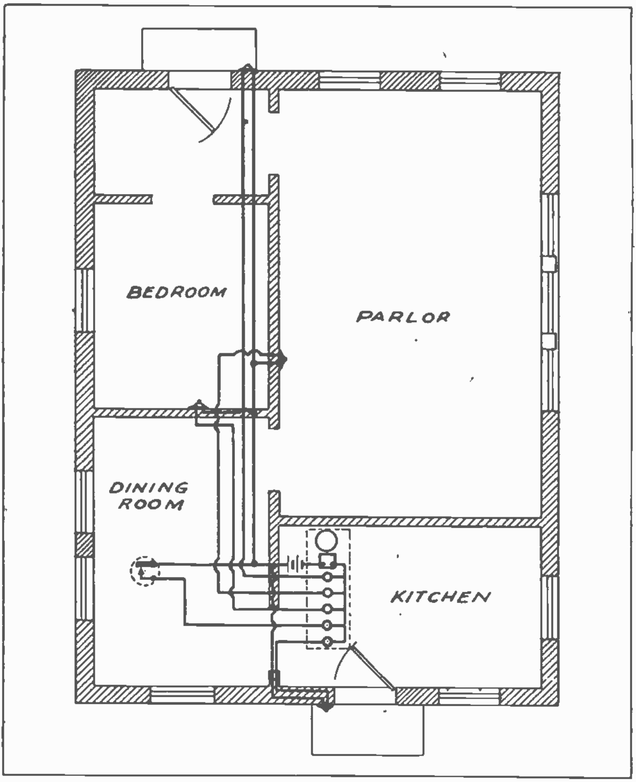


Fig. 6. Diagram showing layout of wiring for doorbell and convenience call system with annunciator. Such systems are commonly used in modern homes and are very well worth their cost of installation.

ESTIMATING JOB COSTS

Try to do all work at a fair price to the customer, and a fair wage, plus a reasonable profit for yourself.

A good plan on the first job or two, is to do them on a "time and material" basis. After determining the type of system desired and parts and materials needed, let the customer buy them, and then charge for your time on installing them by the hour.

Keep a record of your time, wages, materials, and costs, and these will help you estimate future jobs quite accurately. Then you can buy your own materials, and charge 25 per cent or more for handling them and for overhead or miscellaneous expense; in addition to a good wage for your time, all in the estimate figure.

In many cases, time and money can be saved on alarm installations by arranging the relays, bells, batteries, and reset switch all on one panel or shelf board, in advance at your home or shop. Then when you go to the job, it is only necessary to mount this assembled unit and install the wires and proper switches.

And again let us emphasize the value of doing all work neatly and with good workmanship, both for the appearance of the job, and for its quality and dependability of operation.

A customer is usually better satisfied in the end, to have a first class job done at a fair price, than to have a poor job at a cheap price.

12. GOOD WORKMANSHIP IMPORTANT

In every job you do, from the smallest door bell system to the most elaborate burglar or fire alarm system, make a practice of doing nothing but first class work—work that will be a credit to your profession, your school, and yourself.

Whether working for a customer or an employer, start building your reputation with your first job, and keep this thought in mind on all jobs.

13. VALUE OF ADVERTISING

Don't hesitate to let the people in your neighborhood know of your training and ability. With just a little confidence and real ambition you can do many profitable jobs. Prove it to them and to yourself, and be proud of your training, and every job well done.

Very often the repair of bell and signal systems already installed, will bring you some extra money.

14. TOOLS AND SUPPLIES

In case you desire to add to your collection of tools or supplies from time to time the following list will guide you so that you will not purchase items that will be of no value to you. This is a rather complete list and you may not need many of these items until you build up a large active business.

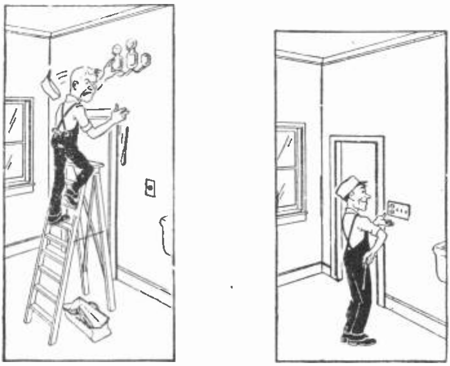
1 2" screw driver for bell adjustments.
1 4" screw driver for small screws.
1 6" screw driver for small screws.
1 ratchet for wood bits.
6 assorted wood bits.
3 long electrician's bits, 24" to 36", for long holes through walls and floors.
1 pair side cutters pliers.
1 pair long nose pliers.
1 pair diagonal pliers.
1 claw hammer.
1 light machine hammer.
1 staple driver.
1 compass saw.
1 hack saw.
1 carpenter's saw.
1 small pipe wrench.
1 small set of socket wrenches.
2 small star drills, for drilling holes in brick, tile, and concrete.
1 Yankee drill.
2 ignition point files, for bell contacts.
50-ft. of steel fish tape.
1 wood chisel.
1 cold chisel.
1 doz. assorted push button switches.
3 to 6 vibrating bells.
3 to 6 vibrating buzzers.
3 drop relays.

3 bell transformers.
12 dry cells, No. 6.
5 lbs. No. 18 annunciator wire.
3 boxes insulated staples.
1 electric or gasoline soldering iron.
3 rolls friction tape.
1 lb. solder.

15. "FLUSHCALL" and "CHIME" Signal Installations

The natural inclination and present trend toward improvements in the home, office and in places of business, is responsible for the steady demand for new modern and improved electrical apparatus of all kinds.

Among the many opportunities that exist in the field of modernization we find electric signaling as used in the home and in business offers an attractive field for the trained electrical man.



A B

Fig. 7 "A". A signal installation using ordinary bell and buzzer signals.

"B". An installation where the "flush" type signals have been used. (Courtesy Edwards & Co.)

Among the many door bell installations which should be made in almost every community each month, there are many installations where the owner would welcome an opportunity to have a new or improved signal system installed. In all such cases the customer will be BETTER SATISFIED with a high quality modern system and the electrician or contractor who makes the installation will MAKE MORE MONEY on such an installation.

16. MODERN DOOR BELL SIGNAL EQUIPMENT

In addition to the standard door bell buzzers and transformers, commonly used in door bell installations, there has been developed special replacement

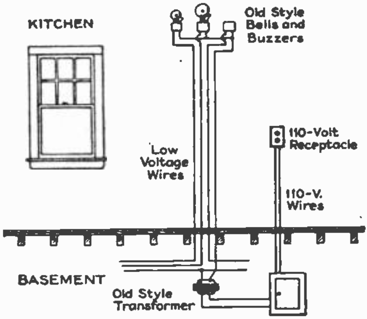


Fig. 8. A typical signal installation showing the wiring required when using regular bell and buzzer signals.

equipment which may be mounted flush with the wall and in regular outlet boxes.

Fig. 7 "A" and "B" show a comparison between the appearance of a regular door bell and buzzer, and a modern "flush" type installation. At "A" the bell and buzzer are being mounted in the regular way while at "B" the flush type installation is being made in the same box with a convenience outlet.

The "flush" type signal installation is a little more costly but makes a much neater installation and eliminates bells and buzzers from the walls where they will collect dust and dirt. Another important factor that will appeal to the Home Owner is that the flush type installation makes less work at decorating time.

Fig. 8 shows a regular door bell and buzzer installation using a door bell transformer and the usual wiring while at Fig. 9 is shown an installation using the "flush" type installation. We can see that in Fig. 9 we simply use the 110 volt circuit

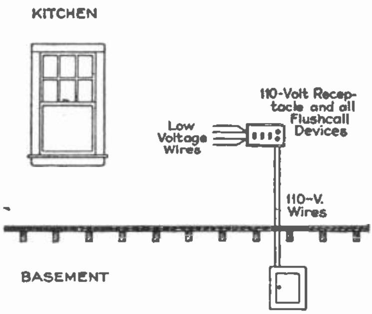


Fig. 9. An installation where the flush type equipment is used requires less wire as shown by the above figure. Compare this diagram with Fig. 8. (Courtesy Edwards & Co.)

which supplies power to the convenience outlet. The only other wires that are required are the low voltage wires which run to the switches.

17. "FLUSH" TYPE SIGNAL EQUIPMENT.

There is nothing complicated about the "flush" type installation, in fact, for those who understand the system there is less work involved than when installing the regular surface type equipment.

The main difference is that in the "flush" type system the transformer, bells, buzzers, and annunciators are so constructed by the manufacturers that they may be mounted in regular switch boxes.

Fig. 10, named by the manufacturers, the "Tucall," consists of two separate signals designed to replace a bell and buzzer combination. You will note that this combination unit has been designed to fit in a regular switch box. In addition to the "Tucall" other signals similar in appearance are obtainable. The "Ringcall" is a single unit designed to replace the regular door bell, and the "Melocall" is a dining room to kitchen signal or "Maids' call."

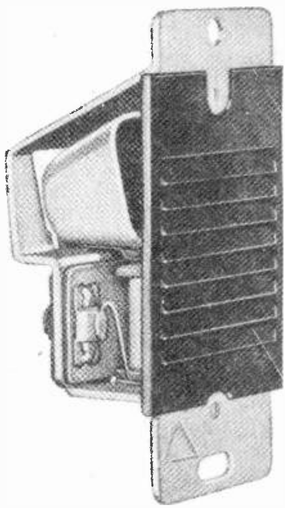
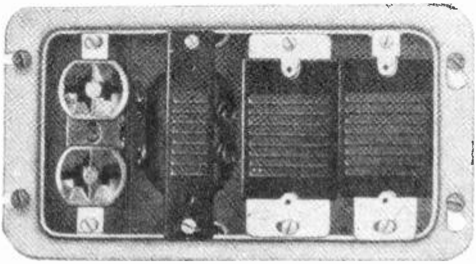


Fig. 10. The "Tucall" flush type signal shown above consists of two different signals designed to fit in a standard switch box.

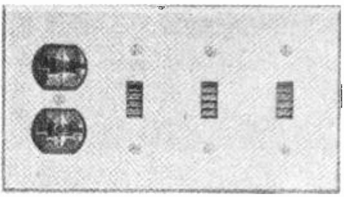
Fig. 11-A shows how a convenience outlet, a "Powacall" (transformer), a "Tucall," and a "Melocall" may all be mounted in a four gang switch box. At 11-B the cover is shown in place.

18. ELECTRIC CHIME SIGNALS

The sweet melodious tone of a cathedral chime may be substituted for the less pleasing sound of ordinary bells and buzzers by the use of modern electric chime signals. There is always a demand for installations of this kind, in fact, most home owners become prospective customers the very first time they hear chime signals and many are anxious to have the new equipment installed at once.



A



B

Fig. 11. At "A" we have from left to right: convenience outlet, "Powacall" transformer, "Tucall" signal, and a "Melocall" signal, all mounted in one gang type flush switch box. At "B" the same kind of an arrangement is shown with the cover in place.
(Courtesy Edwards & Co.)

Chime signal equipment is obtainable in different sizes, from many manufacturers, at prices to suit any pocket book as well as the most fastidious tastes. Prices range from a couple dollars each to $125.00 or more.

Small chimes with one or two bars such as shown by Fig. 12 may be installed to replace the regular bell with no change of power or control equipment.

Larger tubular chimes such as shown are obtainable with single tone, two tone, or as high as four tones. These larger chimes require too much power for operation on a regular door bell transformer. So when installing the large size "Chimes" it is also necessary to install a trans-

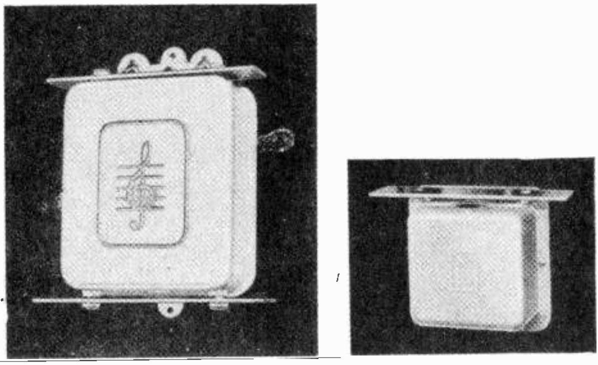


Fig. 12. Small chimes designed to replace regular bell and buzzer systems.

former designed to supply the required voltage and wattage. This equipment usually requires a 16 volt transformer with an output power of 25 watts, and in some cases a 50 watt output is required.

EXAMINATION QUESTIONS

1. In which part of the house is a door bell generally located?

2. Should signal wires be run in conduit with the power or light wires?

3. Is it generally necessary to run low voltage bell wires in conduit?

4. What kind of wire should be used for the 110 volt primary circuit leading to the bell transformers?

5. How are low voltage signal wires held in place when run without conduit?

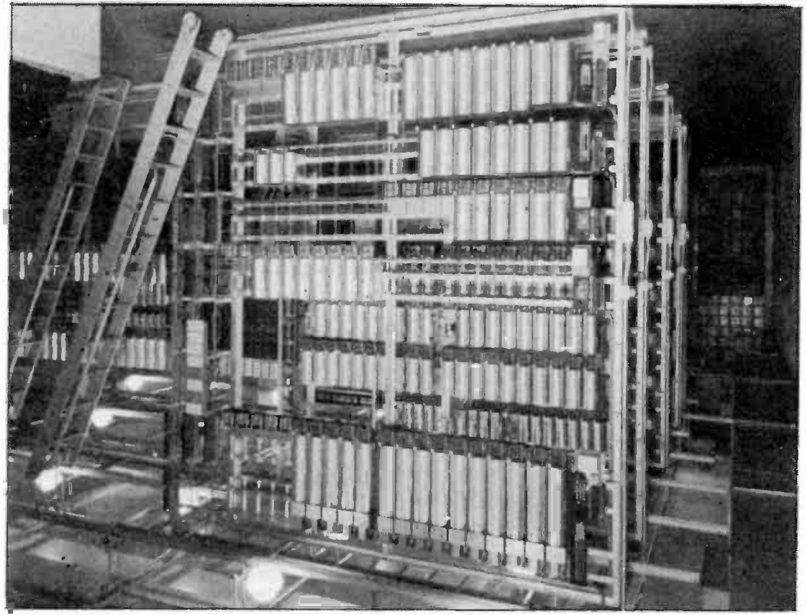
6. Why is insulation used on bell wiring staples?

7. In what part of the building should a bell transformer be located.

8. What two simple methods can be used to locate the proper spot to cut or drill into a floor or partition?

9. What is meant by a "mouse" as used in signal wiring? What is a "fish tape" used for?

10. What equipment would you use to test signal wires for grounds, opens or shorts?



Strowger (Step-By-Step) Dial Telephone Switching equipment (Installed at Logansport, Indiana).

TELEPHONY

Telephony is one of the most fascinating branches of Electricity which we now find such an important part of our every day life that we accept it as a matter of course, and seldom give much attention to the development which brought this interesting and valuable equipment to us.

During the year 1876, Alexander Graham Bell took out the first patent on the telephone. The definition given by him in obtaining his patent was as follows: **An instrument for the transmission of articulate speech by electric current.**

Although the telephone of today is completely electrically operated, the same fundamental operating principle was involved in the operation of the old "Lovers Telephone" which has been a source of amusement for many years. Thousands of young folks have enjoyed talking into an ordinary tin can and having their voice reproduced in another can some distance away by means of a tightly drawn string or wire attached between the two cans. This equipment although very crude was a stepping stone to the wonderful world wide system of today.

The writer can recall when telephones were first being introduced for general use. In those days we thought it quite an accomplishment to telephone over a distance of 50 miles. In fact, at that time one would have more difficulty in talking over a distance of 50 miles than we have today in carrying on a conversation with a person in almost any part of the world.

International Telephone Service is now available to most points in Europe, Asia, Africa, Australia, Central America. Also to the Bermudas, Hawaiian and other Islands.

One may also step to the telephone and carry on a conversation with a party traveling on either of several great liners on the Atlantic Ocean.

1. GREAT FIELD FOR SPECIALISTS WITH ELECTRICAL TRAINING

To keep all this vast and marvelous system of telephones functioning perfectly requires thousands of well trained electrical men who are specialists in circuit tracing, trouble shooting, and care and adjustment of the relays, bells, coils, etc. Many more men are required to install the thousands of new telephones constantly being added to this vast system.

2. TELEPHONE KNOWLEDGE VALUABLE IN ANY LINE OF ELECTRICAL WORK

The telephone field is one in which you can use many of the principles that have been covered in the preceding elementary and signal lessons. And even though you may not desire to specialize in or follow telephone work, you should at least have an understanding of the fundamental principles of telephone equipment. Many power plants, factories, shops and offices have their own private telephone systems, and in any line of electrical maintenance work you are likely to find good use for this knowledge.

3. PRINCIPLES OF OPERATION

The telephone is an instrument for transmitting sounds and voice from one point to another. Telephones do not actually carry the sound itself, but instead reproduce it by means of electric current impulses.

In order to understand how this is done, we should first know something of the nature of sound. Most everyone knows that any sound is transmitted by means of waves in the air. These air waves may be set up by one's voice, clapping of hands, firing a gun, or anything that causes a disturbance of the air.

Different sounds have waves of different volume and frequency. A loud sound has waves of greater volume or energy, and a low or feeble sound has waves of less volume or energy. A high pitched sound has waves of high frequency, and a low note has waves of lower frequency .

These little puffs or waves of air strike our ear drums and cause them to vibrate and transmit impressions of various sounds to our nerves and brain, thus enabling us to hear them. Figs. 1 and 2 show several different forms of sound waves, represented by curves showing their volume and frequency.

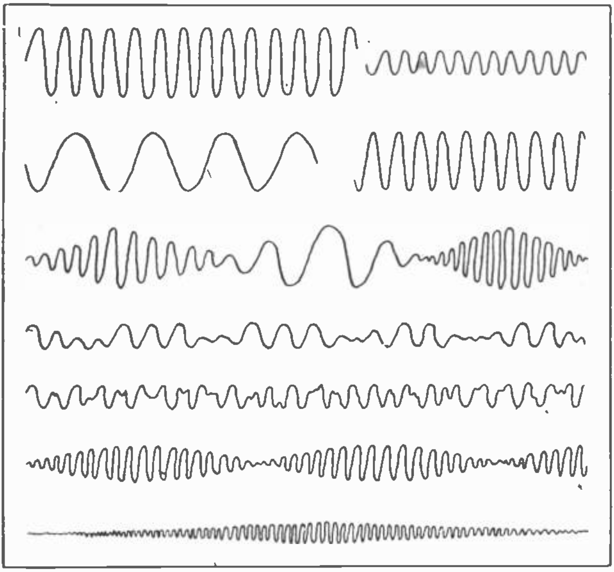


Fig. 1. This sketch shows a number of different forms of sound waves represented by curves. The upper line shows two groups of waves, both of about the same frequency, but the first group of considerably greater volume than the second. The second line shows two groups of about the same volume, but the first is of much lower frequency than the second. The third line shows waves of varying volume and varying frequency.

In order to be heard by the ordinary human ear, sound waves must be between 16 per second and 15,000 per second, in frequency. These are called **Audible** sounds. Many people cannot hear sounds of higher pitch or frequency than 8,000 to 9,000 waves per second, and it is only the highest of musical or whistling notes that reach a frequency of 10,000 or more per second.

Sound waves travel about 1,100 feet per second in air, and about 4,700 feet per second in water.

Ordinary sounds can only be heard at distances from a few feet to a few hundred feet, and the loudest sounds only a few miles.

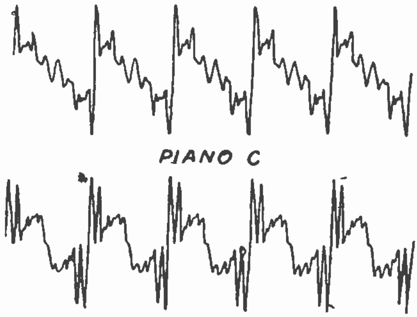


Fig. 2. These waves are typical of various musical notes, having the small variations in frequency and volume occurring at regular intervals, forming groups or large variations in the general note.

This is because the actual amount of energy in the sound waves is very small and is quickly lost in traveling through air.

Electricity travels at the rate of 186,000 miles per second, and can be transmitted over hundreds of miles of wire without much loss. So if we change sound wave energy into electrical impulses and then use these impulses to reproduce the sounds at a distance, we can greatly increase both the speed and the distance sounds can be transmitted.

This is exactly what the telephone does.

4. TRANSMITTING AND REPRODUCING SOUND WAVES ELECTRICALLY

In Fig. 3-A is shown a sketch of a simple form of telephone. Sound waves striking the **Transmitter** at the left, cause it to vary the amount of current flowing from the battery through the transmitter, and also through the **Receiver** at the right. These varying impulses of current through the receiver magnet vibrate a thin diaphragm or disk and set up new air waves with the same frequency and variations as those which operated the transmitter.

Thus the original sound is reproduced quite faithfully.

This illustration of the telephone principle shows that the actual sound does not travel over the wires, but that the wires merely carry the electrical impulses.

Figs. 3-B and 3-C show the same circuit with different amounts of current flowing in each case, as they would be at the time different sound waves strike the transmitter.

This simple telephone would serve to transmit the sound only in one direction, but would not permit return conversation. For two-way conversation we can connect a transmitter and receiver at each end of the line, all in series with a battery, as shown in Fig. 4.

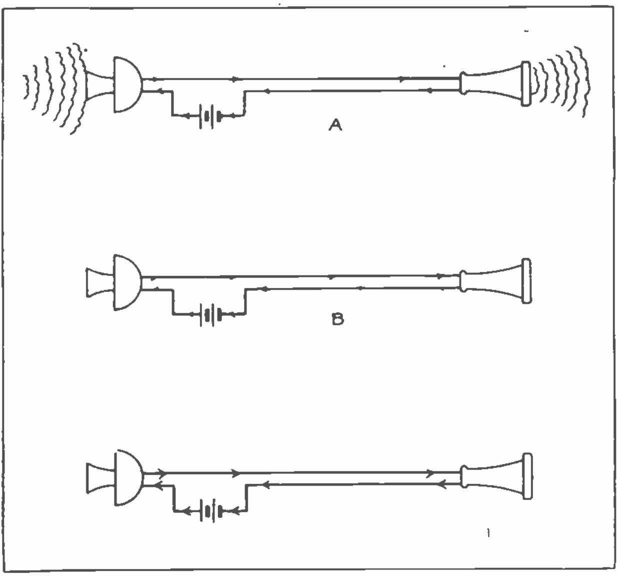


Fig. 3.—A. Sound waves striking the transmitter are reproduced electrically by the magnets in the receiver.
B. When feeble waves strike the transmitter only small currents flow in the circuit.
C. When stronger waves strike it heavier currents flow.

When sound waves enter either transmitter, both receivers are caused to operate; so this system can be used to carry on conversation both ways.

However, we still do not have any means to call the distant party to the telephone.

This can be arranged very easily, as in Fig. 5, by simply attaching a return call bell and push button system. In this circuit we have made use of one of the talking circuit wires, and a ground path for the bell circuit, but it still requires an extra wire for the signal. This wire can be eliminated by the use of a **Receiver Hook Switch,** to separate the talking and ringing circuits when the receiver is up or down.

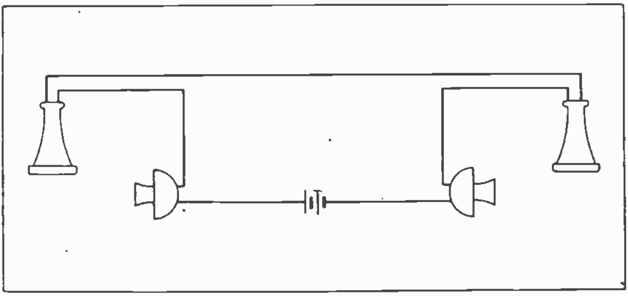


Fig. 4. Two transmitters and two receivers connected in series to forn a simple two-way telephone circuit.

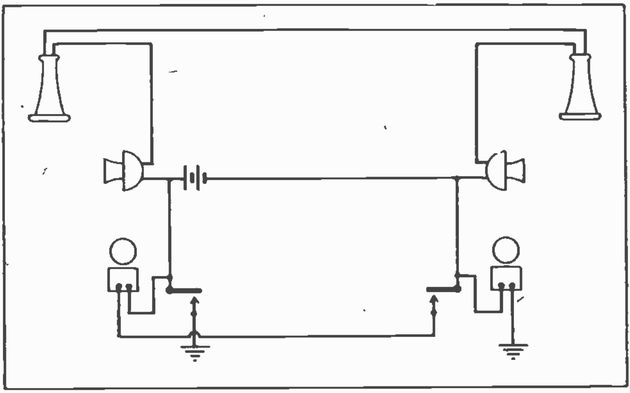


Fig. 5. Simple telephone system for two-way conversations, and including bells and buttons for calling the parties to the telephone.

The circuit shown in Fig. 5 can be used for a very practical telephone for short distances, such as between a house and barn, or in a large shop or office building. But for longer distances we should also have the hook switch to save the extra wire, and an **Induction Coil** to increase the voltage for the long line. The bells should also be of a special high resistance type, so they will operate on less current and maintain better line economy.

5. IMPORTANT TELEPHONE PARTS

Now we have found that the more important parts of a telephone are the **Transmitter, Receiver, Bell, Hook Switch, Induction Coil,** and **Battery,** or source of current supply. Some types of telephones also require a special **Magneto** to operate the high resistance bells.

In order to more thoroughly understand the operation of various types of telephones, and also their care and repair, we should now find out more about each of these important parts.

Although there are many styles of telephones and various circuits and systems, they all use these same fundamental parts, and if you get a good general knowledge of these parts it should be much easier for you to understand any ordinary telephone installation.

6. TRANSMITTER

The transmitter, as was mentioned before, acts as a valve to release from the battery, electric current impulses in synchronism with the sound waves which operate the transmitter. This is done by the use of variable resistance in the form of carbon granules (particles) in a small cup-like container.

This cup has a loose cover or front end, which is attached to the thin disk or diaphragm directly in front of the mouthpiece.

The mouthpiece acts as a sort of funnel, to concentrate the sound waves on this disk. As the waves strike the disk, they cause it to vibrate slightly and this moves the loose end of the carbon container, and compresses and releases, the carbon grains or granules. See Fig. 6 which shows these parts in detail.

The transmitter circuit is arranged so the current from the battery must flow through the carbon granules from one end of the cup to the other. When the carbon particles are compressed tightly the contacts between them are better, their electri-

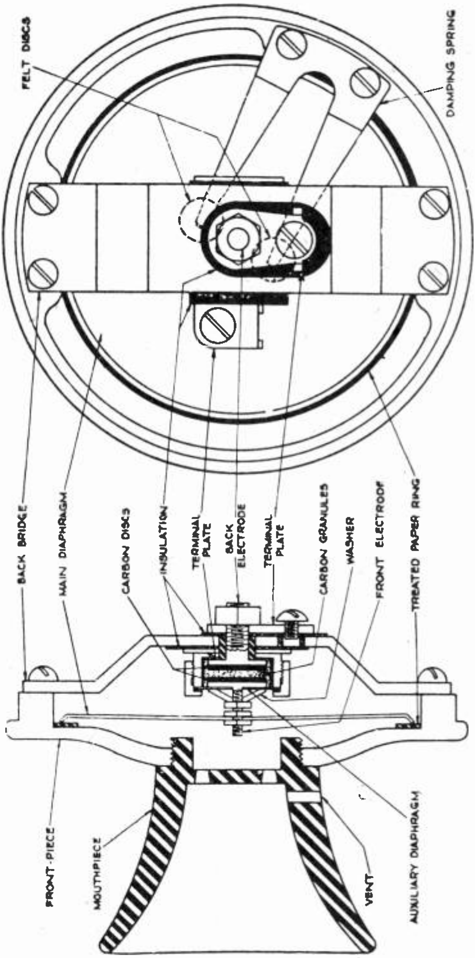


Fig. 6. This diagram shows two different views of a telephone transmitter and its parts. Examine each very closely, and note the names of each part.

cal resistance is lower, and they allow a strong current to flow. When they are released and their contacts loosened, the resistance increases and less current will flow.

So, as the various sounds strike the transmitter and cause the disk and button to vibrate rapidly, it controls or liberates from the battery corresponding impulses of current. Fig. 7 is a sketch showing the connections and electrical circuit through a transmitter.

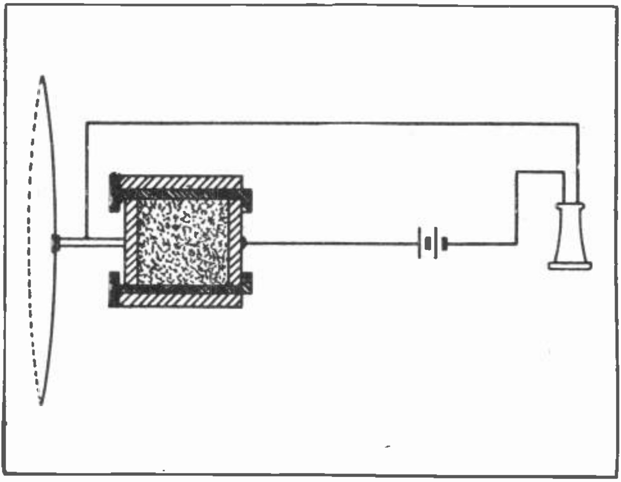


Fig. 7. Simple sketch showing principle of telephone transmitter button, and how the varying pressure on the carbon granules varies the resistance and current flow in the circuit.

Fig. 8 shows several different forms of electric current represented by curves. The straight lines are base or zero lines, and are considered as points of no current value. When the curve goes above the line it represents positive or current in one direction; and when it goes below it means negative or current in the opposite direction. Fig. 8-A shows a steady or continuous flow of direct current, such as the battery would ordinarily supply. Fig. 8-B shows pulsating direct current such as the transmitter would produce. The height of the curve above the line indicates the value of the various current impulses. While this current varies in amount, it is still flowing all in one direction.

Fig. 8-C shows ordinary alternating current, such as a magneto or A. C. generator would produce. This current continually varies in amount and regularly reverses in direction. Fig. 8-D shows

alternating current of irregular frequency and varying volume, such as produced by a telephone induction coil, which will be explained a little later.

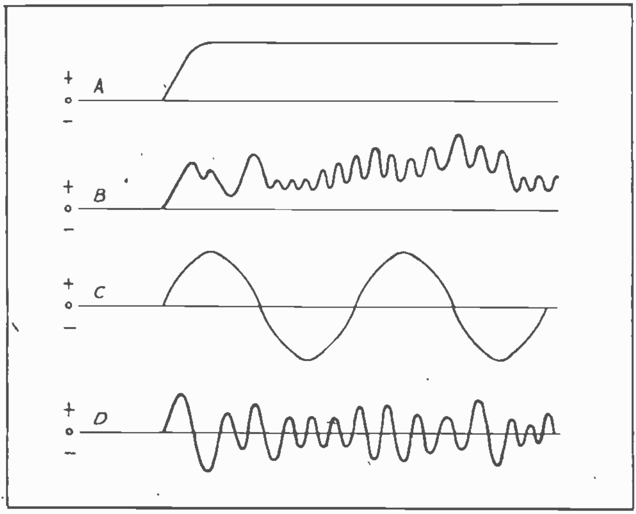


Fig. 8. Various kinds of electrical current represented by curves Examine each curve very closely and compare with the explanations given.

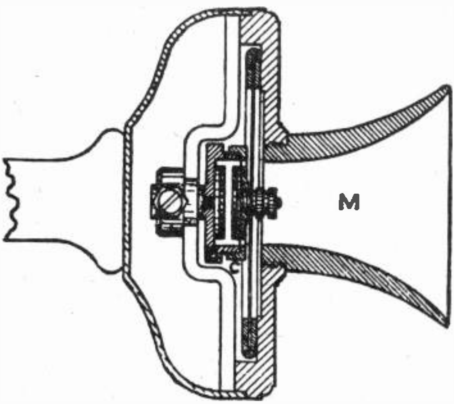


Fig. 9. Sectional view of a common type of telephone transmitter. The carbon cup is here shown empty or without any carbon granules in it.

Fig. 9 shows another type of transmitter of slightly different construction, but similar in operating principle to the one in Fig. 6. This transmitter has the disk or diaphragm mounted in a soft rubber ring, to allow it free movement without rattling or chattering.

Sometimes the carbon granules in a transmitter become packed or worn and need to be removed. In many transmitters the entire cup can be easily removed and exchanged. Loose terminals, broken connections, or dirt around the diaphragm also cause occasional trouble.

7. RECEIVER

The ordinary telephone receiver consists of a strong permanent magnet of horseshoe shape, a pair of electro-magnet coils at the ends of the permanent magnet poles, a thin disk or diaphragm, and the shell and cap in which these parts are enclosed.

See Fig. 10. The receiver at the left shows the parts named, while the one at the right shows a slightly different type which does not use the large permanent magnet, but just a strong electro-magnet instead.

The permanent magnet normally holds the iron disk attracted when the receiver is not in use. When "talking current," or current from the talking circuit, passes through the coils of the electro-magnets, its current variations strengthen and weaken the pull of the permanent magnet on the diaphragm, causing it to vibrate.

Telephones using induction coils have alternating current in the line and receiver circuits. This current reverses rapidly, and the reversals or alternations are of the same corresponding frequency and volume as the sound waves which caused them.

Some of these impulses were shown in Fig. 8-D As these impulses pass through the receiver coils, they not only vary the magnetic strengthen of the coils, but also actually reverse their polarity. This causes the electro-magnets to strength the polarity and aid the pull of the permanent magnets on the diaphragm while the current flows in one direction.

But when it reverses, the magnetism of the coils opposes that of the permanent magnet and weakens it, thus making a considerable variation in pull on the diaphragm.

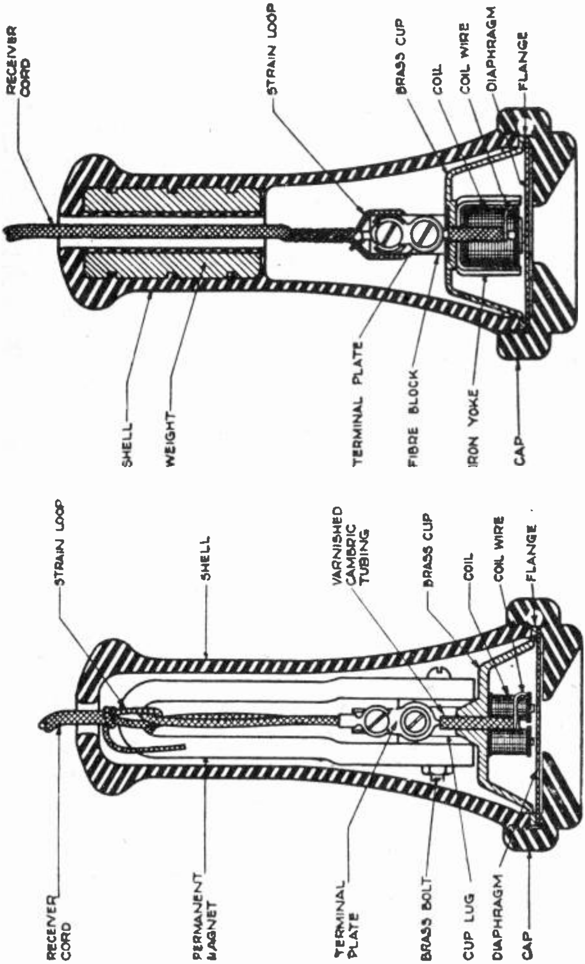


Fig. 10. Two sectional views showing the construction and parts of two types of telephone receivers. Examine all the parts carefully and note the names of each. The receiver on the right has a lead weight at the top of the shell to make it heavy enough to operate the hook switch, which will be explained later.

The coils of the receiver electro-magnets are usually wound with many turns of very fine wire, and if these coils are bruised or scratched it often breaks one or more turns of the wire and stops the operation of the receiver.

Some of the other more common receiver troubles are as follows: Loose end cap, allowing diaphragm to fall away from magnets; bent diaphragm, weak permanent magnet, loose cord connections, or

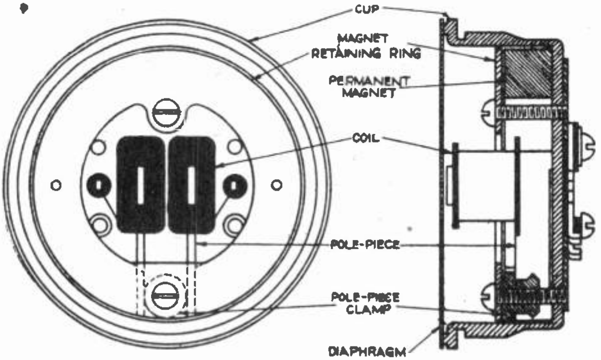


Fig. 11. Sectional view and front view of watch case receiver, such as used on telephone operators' head sets.

broken receiver cord. The wires in these cords often become broken inside the insulation, from twisting and kinking, or from rough handling and dropping of receivers.

Testing with a dry cell, first at the cord tips, then at the receiver terminals, and listening for a click at the diaphragm as the circuit is made and broken, will easily disclose this trouble.

Another type of receiver, often called a "watch case" type, is shown in Fig. 11. These small receivers are used in head sets for telephone operators, and are very similar to those used by radio operators.

Their construction is much the same as the larger ones, except that they are much lighter in weight and have the permanent magnet in more of a circular shape.

8. HOOK SWITCH

The receiver is hung on a spring hook when not in use, and this hook operates a switch to disconnect the talking circuit and place the ringing circuit in readiness for the next call. This is called a **Hook Switch.**

By disconnecting the talking circuit, it saves wasting the battery current when the 'phone is not in use. It also disconnects the bell circuit when the 'phone is in use, and thus prevents the bell from being rung while parties are talking. Having this switch operated by the receiver makes it automatic, as the party naturally removes and replaces the receiver when starting and finishing the conversation.

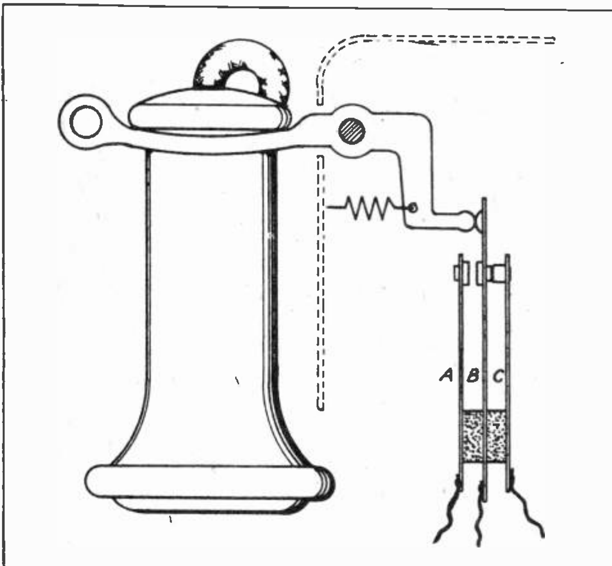


Fig. 12. Sketch showing the principle of a simple "receiver hook switch." Note what the operation of the spring contacts would be if the receiver was raised and lowered.

Fig. 12 shows a very simple type of hook switch. While the receiver is on the hook, the hook is held down, and the end of the hook lever presses against the center contact of the switch, keeping it in contact with the spring "C." This closes the ringing circuit.

When the receiver is removed from the hook, the spring causes the hook to raise and the end of the hook lever to move to the left, allowing the center spring to make contact with "A" and close the talking circuit. It also opens the ringing circuit at the same time.

There are a number of different types of hook switches, but the principle of all of them is very similar and easy to understand.

If the contacts of a hook switch become burned or dirty, or if the contact springs become bent out of shape, it is likely to cause faulty operation of the talking and ringing circuits.

9. BATTERIES AND CURRENT SUPPLY

Telephones require, for the successful operation of their talking circuits, direct current supply of a very "smooth" or constant voltage value. This is because we do not want any variations in the current, except those made by the transmitter and sound waves.

In small private telephone systems and rural lines, dry cell batteries are often used, and in many cases each 'phone has its own battery.

Large telephone systems for city service use storage batteries or D. C. generators for talking current supply. Generators for this use have special windings and commutators for providing "smooth" D. C., as even the slight sparking and variations of voltage at the commutator of an ordinary power generator would produce a disturbing hum in the 'phone receivers.

Rural line telephones often use a hand-operated magneto to supply current to ring the bells, and some small exchanges do also. However, most exchanges use a generator to produce alternating current or pulsating direct current, for the operators to ring the various parties by merely closing a key switch.

10. INDUCTION COIL

As mentioned before, most telephones that are to be used on lines of any great length use an induction coil. The purpose of this coil is to act like a transformer and **increase the voltage** of the impulses in the talking circuit, so they can be **trans-**

mitted over long lines with less loss.

When the transformer "steps up" the voltage, it

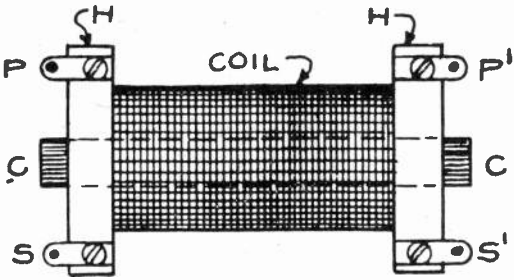


Fig. 13. This sketch shows the construction of the windings and core of a telephone induction coil.

reduces the current in the same proportion, and the less current we have to send through the resistance of any line, the less loss we will have. By briefly recalling your study of Ohms Law and voltage drop principles, this should be quite easily understood.

Induction coils have a primary and secondary winding around a core of soft iron, and when the current impulses are sent through the primary, corresponding impulses of higher voltage are set up in the secondary by magnetic induction. Thus the name, "induction coil."

Fig. 13 shows a sketch of an induction coil. "C" and "C" show the ends of a core which is made of a bundle of soft iron wires. "H" and "H" are ends or "heads" to support the coil on the core. "P" and "P-1" are the terminals of the primary winding. "S" and "S-1" are the terminals of the secondary winding.

The primary winding should be connected in the transmitter and battery circuit. The secondary winding connects to the receiver and line circuit. These connections will be shown a little later, in a diagram of a complete telephone circuit.

Fig. 14 shows a single, and also a double induction coil. Fig. 15 shows a sketch of the coils, core, and terminals of the induction coils as they are often shown in connection diagrams.

We recall from an earlier section on transformer principles, that transformers will not operate on ordinary direct current, but in the case of this telephone induction coil, the current from the battery is caused to pulsate or increase and decrease rapidly, by the action of the transmitter.

These variations in the talking current cause the flux of the primary coil to expand and contract, and induce the higher voltage impulses in the secondary.

11. TELEPHONE BELLS

While some telephones in small private systems

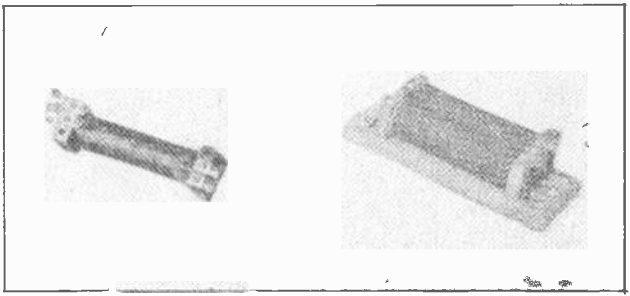


Fig. 14. On the left is shown a single induction coil with the terminal connections plainly visible. On the right is shown a pair of coils mounted on one base.

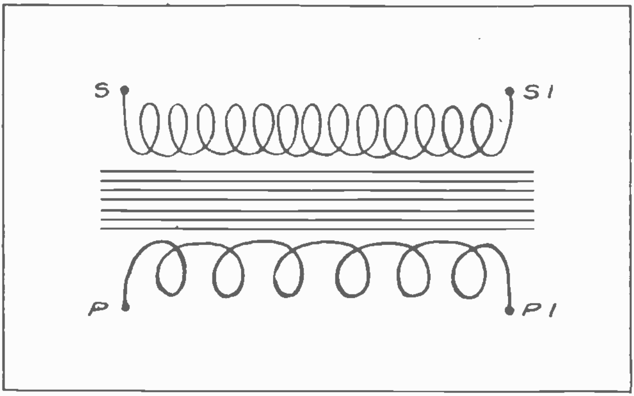


Fig. 15. The primary and secondary windings and core of an induction coil are often shown in the above manner in electrical diagrams.

use ordinary vibrating bells, the more common 'phones in general use in public systems use a

Polarized bell, which operates on **alternating current.**

These bells have two electro-magnets and an armature, which is a permanent magnet; and two gongs instead of one, as in the case of the vibrating bell.

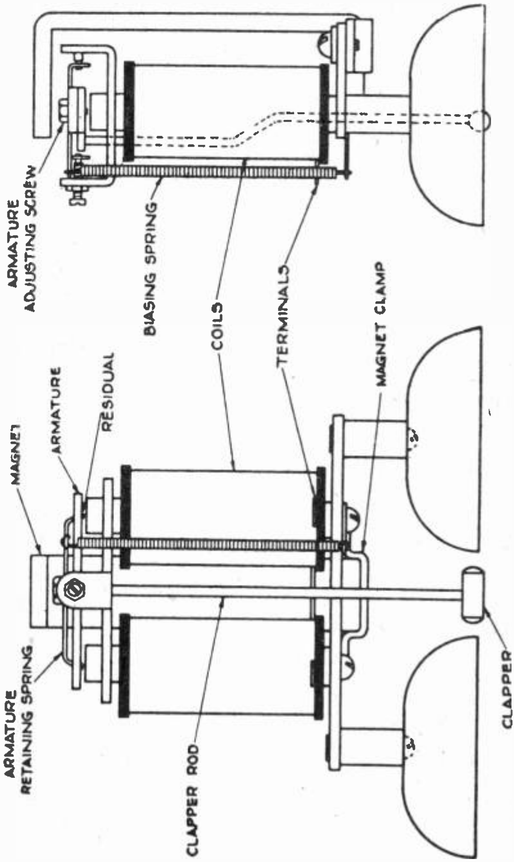


Fig. 16. Front and side views of a polarized telephone bell. Note the end of the permanent magnet, which is used to magnetize the armature by induction. Also note the biasing spring attached to one end of the armature.

Fig. 16 shows two views of this type of telephone bell.

In some cases, instead of the armature itself being a permanent magnet, a larger permanent magnet is mounted behind the bell coils and with one end close enough to the armature to maintain induced poles in it.

The coils of these bells are usually wound with many turns of very fine wire, and are designed to operate on very small amounts of current at rather high voltage, which makes them economical to operate on long lines.

The operating principle of the polarized bell can be easily understood by referring to Fig. 17. You will note that when current flows through the coils in one direction it sets up poles on the electro-magnets, which attract one end of the armature and repel the other, causing the hammer to strike the left gong as in Fig. 17-A.

Then, if we reverse the current as in "B," this reverses the poles of both electro-magnets, causing them to attract and repel opposite ends of the armature to what they did before. This makes the hammer strike the right-hand gong.

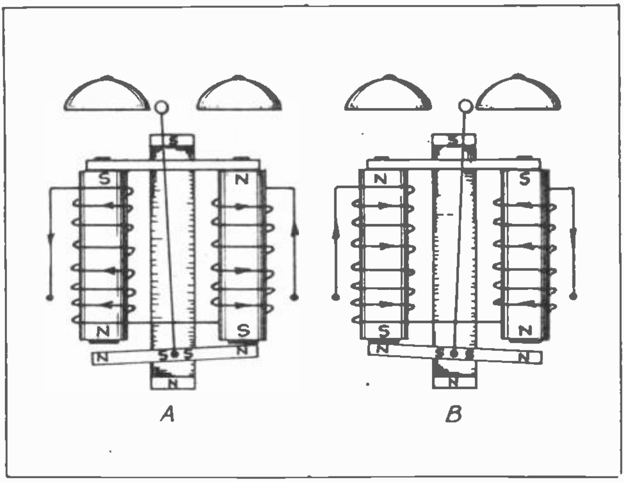


Fig. 17. These sketches show the electrical circuit of a polarized telephone bell. Note the polarity and position of the armature in "A," and again in "B," after the current has been reversed.

Then, if we supply alternating current from a magneto or central generator, it will cause the coils to rapidly reverse and operate the hammer at the same frequency as that of the current supply.

Check carefully the polarity of the permanent magnet, the movable armature, and the electro-magnets in both bells in Fig. 17.

12. BIASED POLARIZED BELLS FOR PULSATING D. C. OPERATION

Sometimes these polarized bells are equipped

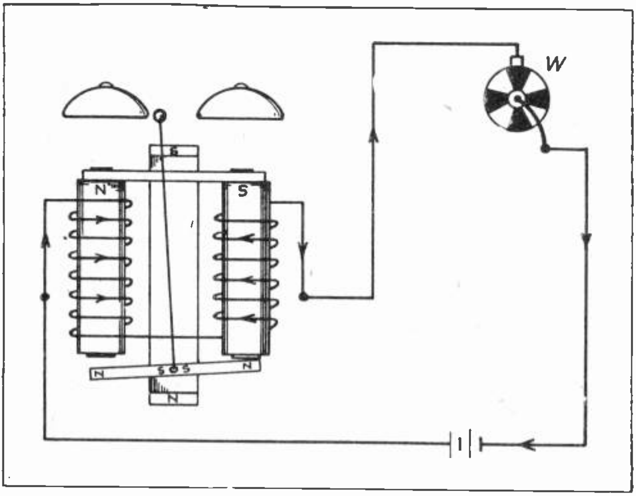


Fig. 18. This sketch shows how a "pulsator" or interruptor can be used to supply pulsating current from a battery and for the operation of telephone bells.

with a Biasing spring attached to their armature. This spring can be noted in Fig. 16. It enables the bell to be operated on pulsating direct current, which is sometimes used by the operators at central stations for ringing various parties on the line.

In such cases a rotary pulsating switch is used in the battery circuit to provide the interruptions in the current. The biasing spring normally holds the hammer against one of the gongs when the bell is idle. When current is sent through the coils in the proper direction, the electro-magnets will attract and repel the proper ends of the armature, to cause the hammer to strike the other gong.

When the current is interrupted, the spring draws the armature and hammer back again, striking the first gong once more. This will be repeated as long as the pulsating current flows. See Fig. 18. The pulsating wheel "W" has alternate sections of metal and insulation, so as it is rotated it rapidly makes and breaks the circuit of the battery and bell.

Fig. 19 shows a very good view of a telephone bell with the gongs removed.

13. POLARIZED BELL WITH PERMANENT MAGNET ARMATURE

Another type of polarized bell used in some telephones, has both coils wound in the same direction and uses the permanent magnet for an armature. See Fig. 20.

In these bells the armature has unlike poles at opposite ends, so in order for one of the electromagnets to attract and the other to repel, they must have like poles. When alternating current is passed through this bell, the polarity of both electro-magnets changes at the same time. This causes attraction of first one end of the armature, and then the other.

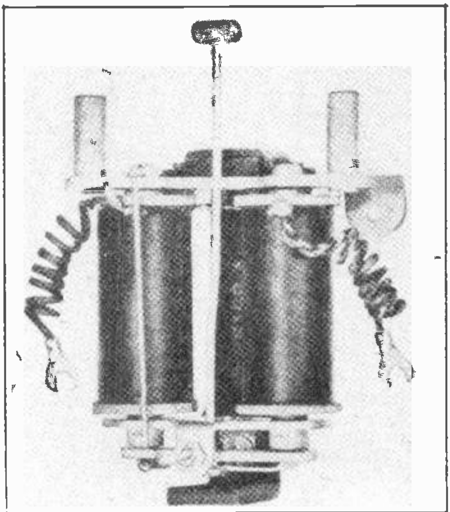


Fig. 19. Photograph of coils, armature, and hammer of a common telephone bell.

Observe carefully the direction of current and polarities of the magnets in both bells "A" and "B" in this figure.

When telephone bells fail to operate, the trouble can usually be found in a loose connection, broken coil lead, weak permanent magnet, loose gongs, or magnet cores loose on keeper or frame.

14. TELEPHONE MAGNETOS

As mentioned before, rural lines often use magnetos at each 'phone for the subscriber to ring any other party on that line, and also to call the central operator. These magnetos, when operated by the hand crank at normal speed, produce alternating current at fairly high voltage, usually from about 80 to 100 volts, and at a frequency of about 20 cycles.

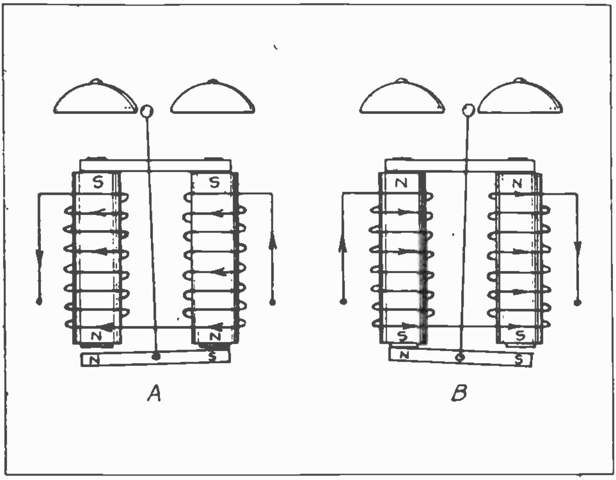


Fig. 20. This sketch shows the construction and windings of another type of polarized bell, which uses a permanent magnet for its armature. Note the polarity and position of armature at "A," and again at "B," after the current has been reversed.

Fig. 21 shows a sketch of a magneto of this type. The armature is usually of the shuttle type with just two large slots in which are wound many turns of very fine wire. It is located in the base of the magneto between the poles of several large horseshoe magnets.

The magnets supply the magnetic flux which is cut by the armature winding to generate the voltage. The armature is revolved quite rapidly by means of a large gear on the hand crank shaft, and small pinion on the armature shaft.

The crank shaft shown at "O" is equipped with a slotted extension and spring which pushes out against the contact spring "N" each time the crank is turned. This operates a sort of "shunt" switch.

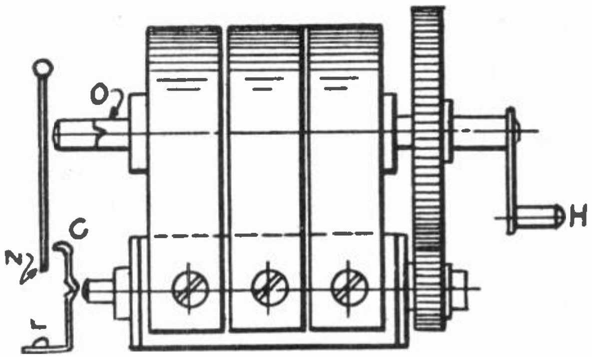


Fig. 21. Diagram of telephone magneto showing shaft extension which operates contact springs.

When the magneto is idle this spring falls back, touching contact "C," and shunts out the magneto winding from the line circuit, so the talking current does not have to pass through this resistance.

When the crank is turned the shaft is forced out a small distance and opens these contacts, allowing the magneto current to flow to the line and bells. One end of the armature winding is usually grounded to the shaft, and the other end is insulated and carried out through the center of the shaft, which is hollow. This end or tip of the shaft is in contact with the small spring as the shaft rotates.

Fig. 22 shows two photos of telephone magnetos. The one at the right is equipped with a hand crank for use in a subscriber's telephone. The one at the left is equipped with an extension shaft such as used by central operators in some of the small exchanges.

Some exchanges use a power-driven magneto, having it operated continuously by a small motor.

In this case it is only necessary for the operator to close a key or switch to ring the party being called.

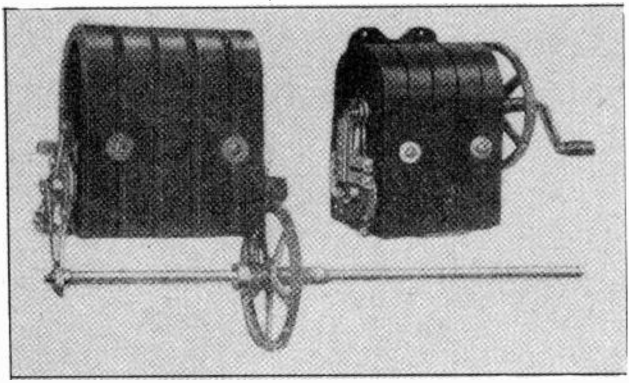


Fig. 22. These photos show two telephone magnetos. The one on the left for use in a small exchange, and the one on the right for a subscriber's telephone.

In Fig. 22 the spring contacts operated by the magneto shaft are quite clearly shown.

The permanent magnets in these magnetos often become weak after a certain age and need to be remagnetized or replaced. Sometimes a little oil and dirt collects on the contact springs, causing them to fail to make good connections; or they may become bent or worn so they do not make proper contact.

EXPERIMENTS

A simple experiment to prove the operating principle of the telephone may be performed as shown by Fig. 3. This experiment requires only one transmitter and one receiver, but if you have an additional telephone or Radio receiver and an extra transmitter you will find the jobs suggested by Figs. 4 and 5 to be very interesting.

EXAMINATION QUESTIONS

1. What is the frequency range of audible sound?

2. At what speed do sound waves travel?

3. At what speed does electricity travel?

4. What kind of bells are usually used on telephones? Why?

5. What kind of current does the telephone magneto supply?

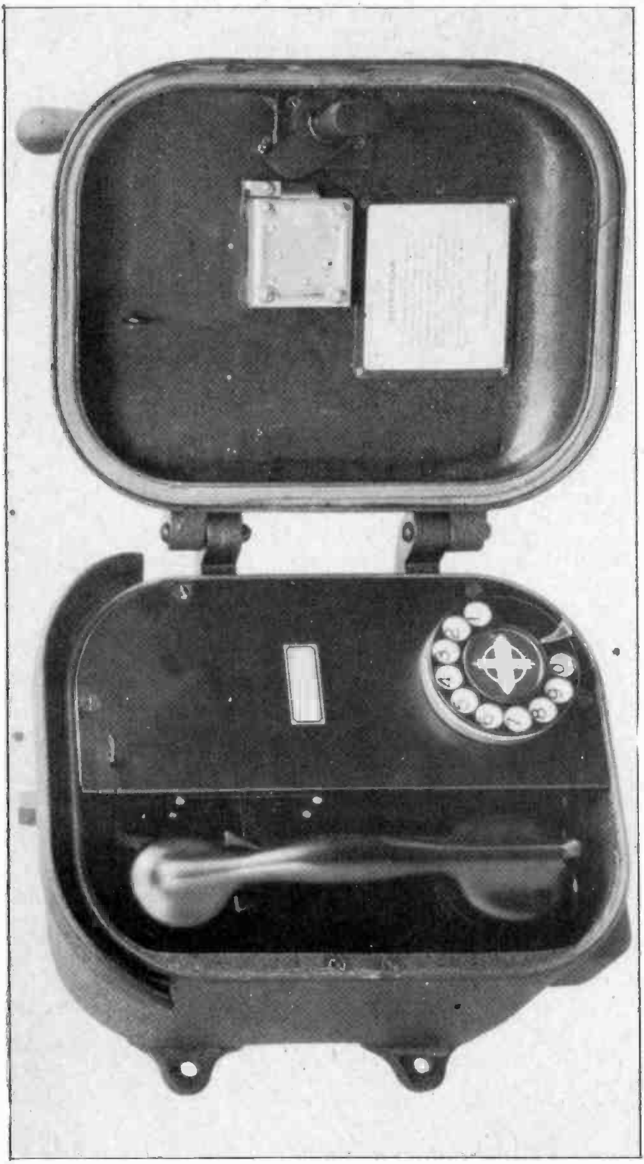
6. For what purpose is the magneto current used on a telephone?

7. Why are induction coils used in telephones?

8. What kind of current should be used in the talking circuit?

9. Name two important parts of the transmitter.

10. What happens to the resistance of the telephone circuit when sound waves strike the diaphragm of the transmitter?



This photo shows the latest type of outdoor MONOPHONE. Rugged equipment of this type is used in mines and other places where a communications system must be maintained both in and out of the buildings.

TELEPHONE CIRCUITS

Now that you understand the function and operation of the important parts of a telephone, let's see how they all work together in the complete 'phone.

Fig. 1 shows a common type of party line telephone used on rural lines and in small towns.

The view on the left shows the box closed, and the location of the receiver, transmitter, and bell gongs. On the right the box is opened up, showing the battery and magneto, hook switch in the upper left corner, and bell magnets on the door. The induction coil is not visible in this picture.

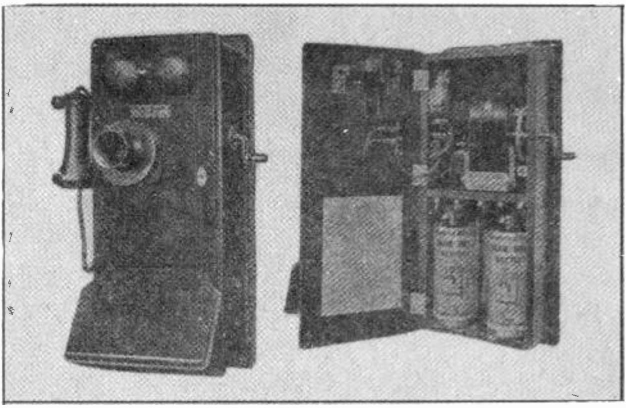


Fig. 1. Common type of party line telephone used on rural lines. This telephone is complete with its own batteries and magneto.

You will note that this 'phone is complete with all necessary parts, and has its own current supply for both talking and ringing circuits.

Two or more telephones of this type can be connected in parallel on a line, and if desired can be operated without any central exchange or any other equipment.

Any party can ring any other party by a system of different calls, arranged in combination of short and long rings, similar to dots and dashes.

Party lines with a number of these 'phones can also be run to a central office, and from there they can be connected to any other line on the entire system. This is the purpose and function of a central office or telephone exchange. It is practical to have on one line only a certain limited number of 'phones, as otherwise the line would always be busy. The service would be very poor because only two subscribers can use the line at one time. On rural lines the number of parties may be from ten to twenty per line. In cities, there may be two, four, or six parties per line.

When a subscriber on one line wishes to talk to someone on another line, he or she signals the central operator, who can, by means of switches and plugs, connect the **Calling Line** to the one called and then ring the party desired on the **Called Line.** The equipment and operation of exchanges is covered later.

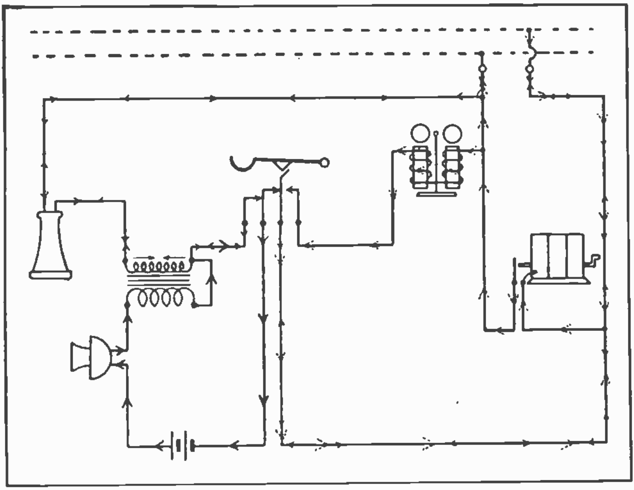


Fig. 2. Diagram showing connections and circuits of a telephone such as shown in Fig. 1.

Fig. 2 shows a complete diagram of the electrical circuit and connections of a telephone of the type shown in Fig. 1. Here we can see the relation of each part to the others and get a clearer idea of how they all operate together.

Trace out this circuit very carefully until you are sure you clearly understand its entire operation.

The receiver is shown off the hook and the hook is raised, allowing the main contact spring to move to the left and close the two contacts on that side, completing the talking and line circuit. The large arrows show where the current flows from the local battery, through the transmitter, induction coil primary, hook switch contacts, and back to the battery.

When the party talks into the transmitter, this local current is caused to pulsate and sets up induced impulses of higher voltage but smaller current, in the secondary coil, receiver and line circuit. This is shown in the small arrows. You will remember that this current induced in the secondary coil and in the receiver circuit is alternating and rapidly reverses, so we show the arrows both ways. It also flows a short distance through one of the same wires with the battery current, but this does no harm.

The magneto is shown here in idle position, so its spring contact is open and keeps the magneto winding out of the ringing and line circuit at present. When the magneto is operated, the shaft pushes out and closes the circuit, and sends current through the bell and also out on the line to the other bells.

In order to ring anyone, the receiver must be on the hook, keeping the hook down and holding the main spring or line contact to the right and in contact with the spring on that side. The ringing current then flows as shown by the dotted arrows.

Fig. 3 shows another telephone circuit, using a hook switch with only three spring contacts instead of four, and a magneto with three contacts instead of one or two. Compare this diagram carefully with Fig. 2. Here again the large arrows show the transmitter and local battery circuit; the small arrows, the receiver and line circuit; and the dotted arrows, the ringing circuit.

You will note that this hook switch does not make and break the ringing circuit as the one did in Fig. 2. Here the ringing circuit is controlled by the magneto springs. When the magneto is idle, the long center spring presses to the right,

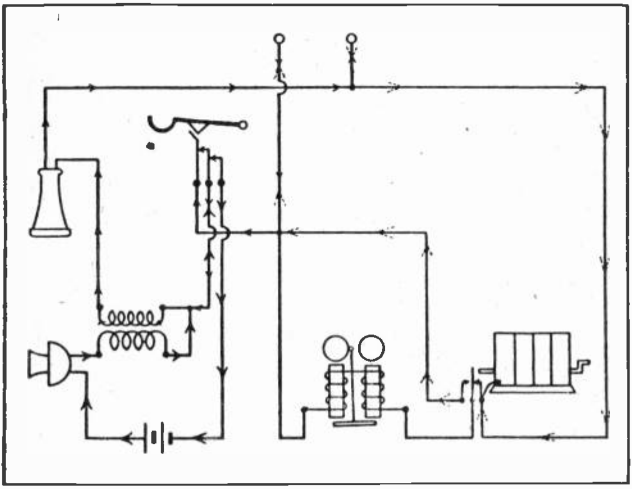


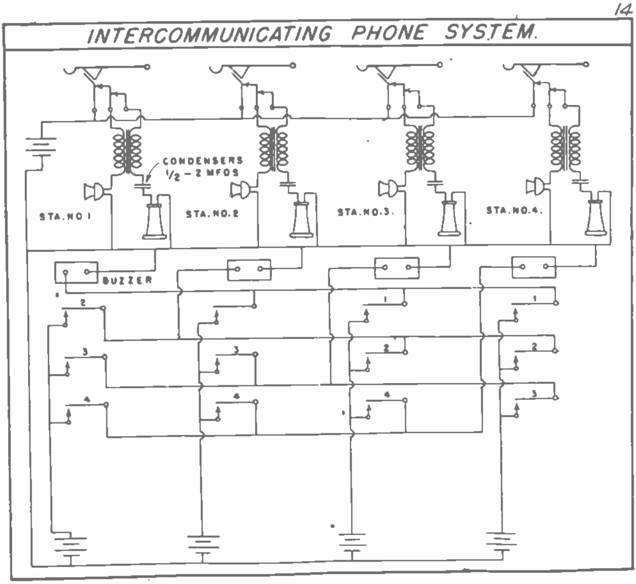
Fig. 3. Circuit diagram of another telephone using a different hook switch and set of magneto contacts. Trace the circuit carefully and observe its operation.

keeping the bell connected to the line, ready to receive an incoming call. When the magneto crank is turned it forces the shaft outward and pushes the center spring to the left. This short-circuits the bell and makes a connection direct to the line to ring outside bells. In this type of 'phone the subscriber's own bell does not ring when the magneto is operated.

There are a number of different ways to arrange party line telephone circuits, hook switches, magneto contacts, etc.; but if you have a good understanding of these fundamental circuits and the operation and purpose of these important parts, you should have no difficulty understanding any 'phone circuit after tracing out its wiring or diagram.

The electrical technician may occasionally be required to install some kind of intercommunicating system, and the above shows an arrangement of battery operated phones that could be used for this purpose. Although the diagram shows a system with four stations, it is evident that a comparable arrangement of equipment could be used for a greater or lesser number of phones.

14



With the arrangement shown, the person at any station may call any other station by merely pressing the appropriate switch; this action operates the buzzer at the called station. When the receivers are lifted, the phones are connected as shown in the diagram, for the hook switches open all transmitting and receiving circuits when they are down. Examination of the sketch shows that a person at any station can call and talk to any or all other stations.

This type of system is usually operated from dry cells, two number 6 cells being used in each battery. The small condensers (one-half to two microfarad in capacity) are used to prevent direct current from the phone battery flowing in the receiver circuit.

2. CENTRAL ENERGY SYSTEMS AND 'PHONES

In large city telephone systems a central source of current supply is generally used for both the talking and ringing. In such systems the subscriber's 'phone does not need a battery or magneto.

The hook switch and circuit are so arranged that as soon as the receiver is removed from the hook, it closes a circuit and lights a small lamp on the exchange operator's switchboard.

The operator then plugs her 'phone onto this calling line and closes her key so the caller can give her the number desired. Then, if the called line is not busy, the operator connects the calling line to it and rings the party to be called.

A simple circuit for a telephone of this type is shown in Fig. 4. Keep in mind, when tracing this circuit, that the current supply comes in on the line from the exchange.

You will note that a condenser is used here to prevent the direct current for the transmitter circuit from passing through the bell or receiver circuits.

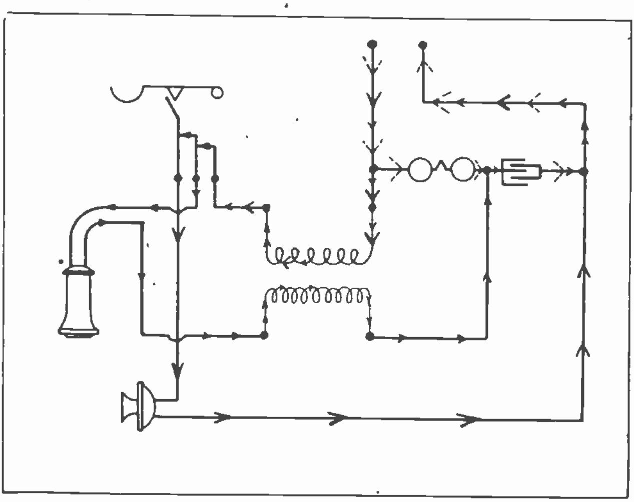


Fig. 4. Wiring diagram for a simple telephone to be used on a central energy system. This telephone gets all the energy from the line and central supply.

A condenser will pass or allow alternating current or pulsating direct current to flow in the circuit, but it blocks or stops ordinary direct current.

The "talking current," shown by the large arrows, comes in on the left line wire and passes through the induction coil primary, hook switch, transmitter, and back out on the right line wire. When the party is talking, the induced current in the secondary coil, shown by small arrows, flows out through the condenser and right line wire, to the receiver of the operator or called party; and back in the left line wire, through the primary coil, hook switch and subscriber's own receiver, and returns to the secondary coil. In tracing the receiver and line circuit, consider the secondary coil as the source of this energy.

A different symbol is used here for the bell, as it is simpler to draw and easier to recognize once you are acquainted with it.

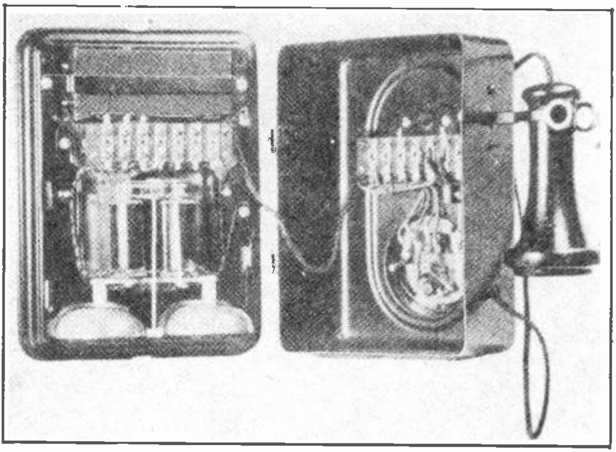


Fig. 5. Photograph of wall type telephone for central energy systems.

Fig. 5 shows a complete telephone of this type, for wall mounting. The bell, condenser and coil are mounted in the box, while the receiver is on the usual hook on the side, and the back of the transmitter can be seen in the front of the open cover.

Note the terminal blocks to which all connections are brought and numbered, making it easy to connect up or test the telephone.

Fig. 6 shows another telephone of the central energy type, for use on a desk. This desk-type 'phone has the receiver and transmitter mounted on a separate stand for convenient use on the desk; while the bell, coil and condenser are in a separate box mounted on the desk or at some nearby location.

The hook switch is inside the upright handle of the stand.

3. TELEPHONE EXCHANGES

As already mentioned, the telephone exchange serves to connect telephones of one line to those of other lines, and there are thousands of these central

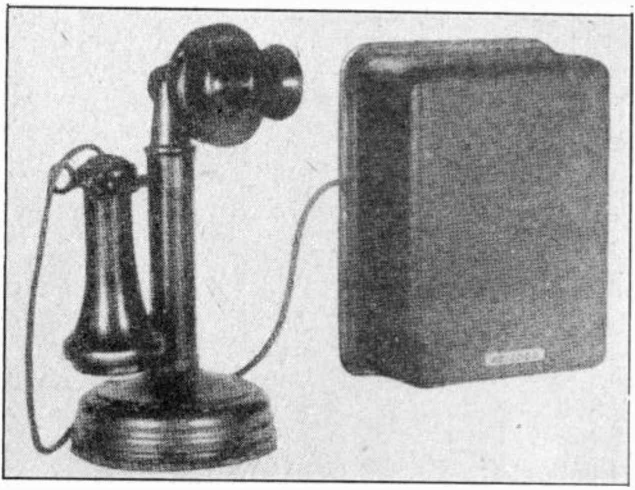


Fig. 6. Common desk type telephone with bell box to be mounted separately.

exchanges throughout this country, to handle the many millions of telephones in use.

The exchange in the small town handles the calls of the subscribers in the town, those of rural lines calling in to city 'phones, and those of one rural line calling through to another line, perhaps running out of town in the opposite direction. Thus this exchange serves the 'phones in that town and surrounding territory. Then it has its **Trunk Lines** connecting to exchanges of other cities, and can complete a circuit for one of its own subscribers, through the exchange of another town several hundred or even several thousand miles away.

This vast network requires many types of elaborate exchange circuits, which it is not our purpose to cover here, as they represent a very highly specialized type of work. They also require much more time than the average electrician cares to spend on such circuits, unless he intends to specialize in telephone work. But, in order to give you a better understanding of the general operation of the exchange in connection with the 'phones we all use daily, and also to give you a good foundation to work from in case you should later specialize in such work, we will cover in the following material some of the fundamental parts and principles of exchanges.

Telephone exchanges are of two general types, namely, manual and automatic.

The general function of either type is to receive a signal from the calling subscriber, and get a connection and ring his party on any other line as quickly as possible.

With the manual exchange, the plugging, switching and ringing operations are performed by human operators, usually girls. With the automatic exchange these operations are performed by electrical and mechanical equipment.

4. SWITCHBOARDS FOR MANUAL OPERATION

Fig. 7 shows a manual exchange or switchboard, for handling one hundred lines. These lines are brought up to **Jacks** on the upright part of the board.

On the flat, desk-like, part of the board is a set of **Plugs,** attached to **Cords** beneath, and also a set of **Key Switches.** Directly above each jack is a **Drop** similar to an annunciator drop.

When a subscriber on any line signals the operator, the little drop window or shutter for his line falls down, showing the operator that someone on that line is calling. There are two plugs in front of that line, one for talking and one for ringing.

The operator lifts the talking plug and inserts it in the line jack opening. Then, by pressing her key in one direction, she can answer the **Calling**

Party and receive the number he wishes to call.

If the line of the party desired is not busy, the

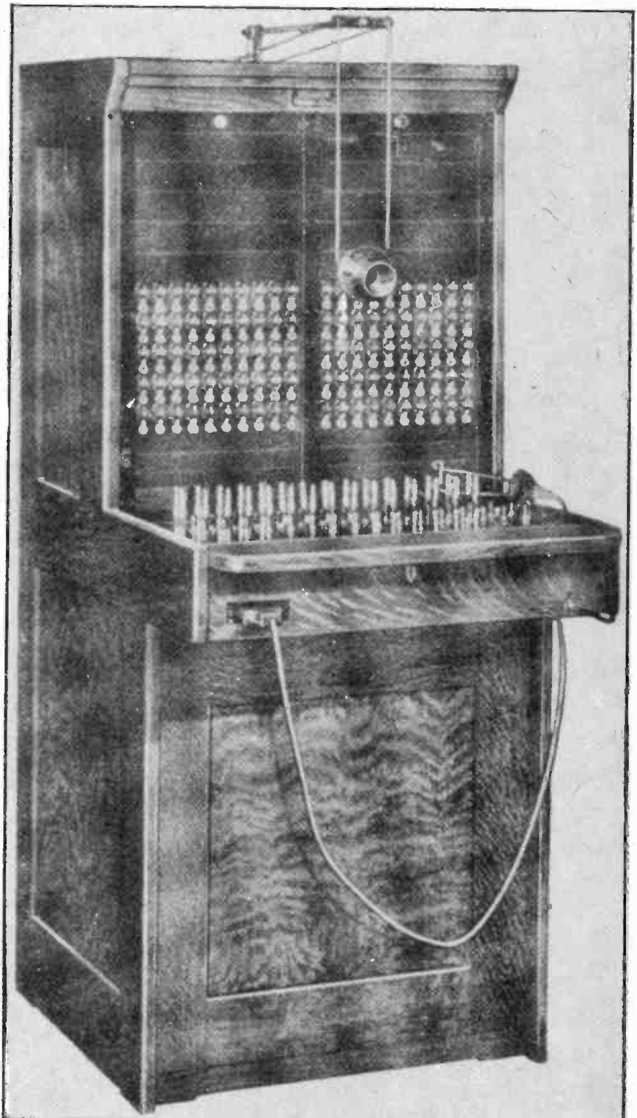


Fig. 7. A small exchange switchboard of the magneto type, showing plugs, jacks, and the operator's transmitter and receiver.

operator then lifts the other plug in line with the first one, and places it in the jack of the "called" line. Then, by pushing the key in the other direction, she can ring the party desired.

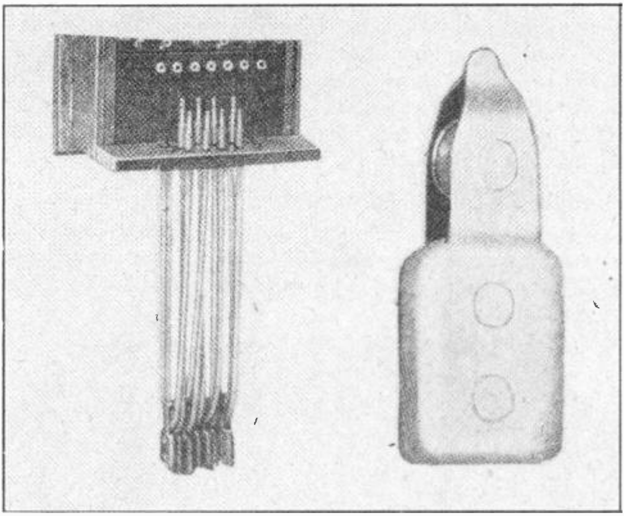


Fig. 8. The view on the left shows the manner in which the plug cords are held straight by the weighted pulleys. A larger view of one of these pulleys is shown on the right.

By pushing the key back to the listening position again, the operator can hear the party answer. When he does, she can release the key to vertical or neutral position. The parties then carry on their conversation through the wires in the cords.

The cords are equipped with very flexible wires, and have weights on little pulleys as shown in the left view in Fig. 8. At the right is shown a large view of the pulley and weight. These weights keep the cords straight and pull them down again each time the plugs are dropped to idle position.

The operator's head-set is shown lying on the keyboard in Fig. 7, and the transmitter is shown on an adjustable arm and cord in front of the board.

Fig. 9 shows a closer view of the keys, plugs, and jacks of a board of this type. The key switches are shown in the foreground, and directly behind these and indicated by the arrow is a row of small lamps to show the condition of the circuit to the operator. Behind the lamps are the plugs, and above are the plug jacks and drops.

5. KEY SWITCHES

A very good view of two switchboard keys is shown in Fig. 10. The levers or key handles can be pushed in either direction, and their lower ends have rollers or cams that push and operate a set of spring contacts on either side, depending on which way they are pushed. Examine these switches and all their parts carefully.

6. SWITCHBOARD LAMPS

Fig. 11 shows a special type of lamp used for switchboard signals, and also two of the glass caps or "bull's-eyes" that are used over the ends of the lamps.

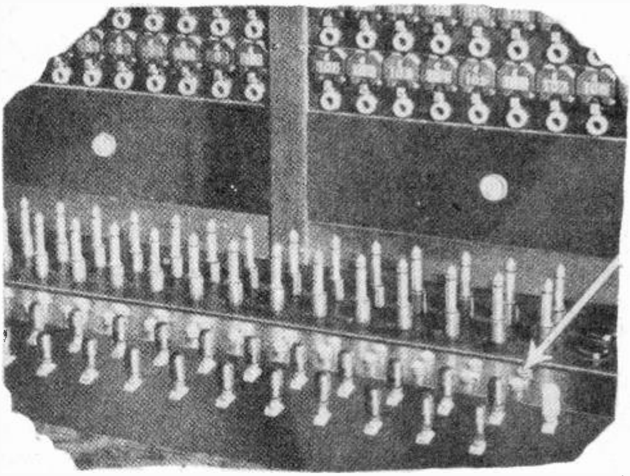


Fig. 9. This photo shows very clearly the arrangement of the operator's key switch, plugs, and jacks.

These lamps are made **very small in order to get them in the small spaces on the boards.** The actual size is only about one-fourth that of the photo in this figure. The bulb is held in the two metal clips shown on the top and bottom, and these are separated at the base by a piece of hard insulation. The lamps are pushed into their sockets endwise, and these metal strips make the contacts to complete the lamp circuit. The forward end of the lamp is all that shows in the opening they are placed in.

The bull's-eyes are made in white and various other colors to indicate various circuit conditions.

7. PLUGS

Fig. 13 shows a cord plug. These plugs can be made with two, three, or more separate metal ele-

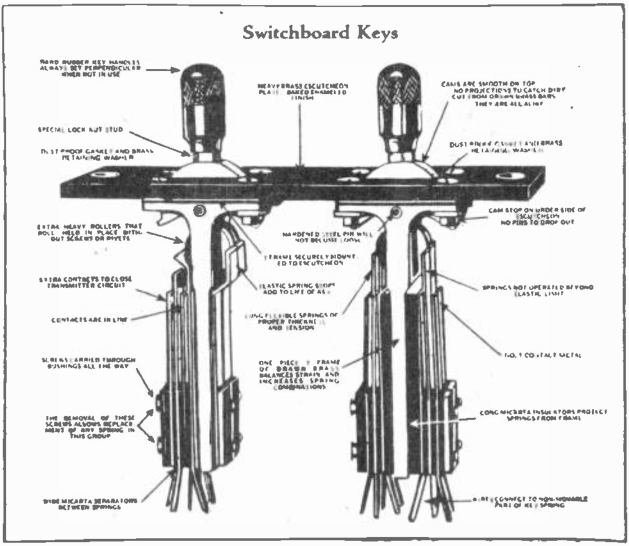


Fig. 10. Here we have an excellent view of two key switches, showing how the key levers and rollers operate the spring contacts, and open and close various circuits.

ments for as many separate circuits through them. The plug tip at the extreme right end is part of a small metal rod which runs through the center of the plug to the left end, where the wires are attached. Around this is placed a tube of insulating material. Then another slightly larger, but shorter, metal sleve is fitted over this. Still another tube of insulation, and a third metal element are often fitted over the first ones, and then an outer shell of insulation over the whole.

The several separate metal elements and ends of the black insulating sleeves can be seen in Fig. 13, which is an actual size view.

When these plugs are inserted in the jacks, the various jack springs make contact separately with each of the plug elements and circuits.

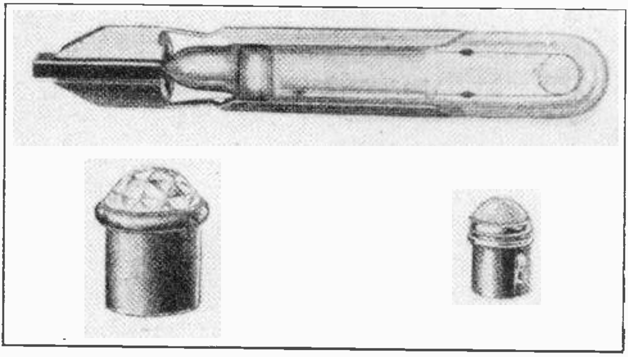


Fig. 11. The upper view shows one of the special telephone switchboard lamps, and below are shown two types of glass caps, or bull's-eyes used with such lamps.

8. JACKS AND DROPS

A complete jack, with the drop and drop magnet counted above it, is shown in Fig. 14. This view clearly shows the jack thimble, contact springs, wire terminals, drop magnet, armature, and shutter. Examine the photo and printed description very carefully.

Note that the armature to operate the drop is at the left end of the drop magnet, hinged at the top, and attached to a long lever arm which runs over the top of the magnet to the drop latch at the right end. This construction enables a very small movement of the armature to give a greater movement at the drop latch.

The plug would be inserted from the right in the thimble at the lower right-hand corner; and as it goes in, its tip and sleeve elements make contact with the spring shown. It forces some of the springs apart, opening certain circuits, and closes others from the springs to the cord wires.

Fig. 15 shows two diagrams of jack and drop circuits from opposite sides, one without the plug and one with the plug.

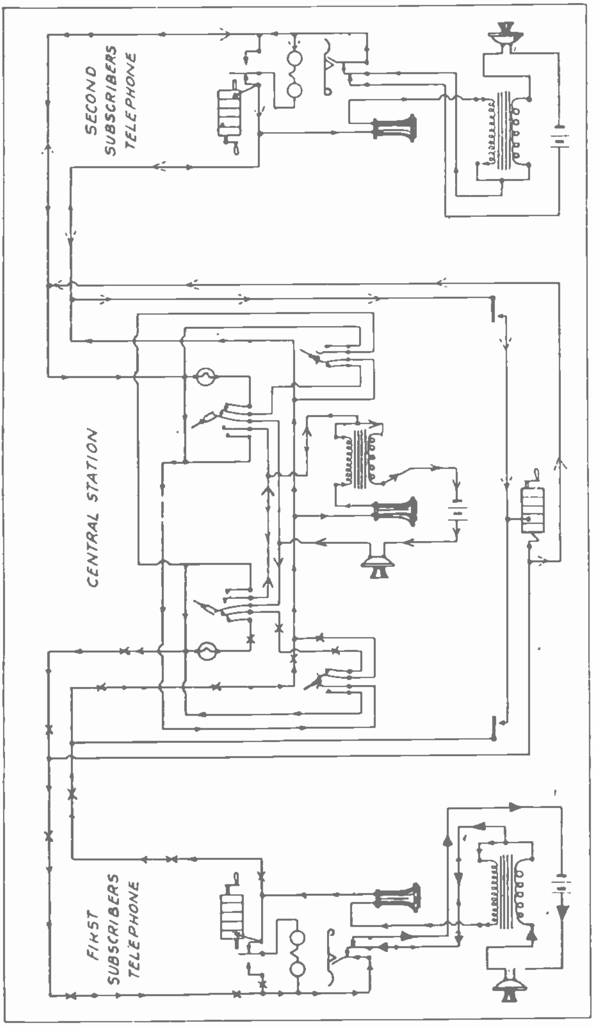


Fig. 12. Complete diagram of a simple telephone exchange with two subscribers' telephones connected. This will enable you to trace the talking and ringing circuits which are marked with different forms of arrows and symbols. Carefully tracing this diagram will help you to understand telephone exchange principles more fully.

In the upper diagram you will note that springs 3 and 4 are making contact, also springs 5 and 6. Springs 5 and 6 close a circuit from the line through the drop magnet.

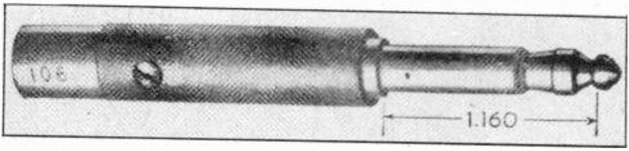


Fig. 13. Full-sized view of a switchboard plug showing how the several circuits are obtained through its tip and insulated sleeves.

In the lower view, showing the plug inserted, we find that springs 5 and 6 have been opened, breaking the circuit through the drop magnet, as it is not needed while the plug is in. Springs 3 and 4 are also opened. This is done by an insulating piece which is not shown here, but fastens 5 and 3 together mechanically, so the upward movement of 5 also forces 3 up. Springs 3 and 4 are not shown connected to any circuit in this illustration.

Referring again to the lower view, we find that the plug has a circuit to its tip and sleeve from

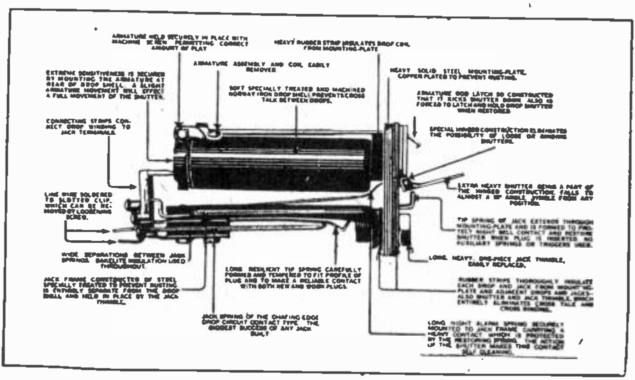


Fig. 14. This descriptive diagram shows the parts of a telephone jack and drop complete. Examine each part and its description very carefully.

spring 5 and thimble 7, thus making a circuit from the line to the cord wires.

9. SIMPLE SWITCHBOARD CONNECTIONS

A sectional view of part of a switchboard is shown in Fig. 16. This shows the line connection to a simple jack and drop of the separated type; and also the plug, cord, and switch connections.

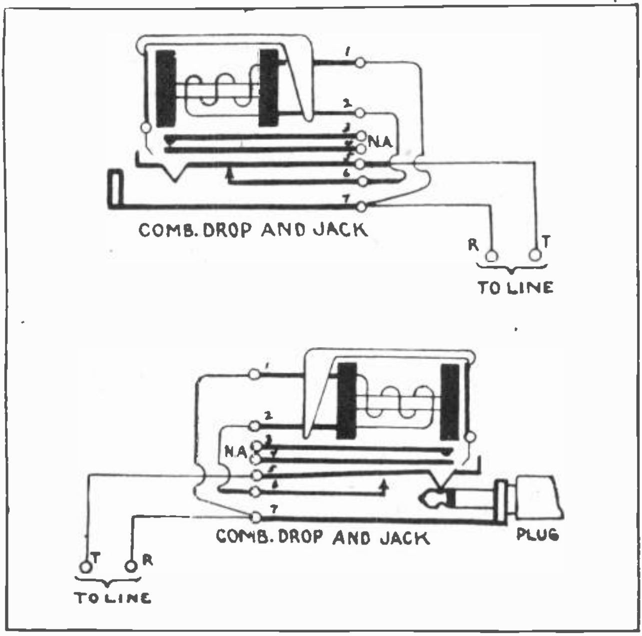


Fig. 15. The upper sketch shows the electrical connections and position of contact springs without the plug inserted. Below are shown the electrical circuit and position of springs with the plug in the jack.

When an impulse comes in on the line, the drop magnet releases the shutter, the operator inserts one plug and closes her key to listening position. After receiving the number she inserts the other plug in the jack of the called line (not shown) and pushes key to ringing position, sending current from the board magneto to ring the called party. When this party answers, the talking current from the two lines flows through the jacks, plugs, cords, and key switch. When the conversation is finished, the plugs are pulled and dropped to their present positions in the diagram, the drop reset, and the key restored to normal position.

Fig. 17 shows a switchboard with some of the cords in place in the jacks for conversations between various lines.

Many large switchboards use only the signal lamps to indicate an incoming call, and do not use the magnetic drops.

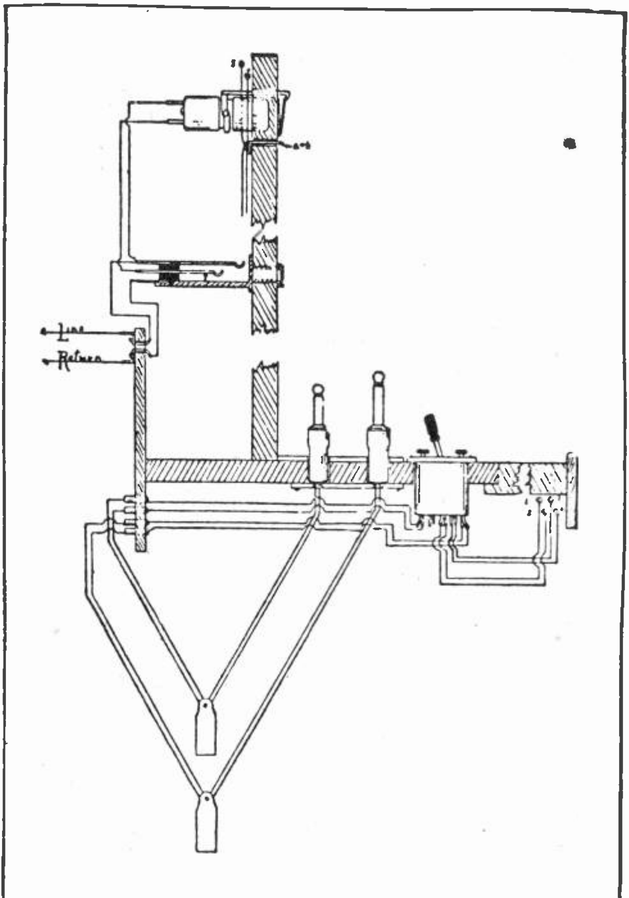


Fig. 16. This simple sketch shows the general operating principle of a manual switchboard.

Fig. 18 shows two views of the inside and back of a manual switchboard. In the left view you can see the drop magnets in the upper section, a group of relays in the center, and the induction coils and part of the terminals below. At the extreme right of this view are shown the wires grouped or cabled along the side of the cabinet.

In the right-hand view the relay panel or "gate" is opened, showing the jacks and cords.

Fig. 19 shows a small desk type switchboard for mounting on a table or desk in private offices, where an operator is to be able to call various people in the building.

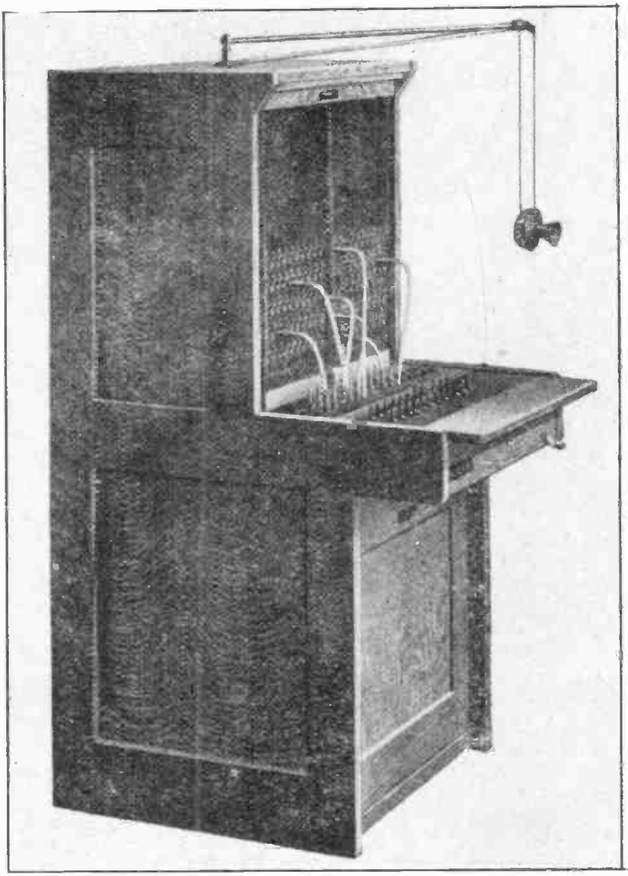


Fig. 17. Side view of a magneto type switchboard with some of the plugs in place in the various line jacks.

Telephone wiring requires men who are expert in reading plans and making careful and accurate connections of the thousands of wires and devices used on the switchboards.

10. TELEPHONE RELAYS

The top photo in Fig. 20 shows a telephone relay. Its armature is at the right-hand end of the magnet, and is bent and hinged to the corner of the magnet frame. When the magnet attracts the lower end of the armature to the left, its upper horizontal portion moves upward at its left end, pushing the center contact springs upward. This causes them to break circuits with the lower contacts and make circuits with the upper ones. So you see that while these relays are constructed differently and are much smaller and more compact

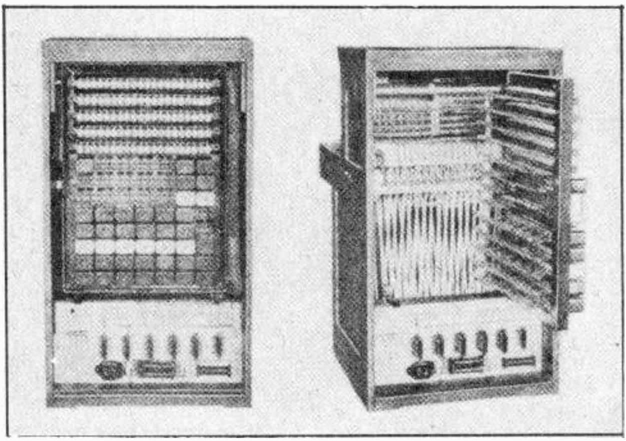


Fig. 18. These two views of the rear of a switchboard show the relays, drops, and cords very clearly. Note the neat and compact arrangement of all parts and wires.

than the pony relays used in alarm and telegraph systems, still their operation and principles are much the same.

11. CABLES AND TERMINALS

The center photo in Fig. 20 shows a piece of lead-covered telephone cable with many paper-covered wires inside it, and covering of extra insulation between them and the lead sheath. Cables of this kind are very necessary to carry the vast numbers of wires in telephone systems.

The lower view in the same figure shows a terminal block to which a number of wires can be neatly and conveniently connected. The wires from a cable can be soldered to the lower ends of the terminal strips, and the switchboard wires connected to the other ends by means of the small screws shown.

These terminal blocks greatly simplify the wiring and testing of telephone and switchboard circuits.

In wiring telephone switchboards, ground connections are also used to simplify much of the wiring. Metal strips and plates are used for common ground connections to the battery negative terminal. This eliminates a number of unnecessary wires.

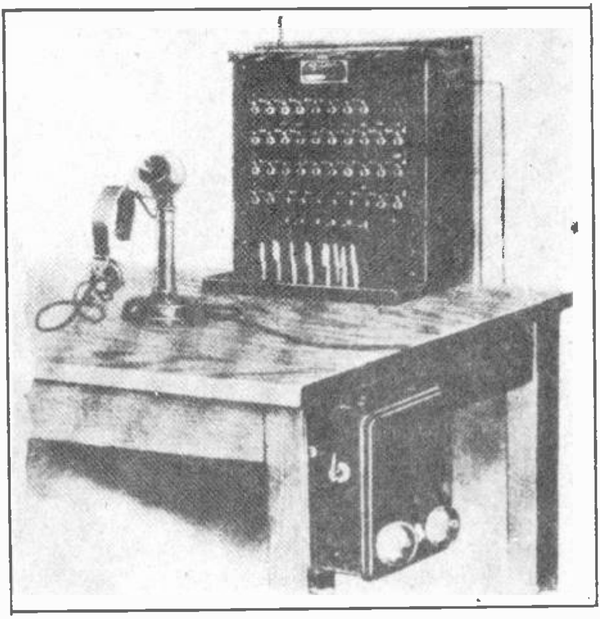


Fig. 19. Small desk type telephone exchange.

Some exchanges also use a ground connection to earth for ringing their subscribers.

Fig. 12, is a complete wiring diagram of a simple manual exchange showing just two subscribers' 'phones connected through the exchange. The different circuits are marked with different kinds of arrows and symbols.

Trace out carefully, one at a time, the transmitter and receiver circuits of the calling subscriber's 'phone at the left, and through the exchange to the called subscriber's 'phone at the right. Also trace the operator's magneto and calling circuit to the called 'phone; and the operator's talking circuit. Note the positions the various keys must be in to

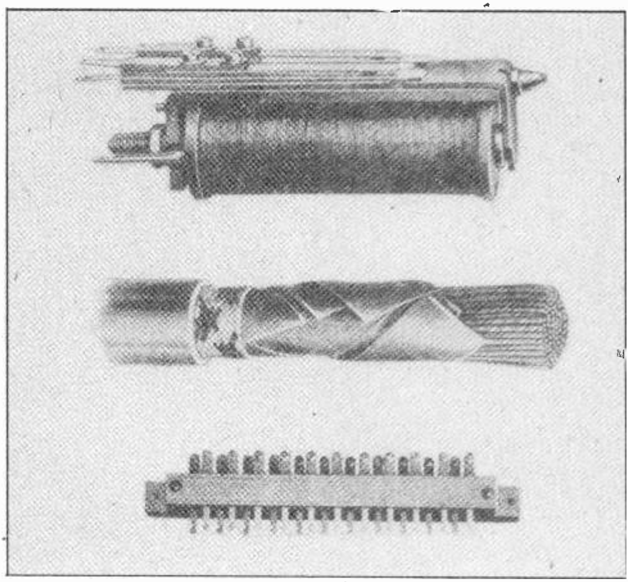


Fig. 20. The upper view shows a telephone relay. In the center is shown a section of telephone cable. Below is a group of terminal springs in a terminal block.

get the different circuits closed, and in order to trace some of the circuits it will be necessary for you to imagine certain switches are closed to the opposite positions.

There are many other types of exchange circuits, and this simple one shown here is more typical of an army field telephone exchange, but is chosen because of its simplicity and just to give you a good idea of their general nature.

Fig. 21 is a simplified diagram showing how a call from one subscriber is routed through his local exchange over a trunk line to the distant exchange and from there to the called subscriber.

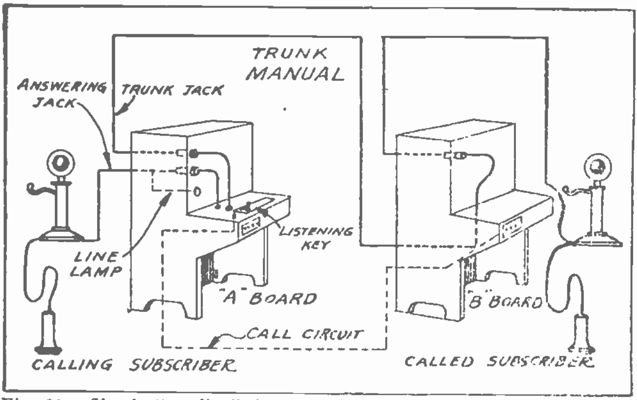


Fig. 21. Simple "one-line" diagram showing a telephone circuit through two exchanges and a trunk line.

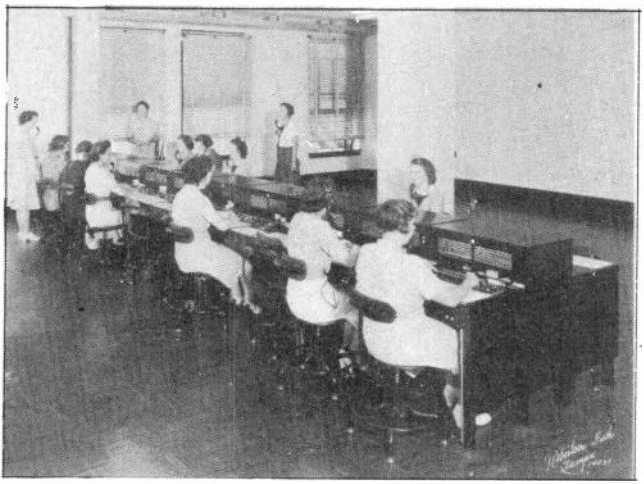


Fig. 22. This photograph shows a section of a large manual telephone exchange. Each operator controls a section of the board

This sketch is what is known as a one-line diagram, using only one line to trace the pairs of line wires actually used.

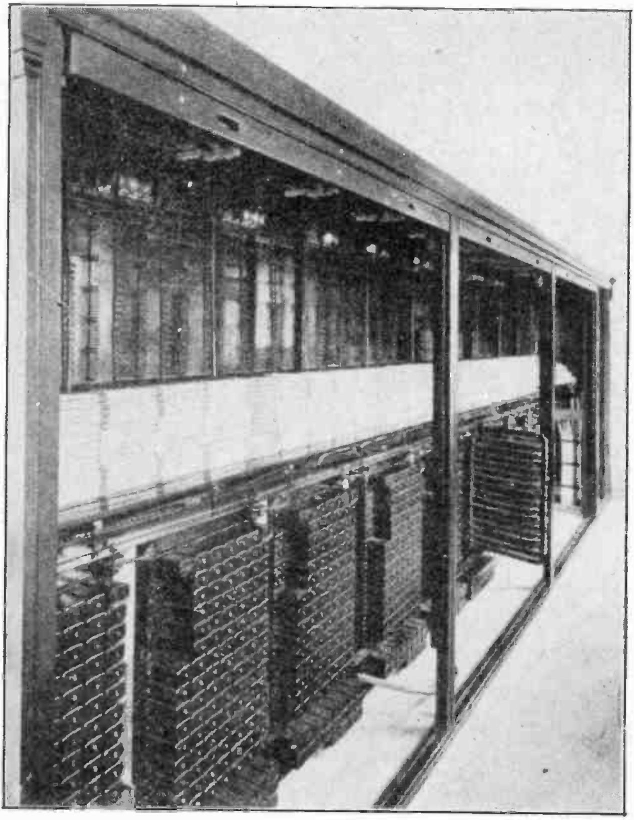


Fig. 23. Rear view of a central exchange switchboard. Note the very neat and compact manner in which all parts and wires are arranged to simplify connections and testing of such exchange units.

In apartment houses and offices, small telephone installations called inter-communicating systems are often used.

Any party of the group can call any other party by means of proper push buttons. There are separate push buttons and call circuits for each 'phone.

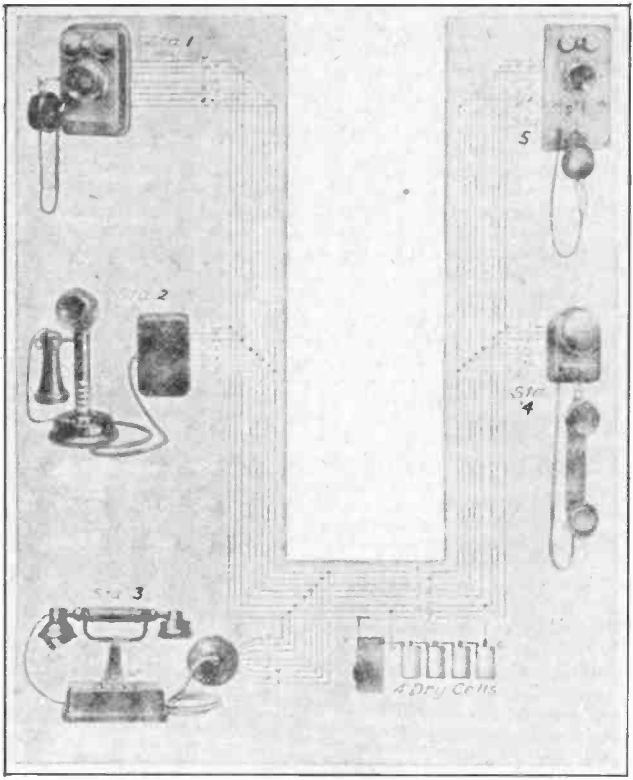


Fig. 24. Photo diagram of several types of inter-communicating telephones, showing their connections and batteries, and ringing and talking wires. Such telephone systems are commonly used to communicate with various offices in one building. No exchange or operator is needed, as each party is called by one of a number of push buttons.

These systems are very useful and practical where the lines are not long and where the system is not large enough to pay to keep an operator.

Fig. 25 shows the wiring diagram for three such 'phones. Trace out the talking and ringing circuits, and the operation of the system will be clearly understood. A, B, and C are groups of push buttons for calling the different 'phones. The numbers on each button contact indicate which 'phone it will call.

Fig. 24 shows a photo diagram of five different styles of 'phones which can be obtained for such inter-communicating service.

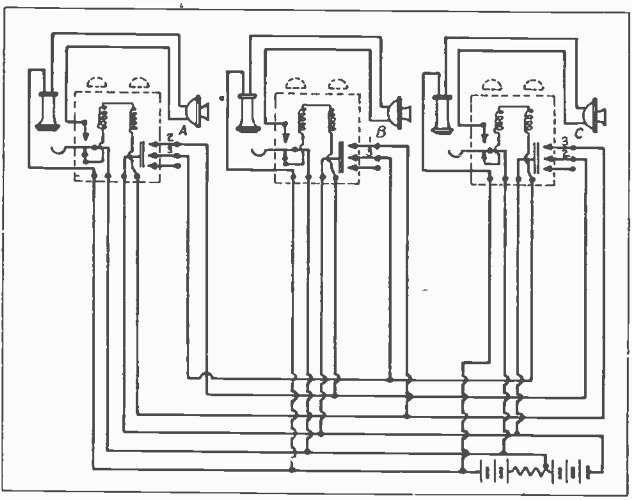


Fig. 25. Wiring diagram of three telephones on an inter-communicating system.

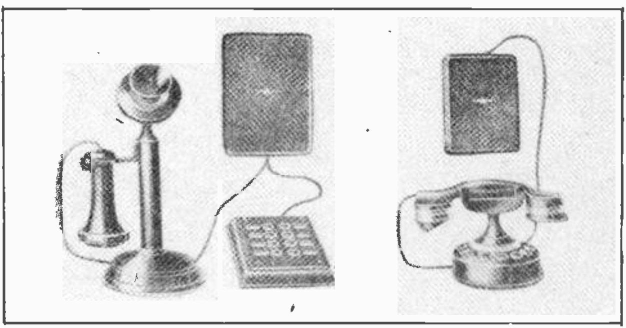


Fig. 26. Two types of inter-communicating telephones. The one on the right has the call buttons on the base of its stand.

Fig. 26 shows two types of inter-communicating 'phones, one with the push buttons on a desk block, and the other having them on its base.

EXAMINATION QUESTIONS

1—Name the six important parts of a telephone such as used on a rural party line.

2—Will the bell shown in Fig. 2, ring when the receiver is off the hook? Why?

3—Are batteries used on each subscribers' telephone in City systems?

4—What kind of a bell is shown in Fig. 3?

5—Referring to Figs. 2 and 3, what piece of electrical equipment do you find is used in supplying the bell ringing current?

6—Where is the power supply located for operating a telephone such as shown by Fig. 4?

7—What kind of current will a condenser allow to flow in a circuit. (b) What kind of current will a condenser stop?

8—Why are telephone switch-board lamps small and slender?

9—Do all telephone switch-boards use magnetic drops?

10—What is the purpose or advantage of telephone terminal blocks?

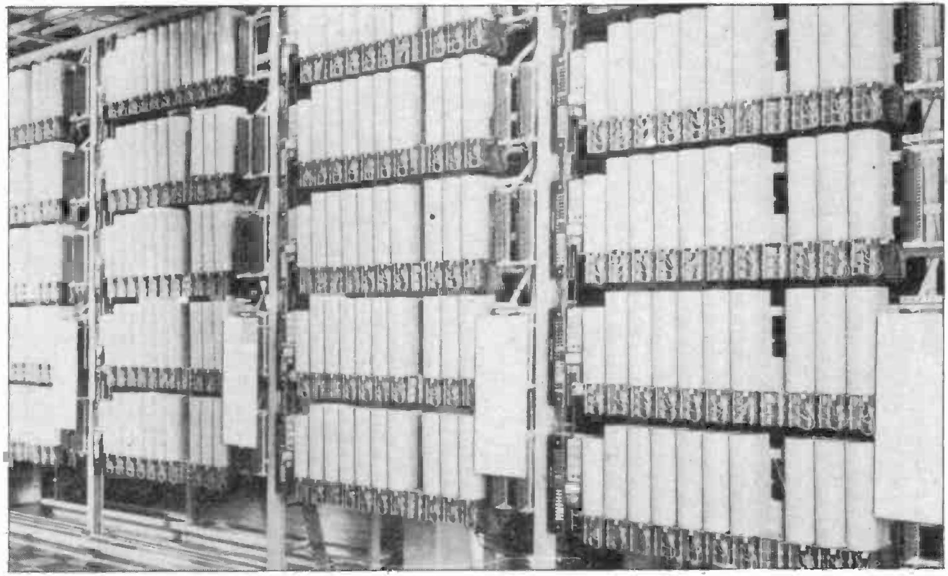


Photo shows Strowger (Step-By-Step) Dial Telephone Switching Equipment. Note the compact neat arrangement of all parts and equipment. (Photo Automatic Electric Co.)

AUTOMATIC TELEPHONES

Automatic exchanges do all switching, ringing, and signaling by means of electrical and mechanical equipment. This not only saves the cost of labor of numerous operators, but accomplishes faster and more accurate operation. It provides much more complete privacy for telephone conversations, and, because it is purely electrical and mechanical, the possibility of human errors is largely eliminated.

The automatic telephone exchange is undoubtedly one of the greatest triumphs of telephone engineering, and they are rapidly replacing many of the largest manual exchanges in this country.

There are several different types of automatic telephone equipment, and most of them are still undergoing rapid changes in the processes of development and perfection. One of the most successful systems is call the "Strowger System," after the man who developed it.

Complete automatic exchange circuits require a great deal more time and study than most students would care to spend on the subject, unless they were preparing to specialize in this work. The fundamental principles of this equipment, however, can be quite simply explained.

The following paragraphs are intended to give you a good understanding of automatic telephones.

1. SIMPLE OPERATING PRINCIPLE

The Strowger System uses what is known as the "step by step" equipment. When the subscriber wishes to call a certain party, he dials the desired number with the dial on his own telephone. This dial in its rotation sends a number of impulses to magnets and relays at the exchange, causing them to move a selector element which picks out the desired line. Other parts of the mechanism then test the line to determine whether it is busy or not, and if it is clear an automatic switch starts ringing the desired number.

2. DIALS, CONSTRUCTION, AND OPERATION.

The principle difference between a subscriber's phone to be used on an automatic exchange and those for manual systems is the dial. The trans-

Fig. 1. Desk telephone equipped with dial for use on automatic exchange systems.

mitter, receiver, and other parts remaining fundamentally the same.

Fig. 1 shows an ordinary desk telephone, equipped with a dial for automatic operation. You will note that this dial has ten holes or finger openings, around the outer edge of the rotating part.

When this finger plate rests in the normal position, there is a number on a white stationary disk directly under each of these openings. Starting at the one on the right hand side, and reading counter-clockwise, these numbers are 1, 2, 3, 4, 5, 6, 7, 8, 9 and 0.

When the subscriber wishes to dial or call party No. 246, he places his finger in the opening over No. 2, and pulls the dial around to the right until his finger strikes the **Stop Hook** shown at the bottom of the dial, and then releases it. He then places his finger in the opening over No. 4, and again pulls the dial around to the right until his finger is stopped by the hook. Once more the dial is released, and allowed to return to normal position. Then No. 6 is dialed in the same manner.

Each time the dial is rotated clockwise it catches and winds a helical spring inside the case, and a pawl secured to the rotating plate slides over the teeth of the ratchet on a combined ratchet and gear wheel. When the finger plate is released the spring causes it to return to normal position, and the pawl in this backward movement engages the ratchet and gear wheel, turning them back with it at a definite speed a certain exact distance for each number dialed.

3. IMPULSE SPRINGS.

The rotation of this main gear drives a smaller gear or pinion at higher speed, and this pinion rotates an **Impulse Cam,** which rapidly opens and closes a set of contacts or **Impulse Springs.** By means of a worm wheel the pinion also rotates a small speed governor, which causes the gear and dial to turn at a definite speed. This, of course, is necessary to make the impulse springs open and close at regular intervals.

Fig. 2 is a sketch showing the various parts we have just mentioned. Examine this sketch closely, and observe how the main gear drives the pinion, impulse cam, and governor. In the lower right hand corner of the sketch another view of the cam and impulse springs is shown. The arrows indicate their position with respect to the other parts. This view of the governor shows quite clearly how it operates.

If the governor shaft attempts to rotate too fast the small governor balls fly outward on their springs, due to centrifugal force, and rub the inside of the cup, thus retarding the speed of the mechanism.

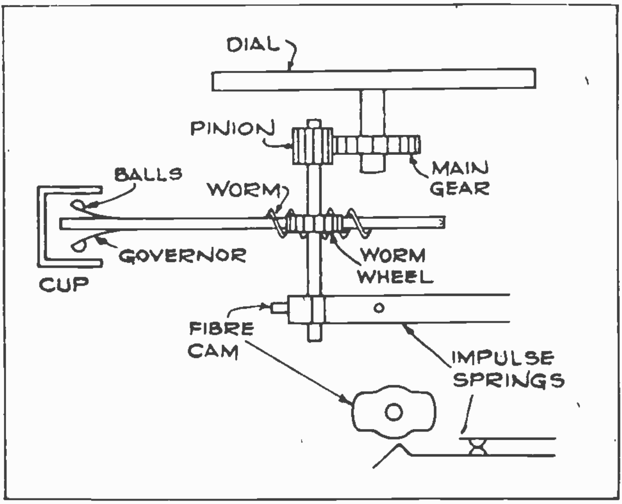


Fig. 2. This sketch shows the mechanism and operating principles of the dial and impulse springs.

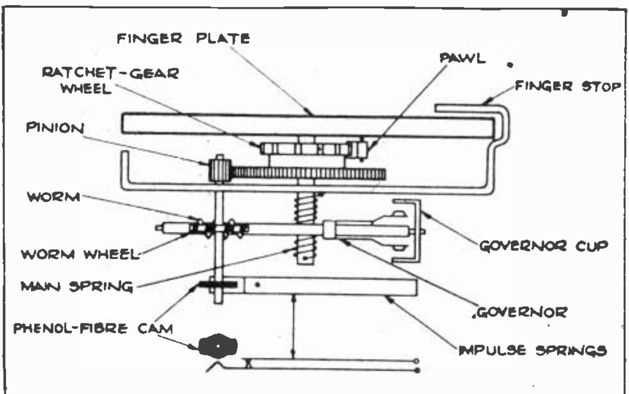


Fig. 3. Another view showing some parts of the dial mechanism more clearly.

Fig. 3 shows another view of this same mechanism, in which some parts can be seen a little more clearly than in Fig. 2.

Fig. 4 shows a photo of the complete dial mechanism. In this view you can get an excellent idea of the arrangement of the parts. In addition to the impulse springs at the left of the cam, you will also note an extra set of spring contacts called **"Shunt Springs."** These are used to temporarily short circuit the other parts of the telephone, during ringing operation. This is necessary because it would be difficult to send the ringing impulses through the resistance of these other parts.

These springs are operated by a small additional cam as soon as the dial is turned from the "off-normal" position. But they are opened as soon as the dial returns to normal. In addition to cutting out the resistance of the other telephone parts, these springs also prevent the clicking that would otherwise occur in the receiver during the operation of the dial.

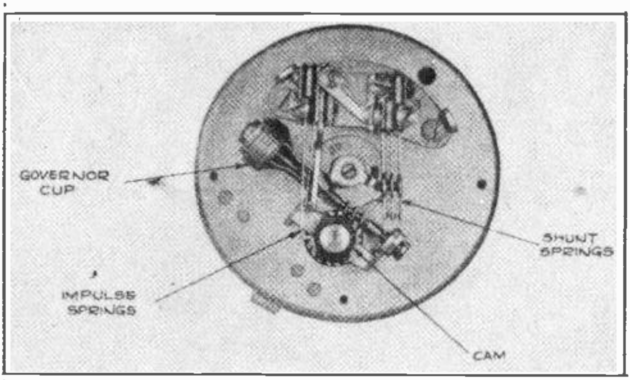


Fig. 4. This photograph shows an excellent view of the impulse springs and cam, shunt springs, and governor of a dial.

The impulse cam revolves one-half revolution for each movement of one number on the dial, and as the cam has two projections it opens the impulse springs twice in each revolution. Thus when we dial the number 8, the cam makes four revolutions, and opens the spring contacts eight times. The dial is so set with a certain distance from the number 1 to the finger hook, that an extra one-half revolution is made each time any number is dialed. This will be explained later.

Fig. 5 shows a better view of the top of the dial, and its numbers.

4. LINE BANKS AND "WIPER" CONTACTS.

The various groups of impulses, sent into the exchange by dialing different numbers, cause certain relays to energize as each impulse passes through them. These relays and magnets, as before stated, perform the switching and ringing operations.

In order to enable you to understand this equipment and these circuits more easily, let us first

Fig. 5. Front view of dial, showing finger plate, holes, numbers and finger stop.

examine the arrangement of the various line terminals at the exchange.

For an exchange to handle 100 lines, the terminals of the lines would be arranged in a **Bank of Connectors** as shown in Fig. 6.

In order to eliminate unnecessary wires and simplify this figure only two telephones, Nos. 14 and 33, are shown connected to the bank at present. At first glance the arrangement of the line numbers in this connector bank may seem peculiar, but suppose some automatic device was to move the

Wipers of the calling telephone step by step, up into this bank and select a certain line, say No. 14.

One step upward would bring the wipers in line with the lower row of connectors. Then four steps to the right would bring them in contact with No. 14. Dialing the numbers 1 and 4 would have accomplished this

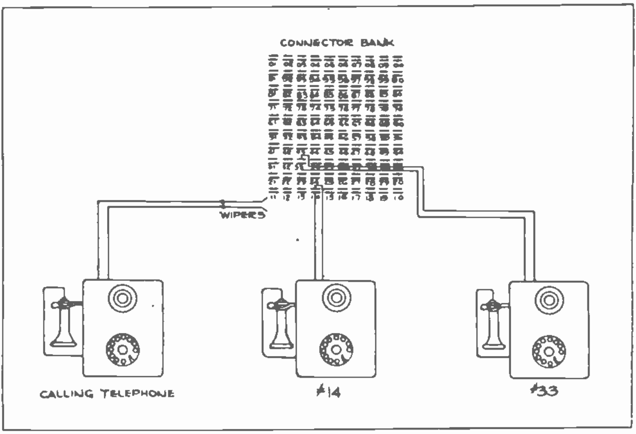


Fig. 6. Simple sketch showing the arrangement and principle of the connector bank of an automatic exchange.

Then suppose we dial the number 33. The first three impulses sent in by the dial would cause the switching magnet to lift the wiper three steps bringing it in line with the third row of contacts from the bottom. The next three impulses received would cause the wipers to make three steps to the right, and engage line No. 33.

So we find that these numbers are arranged as they are, for convenience and simplicity in the operation of the mechanical selector.

This figure gives us some idea of the arrangement of the various lines and the connector bank at the exchange.

5. WIPER SHAFT AND SELECTOR MECHANISM.

Fig. 7 shows a sketch of the wipers attached to the shaft which raises and rotates them step by step. It also shows the **Vertical Magnets**—V. M., and the **Rotary Magnets**—R. M., which lift and rotate the shaft step by step.

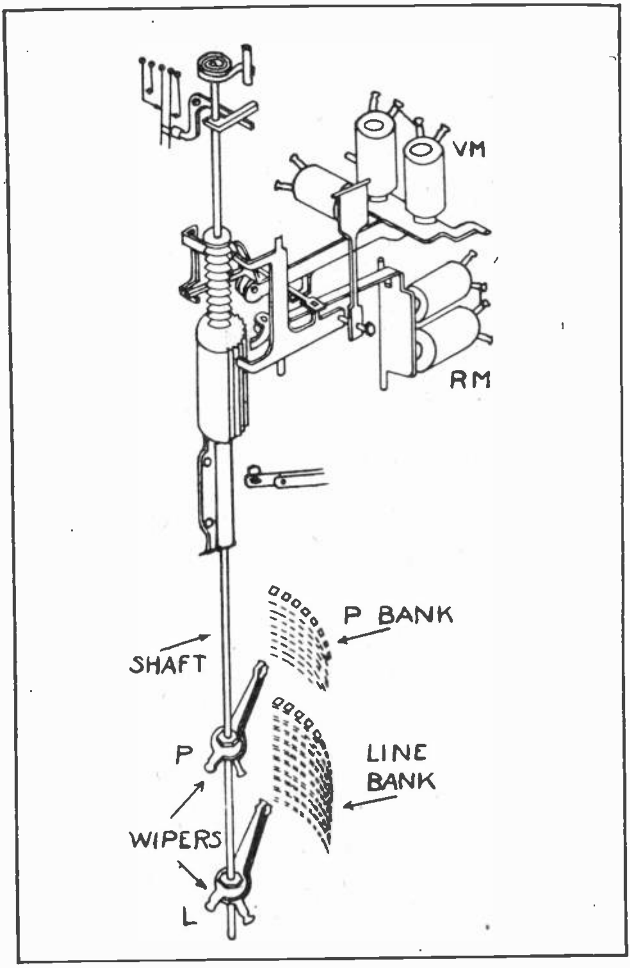


Fig. 7. This diagram shows the arrangement of the selector mechanism with its vertical magnets, rotary magnets, wipers, and wiper shaft.

By means of a special relay in the exchange circuit the first impulses which are sent in by the dial come to the lifting magnets, and the next group of impulses are switched to the rotary magnets.

Fig. 9 shows photos of both sides of one of these selector units.

Figs. 7 and 9 should be referred to while tracing out the circuit diagram in Fig. 8.

At the top of each unit in Fig. 9 are the relays which perform different switching operations in the exchange circuit. Underneath these are the vertical magnets or lifting magnets, and below are the rotary magnets.

On the shaft are two sets of notches called the **Vertical Rack** and **Rotary Rack** respectively. These are engaged by the hooks which are operated by the lifting and rotary magnets.

After the selector has completed a connection to a certain line, and the conversation is finished, then, when the subscriber hangs up his receiver, it closes a circuit to the **Release Magnet,** which trips the locking mechanism, allowing the wipers and shaft to return to normal position by the action of a spring and gravity.

6. SIMPLIFIED CIRCUIT OF IMPORTANT PARTS.

In Fig. 8 is shown quite a complete diagram of the more important circuits of the automatic exchange.

It is not at all necessary for every student to trace and understand this diagram at present, but it provides excellent circuit tracing practice, and if you are sufficiently interested in the principles of automatic telephones, or should later decide to prepare to specialize in this field, this simplified circuit should be of great help to you in obtaining an understanding of the most important parts.

In order to trace a circuit of this kind, it is necessary to do it step by step, and very carefully. If this method is followed, it will be found very interesting and not nearly as difficult as it first appears.

This diagram shows a complete connection between a calling telephone, the automatic exchange, and the called telephone. Each circuit is traced with different types of arrows to make them easier to follow.

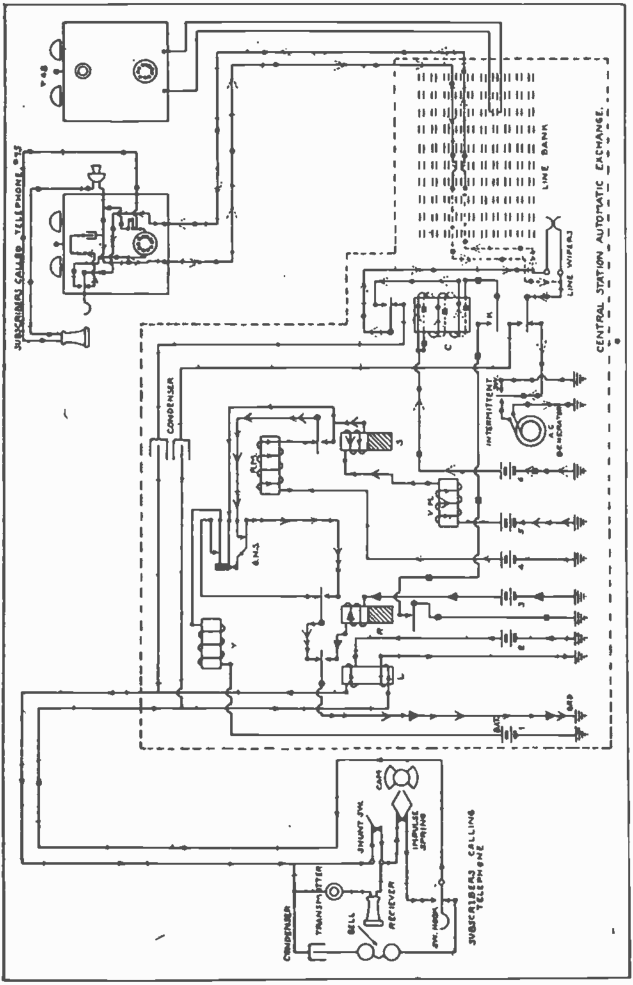


Fig. 8. Complete simplified diagram showing the wiring and operating principle of the fundamental parts of an automatic telephone exchange. Trace this circuit very carefully with the complete instructions given in these pages.

The equipment in the calling phone consists of an ordinary transmitter, receiver, bell, condenser, and switch hook; and in addition to these, the impulse springs, and shunt springs used with the dial telephone.

As soon as the receiver is lifted from the hook, the hook switch will close the circuit, shown by the small solid arrows, from the positive terminal of battery No. 2, through the top winding of relay "L." Then through the shunt switch, impulse springs, and top contact of the hook switch at caller's 'phone, back through the lower winding of relay "L," and to ground.

You will note that the ground connections in this circuit are returned to negative of the batteries, so when starting to trace a circuit from any battery, as soon as this circuit is completed back to ground, you will know it has returned to negative of the battery.

To simplify this circuit a number of separate batteries are shown.

These current impulses in the circuit we have just traced, will cause relay "L" to become energized and attract its armature. When this armature is pulled down it closes a circuit shown by the large solid arrows from the positive of battery No. 3, through the coil of relay "R," "make" contact of relay "L", and to ground, which completes this circuit.

The term "make contact" is used here, meaning the contacts made when the relay is energized and the armature attracted. The term "break contact" when used, means the contacts that are closed when the relay is de-energized. In other words, the contacts made when the armature is attracted are referred to as "make contacts". Those made when the armature is released are called "break contacts".

When the circuit just traced through relay "R" is completed this relay becomes energized and attracts its armature. So we find that both relays "L" and "R" became energized merely by the subscriber removing his receiver from the hook.

Now, assume that he dials the figure 1. When the dial is released, and as it returns to normal, the cam is rotated one-half turn, and opens the impulse spring once. This momentarily opens the circuit of the line relay "L", which is de-energized for an instant, and its contacts open the circuit of release relay "R".

However, relay "R" remains energized through this short period even though its circuit was momentarily opened. This is because it is a **Slow Acting** relay, and does not release its armature the instant the current is interrupted, but holds it for about a second afterward. This will be explained later.

If the calling subscriber now dials the number 7, opening the impulse springs seven times, the circuit of relay "L" will be broken each time, and allow its armature to release momentarily seven times. Each time it releases, the circuit of relay "R" is broken for an instant, but relay "R" acts too slowly to de-energize and release its armature during these periods, so it remains closed throughout the seven short interruptions of its circuit. But something else did happen.

Keeping in mind that the armature of relay "R" is now attracted to the "make contact", we find that the first time the armature of relay "L" was released it closed a circuit shown by the small open arrows from the positive of battery No. 5 through the vertical magnet, V.M., through relay "S", "break contact" of O.N.S., "make contact" of relay "R", "break contact" of relay "L", and to ground.

The letters "O.N.S." stand for **Off Normal Switch,** which will be explained later.

This circuit we have just traced energizes both the vertical magnet and relay "S". Relay "S", being another slow acting relay, will retain its armature in an attracted position during current interruptions of a fraction of a second.

The second time the armature of relay "L" was released it allowed current to flow, as shown by the large open arrows, from positive of battery No. 5 through vertical magnet and relay "S" again, then through the "make contact" of relay "S," "make contact" of the off normal switch, "make contact" of Relay "R", "break contact" of relay "L," and to ground.

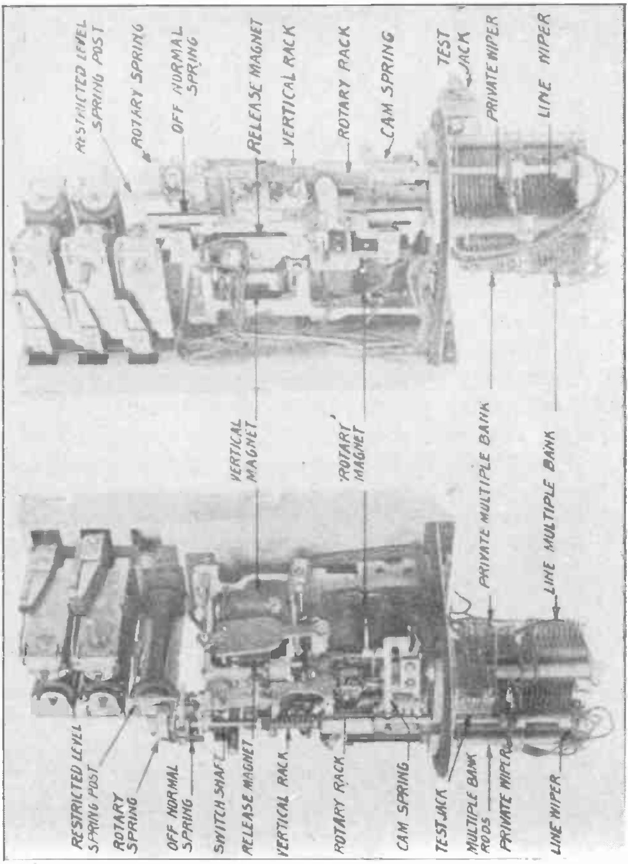

RESTRICTED LEVEL SPRING POST
ROTARY SPRING
OFF NORMAL SPRING
RELEASE MAGNET
VERTICAL RACK
ROTARY RACK
CAM SPRING
TEST JACK
PRIVATE WIPER
LINE WIPER
VERTICAL MAGNET
ROTARY MAGNET
PRIVATE MULTIPLE BANK
LINE MULTIPLE BANK
RESTRICTED LEVEL SPRING POST
ROTARY SPRING
OFF NORMAL SPRING
SWITCH SHAF
RELEASE MAGNET
VERTICAL RACK
ROTARY RACK
CAM SPRING
TEST JACK
MULTIPLE BANK RODS
PRIVATE WIPER
LINE WIPER

Fig. 9

The off normal switch is operated by the line wiper shaft as soon as it moves from off normal position. So as soon as the dialing operation is started, the first movement of this shaft closes certain contacts and circuits, but when the shaft is dropped and allowed to fall back to normal, it again opens these circuits.

Shortly after the last impulse of current has passed through the relay "S" it will de-energize and cannot again become energized, because the circuit has been opened at the off normal springs. Each of the seven impulses passing through the vertical magnet causes it to raise the wiper shaft one step, so the line wiper will now rest in line with the seventh row of line bank contacts.

Now we are ready for the subscriber to dial the second number. Let's assume that he dials No. 5. This again rapidly opens the line circuit five times, causing the line relay "L" to release momentarily the same number of times. Each time relay "L" is de-energized, now since the off normal switch is opened, a circuit can be traced as shown by the small dotted arrows from the positive of battery No. 4, through the rotary magnet R. M., break springs of relay "S," "make contact" of off normal springs, "make contact" of relay "R," "break contact" of relay "L," and to ground.

These impulses in this circuit will cause the rotary magnet to become energized each time and rotate the wiper shaft, carrying the wipers five steps to the right. This brings them in contact with No. 75 of the line bank, as indicated in the diagram.

The dotted lines from the normal position of the line wipers show the upward movement of the shaft caused by the vertical magnet, and the rotating movement to the right caused by the rotary magnet; and they show the circuit which will now be completed to the called subscriber's telephone.

As soon as the line wipers are in contact with No. 75 in the bank a circuit is completed through the bell of the called telephone. This circuit can be traced (backwards) by the large dotted arrows from the top brush of the generator, through **Inter-**

mittent Ringing Switch, "break contacts" of relay "C", lower switch spring and lower contact No. 75 on the bank, "make contact" of hook switch, bell and condenser, then back to the upper contact in the bank and upper wiper spring, on through the top "break contact" of relay "C," low resistance winding of relay "C," through battery No. 6, to ground.

This is a long circuit to trace and should be gone over again until you have it well in mind.

You will note that relay "C" has two windings, one of low resistance and the other a high resistance coil of many more turns. The low resistance coil is to receive a heavy current impulse to first attract the relay armature, then the high resistance locking coil will hold the armature atracted with less current.

The current from the generator is A. C. and will not energize the coil of relay "C." The intermittent switch at the generator keeps making and breaking the circuit at regular intervals, so the called subscriber's bell rings for short, repeated periods and not continuously.

This flow of alterating current through battery No. 6 to ground does no particular harm to the battery. We will remember from an earlier article that the alternating current will pass through the condenser at the bell, but this same condenser will not allow direct current to pass. As soon as the called subscriber lifts his receiver off the hook a flow of direct current from battery No. 6, and traced by the round dots, passes over the same circuit we have just traced to the bell, except that the bell is now cut out by the hook switch, and the transmitter is placed across the line.

Trace this carefully by following the round dots. This flow of direct current will now energize the low resistance winding of relay "C," closing contact "K," which acts quickly before any of the other contacts of this relay can move, thus closing a lock circuit in which current flows from the positive of battery No. 6 through the high resistance winding of "C," lower "make contact" of relay "C," "make contact" of relay "R," and to ground. This circuit is traced by the square dots.

With relay "C" fully operated, the talking circuit is now complete through both telephones. This circuit can be traced by the short dashes across the line.

Now, when the calling subscriber hangs up his receiver and breaks the circuit through the line relay "L," it in turn releases and breaks the circuit through relay "R," which, after an instant of delay because of its slow action, releases its upper armature and makes the circuit from battery No. 1 through the release magnet "Y," "make contact" of off normal spring, "break contact" of relay "R," "break contact" of relay "L," and to ground.

This circuit will energize the release magnet "Y," which trips the wiper shaft, allowing it to fall back to normal position. This action interrupts the circuit of release magnet "Y," because the dropping of the wiper shaft opens the "make contact" of the off normal spring.

When relay "R" was de-energized it also opened the high resistance locking circuit of relay "C," allowing its contact to move back to normal position.

Telephone No. 48 merely shows where another telephone of this number would be connected in the back. It is not expected that you will perfectly understand all of this diagram the first time you trace it through, as it is rather complicated and one which requires some time to absorb. But if you are interested enough in this branch of work to trace each step of the operation through this circuit several times it will not only be excellent practice, but will give you a good understanding of the fundamental principle and more important parts of this type of automatic telephone.

There are a number of other auxiliary relays and contacts used with this equipment in larger exchanges where it is necessary to have a number of line banks from which to select.

There is also an added mechanism which automatically tests out any line before completing the calling circuit. If that particular line is busy at that instant, this relay will close a circuit which gives an intermittent buzzing note to the calling subscriber, indicating that the line he desires is busy.

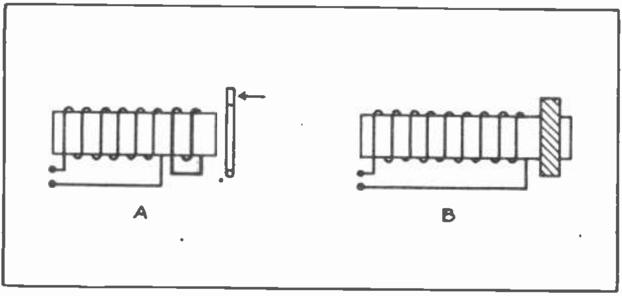


Fig. 10. Two types of slow acting relays. The one on the left has a short-circuited coil of a few turns, and the one on the right has a larger copper ring around the end of the core.

7. SLOW ACTING RELAYS

The slow acting relays used with these automatic telephones are very interesting devices. In addition to the regular winding on the core there is also a heavy ring of solid copper placed around the core end. Or, in some cases, just a short-circuited winding of a few turns. This copper sleeve, as it is called, acts as a single turn secondary winding.

When the current is interrupted in the main coil of the relay its collapsing flux induces a rather heavy current in this copper ring. The extremely low resistance of this ring circuit allows the current flow to continue with infinitely small voltage, and as long as there is any flux left from the decreasing current, both in the main coil and in the ring itself.

This persisting flow of current in the ring develops enough magnetism in the core to cause it to retain its armature a little longer. Thus we get the term "slow acting" relay.

By changing the size of these copper rings, or the number of turns when a shorted coil is used, we can vary the amount of time the relay will delay its action from a very small fraction of a second to one or more seconds.

Fig. 10 shows two sketches of relays of this type. The one at "A" uses a short-circuited coil. The one at "B" uses a copper ring.

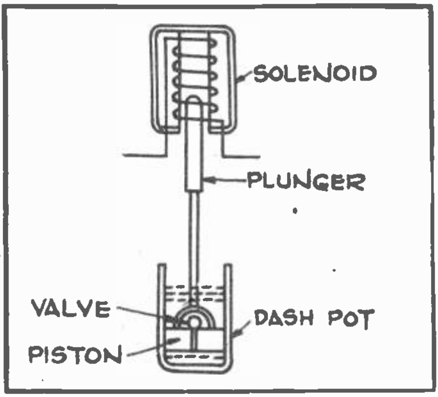


Fig. 11. This sketch shows the use of a dash-pot to slow the action of solenoids and electro-magnets.

Some relays have what is called a "dash-pot" attached to their armature to slow its action. These dash-pots may consist of a plunger in a cylinder filled with oil or air which only allows the plunger to move rather slowly as the oil or air escapes past the edges or through the small opening in the plunger.

Fig. 11 shows a relay equiped with such a dash-pot.

Various selective circuits can be arranged in automatic telephone systems by the use of condensers and choke coils of different sizes.

A condenser placed in the circuit of certain relays will only allow alternating current to pass through and stops all flow of direct current. A choke coil, however, will allow direct current to pass rather freely, but quite effectively blocks the flow of alternating current.

Many of the telephones being installed nowadays for use with manual exchanges are also equipped with a place to mount the dial, because in many localities it is expected that the automatic exchange will replace the manual in a short time.

Fig. 12 shows a very convenient, modern type of desk telephone. With this telephone the receiver and transmitter are both mounted on one handle, so the subscriber doesn't have to move a transmitter stand close to his mouth to carry on a conversation. This receiver and transmitter, when not in use, are laid in a "cradle" which has a small strip in the bottom that is attached to a spring in the stand. This operates a hook switch each time the receiver is removed from or replaced in the "cradle"

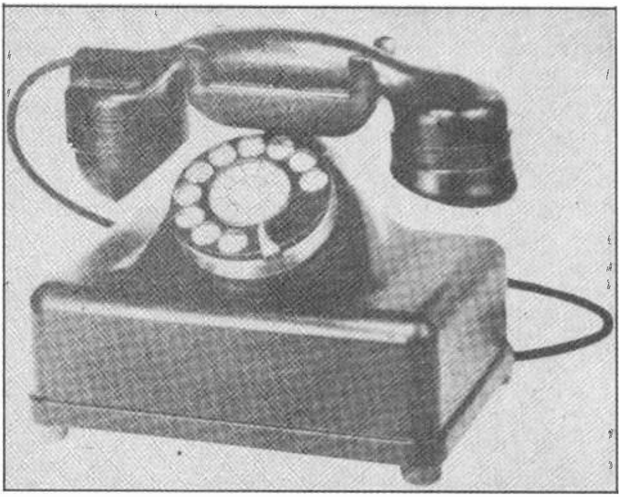


Fig. 12. Modern desk type telephone equipped with dial for automatic operation.

8. TELEPHONE LINES

The operation of the millions of telephones in this country today requires a vast network of telephone lines. These lines can be divided into two general classes—the small individual or party lines which connect one telephone or a small group of telephones to the central exchange, and main lines, or Trunk lines, as they are called, which connect from one exchange to another.

The individual or party lines, of course, are only in use when the subscribers whose telephones are on them are talking.

The trunk lines, however, carry the main business between exchanges and large towns, and are kept busy the greater portion of the time. These trunk lines might be called the arteries of the telephone system and are fed by the smaller branch lines from each exchange.

9. GROUND CIRCUITS. CABLES

Some telephone lines are made up of **two insulated wires** for each circuit and known as metallic circuits. Other lines use one insulated wire on the poles and the other side of **the circuit is completed through earth** by carefully made ground connections. Some lines which use a two-wire or metallic talking circuit use a ground circuit for ringing.

Telephone line wires are usually bare and without any insulation except the small glass insulators which support them on the poles. Under normal conditions this is sufficient insulation because they do not operate a high voltage. Many telephone lines use galvanized steel wire and some use copper wires. Most all of us have seen trunk lines following highways or railroads from one town to another and with their dozens of wires on numerous cross-arms on the poles. This type of line is being replaced in many localities by the more compact telephone cables.

The large masses of open wires on the older lines offer a great deal of wind resistance and accumulate enormous loads of sleet at certain times of the year. This has a tendency to break down poles and disable the lines, making them very costly to keep in repair. Where cables are used, one lead sheath about 2 to 3 inches in diameter may carry from 500 to 1,200 pairs of small wires. These individual wires are all insulated from each other with proper wrappings and the entire cable insulated from the lead with an additional wrapping. **Such cables are very heavy and not strong enough to support their own weight between long spans.** Therefore, they are usually supported by what is called a **"Messenger"** cable made of stranded steel wires, and to which the lead cable is attached at frequent intervals by means of hooks or wire supports.

The lead sheath protects the wires from moisture and injury, and cables of this type can be run underground in cities, as well as overhead on poles across the country. In connecting or repairing such cables the small wires are spliced separately, soldered, and carefully reinsulated with sleeves of paper or other insulation over the splice. The numerous splices are often staggered or made a few inches apart to prevent too large a bulge in the cable at the joints.

When the wires are all spliced; a large lead sleeve, which has been previously slipped over the cable, is then slid over the splice and sealed in place with hot lead, similar to a "wiped" joint in lead piping.

The entire splice is then dried out by pouring hot parafin through it and finally filled with parafin or other insulating compound, and the small filler hole in the lead sleeve is then sealed tightly

All moisture must be kept from the inside of such cables and splices.

10. LIGHTNING PROTECTION AND TRANSPOSITION

Where open wire lines are used, it is customary to run lightning ground wires from the top of certain poles along the line down to an earth ground at the bottom of the pole. These wires serve as small lightning rods to drain severe static charges and lightning from the telephone line. Small lightning arresters are often used at the 'phones on rural party lines to ground any lightning charges and prevent damage to telephones and property.

Where telephone lines run parallel to power lines they often pick up, by magnetic induction, an interfering hum. To avoid this, the pairs of wires should occasionally be crossed into opposite positions on the poles or cross arms, so that one wire will not be closest to the transmission line throughout its entire length.

This crossing of wires to prevent induced interference is known as **transposition.** Sometimes it is also done to avoid "cross-talk" or induction from other telephone wires.

Transposing the wires **frequently** and **evenly** will balance out most of this induction. Telephone lines should never be left close enough to high voltage power lines so that there would be danger of them coming in contact with each other, for in case they did people using the telephone lines might be injured.

Satisfactory telephone operation depends to quite an extent on proper line construction. Therefore, all telephone lines should be made with the proper materials and the wires properly spliced with low resistance joints, ground connections kept in good condition, etc.

11. PHANTOM CIRCUITS

Considerable **economy and saving of wire** can be effected in telephone line construction by the use of what are known as "**Phantom**" circuits. By this method one additional circuit can be obtained for each pair of lines already in existence. This can be done without the addition of any other wires, merely by using two existing lines, one to form each side of the new line or phantom circuit.

By the use of proper induction coils, or **Repeater Coils**, as they are called, a conversation can be carried on over this phantom line without interfering with either of the two actual lines. A repeater coil is simply a transformer with primary and secondary windings of an equal number of turns.

Fig. 15 shows the manner in which a phantom circuit is obtained from two metallic circuits. Lines No. 1 and 2 are ordinary metallic lines or physical circuits using repeater coils to transfer the current impulses from the transmitter circuits to the lines. Line No. 3 is a phantom circuit obtained by connection of its coil to the exact center of each of the others on lines 1 and 2. With this connection the current in line 3 can divide equally through each of the other lines or pairs of wires and, therefore, dos not interfere with their talking currents at all.

With four metallic circuits we can obtain two phantom circuits directly, and then a third phantom circuit between the first two, so we find that where a considerable number of trunk lines are run from point to point a large number of phantom circuits can be arranged to use the same lines.

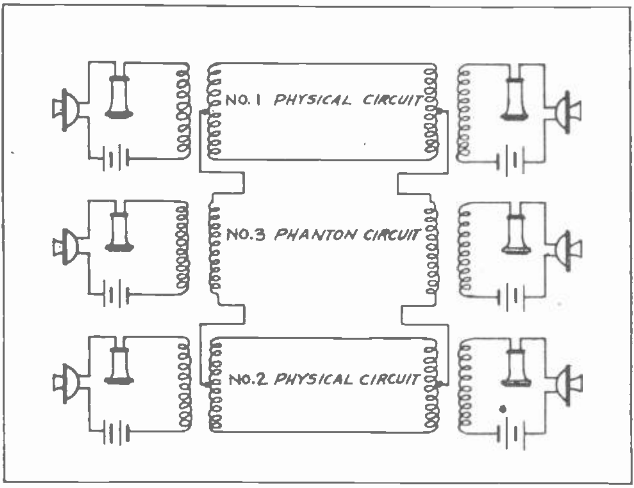


Fig. 15. Elementary sketch showing how a phantom circuit is obtained from two metallic or physical circuits.

This practice is also followed in telegraph work.

Telephone lines, if used on trunk circuits and special radio station wires, are constructed with a carefully determined amount of resistance. Special resistance and impedance coils are placed in the circuit of such lines to make them most efficient in the handling of certain frequencies set up by voices or musical notes. This principle will be more fully explained in a later section on radio.

Operators of radio broadcast stations frequently lease wires from the telephone companies to use in picking up and transmitting certain news or entertainment features at quite a distance from a broadcast station. Telephone systems are becoming more and more linked up with radio stations, not only for amusement programs, but for the trans-oceanic and commercial conversations as well.

12. TELEPHONE TROUBLES

Faults and troubles arising in telephones or telephone exchanges can usually be located by the same general methods of systematic testing that have been covered in connection with other signal circuits. A diagram of the wiring and connections is always of the greatest help in testing any telephone circuit.

Some of the more common telephone troubles which occur in the separate parts, such as a transmitter, receiver, hook switch, etc., have already been mentioned. Other likely places to look for faults are at the spring contacts of key switches and relays, which may have become burned, dirty, or bent out of shape; wire terminals, which may have become corroded or loose on the binding screws; weak batteries, weak magneto magnets, weak receiver magnets, etc.

Telephone circuits and equipment can often be tested very conveniently with a telephone receiver, as well as with test lamps and buzzers. The receiver can be used to determine if the talking current is coming through to certain circuits, and also to determine whether high resistance circuits are completed or not, by the clicks which should be heard in the receiver when its terminals are touched to any line circuit.

Careful application of your knowledge of the principles of fundamental telephone parts and circuits and methods of systematic trouble shooting should enable you to locate most any of the ordinary troubles in telephone equipment.

EXAMINATION QUESTIONS

1.—Give the name of one automatic Telephone system that has proven to be very successful.

2.—Is a central operator required to complete a call on an automatic system?

3.—What operation does the impulse cam perform on an automatic Telephone?

4.—For what are shunt springs used in the automatic Telephone?

5.—What operation does the release Magnet perform?

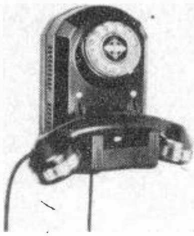
6.—What is the main difference between a "slow acting" relay and an ordinary relay?

7.—Do all telephones require two lines wires?

8.—For what purpose is the MESSENGER cable used?

9.—How may telephone wires be arranged to prevent "cross-talk" or inductive interference?

10.—What advantage is there in using Phantom Circuits?



Top left shows wall mounted Monophone for home or office. Top right is the latest type "Two line" Monophone. Lower left shows compact Monophone mounted on side of desk—this saves space on the desk itself. Lower left is a telephone set combining all the grace and beauty of the telephonic science. All these photos show Automatic Electric Company equipment.

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MASTER REFERENCE INDEX

The value of any good set of Electrical Reference books is determined to a large extent by two important factors.

1. The completeness and accuracy of the material covered.

2. *The methods of indexing showing where all the material needed to answer problems can be quickly found.*

This section is your *Master Reference Index.* It contains a listing of *every subject* in *every volume* of this 7-Volume Set *Applied Practical Electricity.* In other words, through this Master Reference Index you can find out where any subject is and *what particular volume it is in.* Here are a few simple instructions on how to use this *Master Reference Index.*

First of all, wherever we show a volume number in the MASTER REFERENCE INDEX we use a capital letter V. As an example, V1 means Volume 1, V2 means Volume 2, V3 means Volume 3, etc. for all 7 volumes of the set. All page numbers will be indicated by a letter P before the number. As an example, *APPLIANCES* are indexed as V2-P419-P465. That means APPLIANCES are in Volume 2 from pages 419 to 465.

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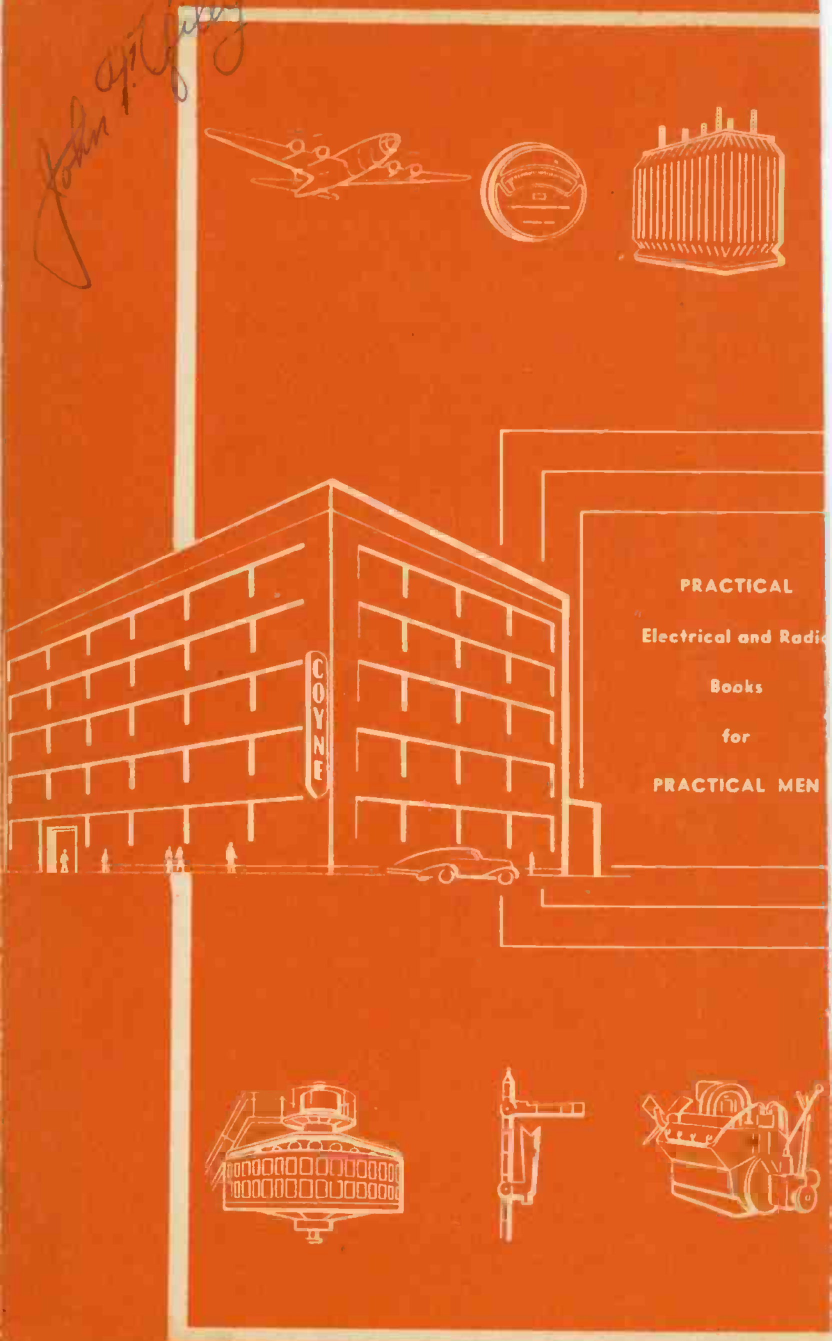
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