ELECTRICIANS NOTES

L. L. COOKE
CHIEF ENGINEER
Chicago Engineering Works
CHICAGO

CHICAGO ENGINEERING WORKS
2154 Lawrence Ave.
Chicago

NOTICE TO STUDENTS

READ CAREFULLY

In sending in work for correction, remittances, or letters, **be sure** to observe the following:

Write your scholarship number, name and address plainly on all answers, letters and remittances. This will insure prompt and better service.

Send all remittances by post office money order, express money order, bank draft, or personal check. DO NOT SEND CASH under any condition unless you register the letter, as it is very liable to be lost in the mail and there is no way of tracing it.

I will endeavor to send you a reminder each month, but in case it does not reach you send in your remittance without it.

Students living in the United States, Mexico, Cuba, or Panama should send their work to me sealed in the large envelopes which I furnish them. It should be sent as first class postage at 2c per ounce. Students residing in foreign countries should take pains to see that the necessary amount of postage is put on for first class mail.

After writing out your answers to two lessons, put your pages in order and mail them to me, and then go on studying the next two lessons. When I return your corrected answers on the two lessons set in, I will send you, in the same envelope, two new lessons to take their place. In this way you will always be supplied with work. If lessons do not reach you in due time, notify me without fail so that I may arrange to duplicate.

In the case of foreign students (residing outside of the United States) the corrected answers will be mailed in one envelope (first-class) and the new lessons in another (3rd class).

Do not return your lessons, but keep them on file in this binder. You are only expected to send in the answers to the question on each lesson. In marking papers, I give each part of the work its proper valuation. Neatness and clearness of expression are also considered in your grade. In order to pass on any lesson, you must have a grade of 75 per cent. If it is less than 75 per cent I will return your work and ask you to send new answers to the questions on which you failed.

If your work is not coming right, I will call your attention to it.

Write your answers on the examination sheets which I send you, using pen and ink or typewriter—and write on one side of the paper only. **(Do not use red ink.)**

Remember I am always trying to give you the best possible service, but if you do not get it don't be afraid to notify me of the fact. It is only by knowing of mistakes that I can correct them. So unless I hear from you to the contrary I will take it for granted that everything is all right.

If the letters and lessons you receive from me have your name spelled improperly or are insufficiently addressed, kindly call my attention to it.

Read this over occasionally.

L. L. COOKE, Chief Engineer.

P. S.—Never send in more than 2 lessons at a time, and try to keep lessons to be sent in about one week apart, thus giving me time to get new lessons to you, before the next lot of lessons are sent in.

CHICAGO ENGINEERING WORKS
CHICAGO, ILLINOIS

Radio Lesson 1

Modern Radio Communication

COMMUNICATION AND WORLD PROGRESS.

Before presenting to my students the technical details involved in wireless communication it is important to first have a brief understanding of present day methods of communication and their value to world progress.

The average citizen on picking up the morning paper reads the current events from every point not only in the U. S., but the whole world. Some of the articles deal with happenings of but a few hours before, and none of the news, even that from the most remote corners of the globe, is more than twenty-four hours old. Stop then and consider for a moment what it would mean if this news had to be brought to us by train, even under our present day methods of rapid transportation.

It takes over one hundred hours for the fastest moving express train to go from New York to San Francisco; hence news from either place would be over five days old. Imagine such a condition, and what it would mean to the financial and political world were New York to be without news from San Francisco for five or more days. It would be tragic. Yet we consider our present modes of transportation rapid, and they are rapid as human carriers, but not as carriers of world important news.

We have become so accustomed to our modern methods of gathering news, viz.—to the use of the telegraph and telephone—that the average person fails to visualize the intricate system and marvelously designed apparatus, all working in unison, which make it possible for us to talk to our associates, whether in the same town or thousands of miles away. Any one can talk from New Orleans to New York, or from New York to San Francisco, with the same ease as telephoning from the home to the office. Electricity has made this possible.

I have mentioned the speed by which news can be transported by trains from New York to San Francisco,—approximately one hundred hours. The speed of electricity is 186,000 miles per second. The distance between New York and San Francisco is 3,400 miles. Therefore, a word spoken in San Francisco, using electricity as its carrier, would —once the connection was made—be heard 18 thousandths of a second later in New York. The student can, therefore, understand that for all practical purposes the transmission of communications by electricity can be classed as instantaneous.

Money, in the form of actual Gold and Silver, can be and often is, physically transferred (actually carried) from one country or one city to another to settle debts. But in this day and age we are more likely to use the telegraph or telephone by means of which transfer of credits between countries, or cities, or merchants is made without the actual shipment of money. Such credit transfers require but few minutes of time, whereas, were actual cash to be shipped, days and weeks might be consumed.

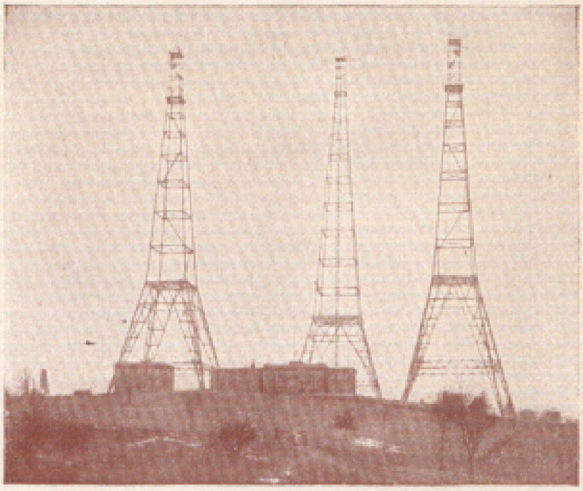
In this and a hundred other ways have we come to depend on the electric spark to carry our news, extend our credits, make our collections, and handle our business transactions, so much so that Commerce, in a modern sense, is actually dependent on this system of rapid communication.

But fast as is the telegraph and telephone, Science has recently produced a still faster method of communication—Radio, or Wireless Telegraphy and Telephony.

So rapid has been the advancement in Radio, so astonishingly swift the evolution from wire communication to wireless, that, almost unconsciously, we have been transported from one period of rapid communication to another, for we ARE entering a new phase in world communication.

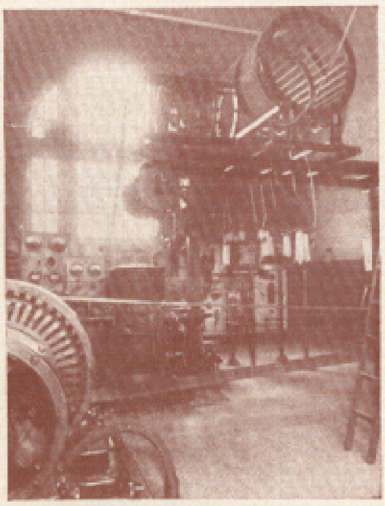
It may be a few or many years before Wireless will have entirely displaced the telegraph and telephone of today, but displace it it surely will because Wireless is not only an advancement,—a big step forward,—but also a big improvement over present day methods of communication.

How many times have we heard of instances where the engineer, failing to get the signal, rushed on with his train to inevitable destruction to himself and passengers. The station despatcher, while aware that certain destruction was to follow, was powerless to prevent it—communication between his station and the train by regular telegraph



A wireless station for the broadcasting of musical entertainments. More and more of these are being put into service for the entertainment of hundreds of thousands of listeners with radio receiving apparatus.

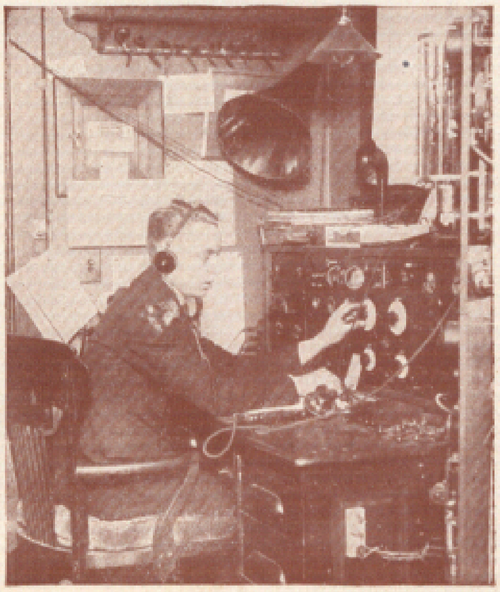
These stations send out music, news, lectures, market reports and things of general interest on regular programs. Their equipment is very complete and every station requires the services of a number of men with a thorough knowledge of transmitting by wireless.



The United States Naval Radio Station at Arlington, Va. This is one of the highest powered stations in the world. The towers are 600 feet high and built to form a triangle. Speech has been transmitted from Arlington to Eiffel Tower, Paris, a distance of 3,900 miles, and from Arlington to Hawaii, a distance of 5,100 miles.

Picture in Center

The interior of the Government station at Arlington. This shows a section of the power room with 30 K.W. arc transmitters, switchboards and oscillation transformers.



Picture to left shows a very compact radio set with the apparatus for transmitting and receiving combined on one panel. This set is used for either speech or code transmission. The small horn you see on top of the cabinet is attached to a magnavox which amplifies the incoming signals so that any one in the room can hear them without using the head receivers. The large horn is for the transmission of music.

or telephone was impossible. But with wireless such accidents cannot happen—the engineer will be in constant touch with the despatcher at all times, at any point on the line. In times of severe storms, when wires are "down," trains "stalled," and service crippled in general, wireless, and wireless alone, can keep the affected districts in touch with the outside world.

And so too, at sea. Here wireless has, perhaps, won its greatest victories. A sinking ship, or a vessel in distress is able not only to signal for help, but to talk with its would-be rescuers as they are rushing to its assistance, a thing that is and has been impossible with wire communication.

Thus, Wireless bridges the greatest gaps—distance is only a matter of moment. Communication by wireless may be had instantly with the most remote corners of the globe, the arctic wastes, the lonely rancher or miner hundreds of miles from the nearest habitation, or ships on the farthest seas. And it is so inexpensive as compared with wire communication—the miles on miles of strung wire, or deeply laid ocean cable,—that its future is as assured as is the future of Electricity itself—Wireless is here to stay.

SOUND AND SOUND WAVES.

I want you at this point to have an understanding of sound and its relation to the human ear as the receiver. When two people are talking to each other we cannot rightfully say that the sound travels between them as sound is the result produced by waves transmitted to the ear drum from which a sensation is sent over the auditory nerve to the brain. Waves themselves do not produce sound. If there are no ears to receive this wave motion and transmit the sensation to the brain there is no sound.

In speech the vibration is created in the back of the throat by a membrane known as the vocal cords which are set in motion by the breath. This vibration disturbs the surrounding air and sets it into a wave motion which is transmitted to the ear.

From the above we learn that there are three essential elements in the production of sound, namely vibration, a medium through which these vibrations can be carried, and a receiver to accept and transform them. In the above example the vocal cords are the vibrator, the air the conducting medium and the ear the receiver. Therefore, in the case of ordinary speech, if the conducting medium were removed, there would be no sensation of sound.

An interesting experiment in this connection is to hang an electric bell inside of a bell jar, Fig. 1, the bell is then connected to a battery and the ringing is plainly heard. While the bell is ringing, extract the air from the jar with a suction pump, you will notice that the ringing becomes dimmer and dimmer until it fades out entirely when all of the air is extracted from the jar. The observer will hear no sound but he can readily see that the bell is ringing as the clapper is in motion.

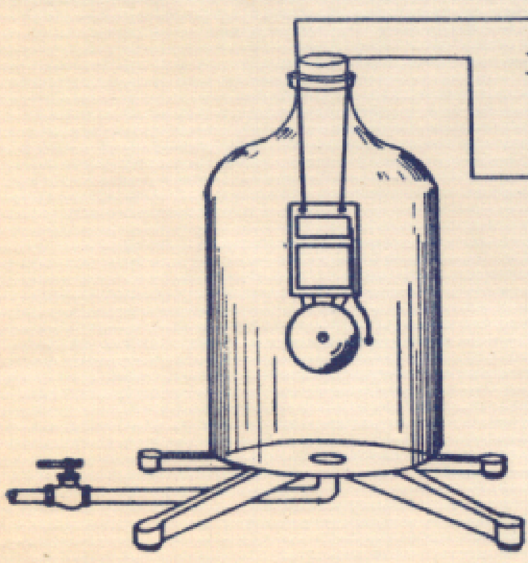


FIG. 1 BELL JAR

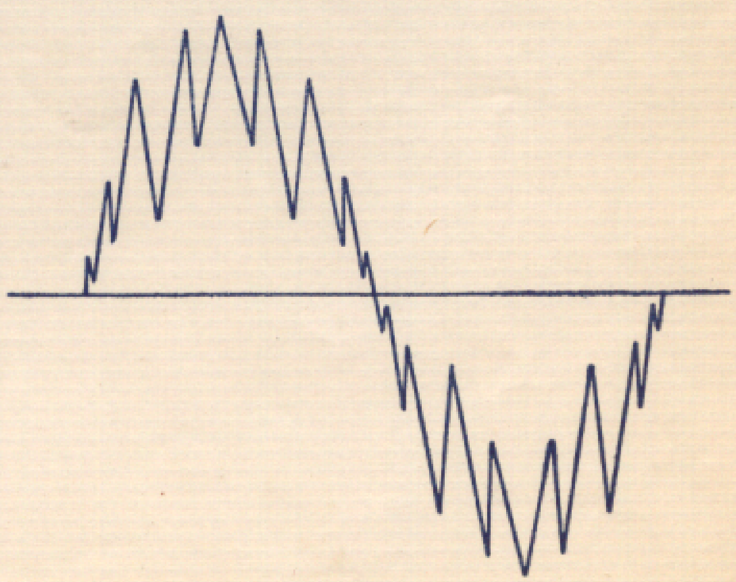
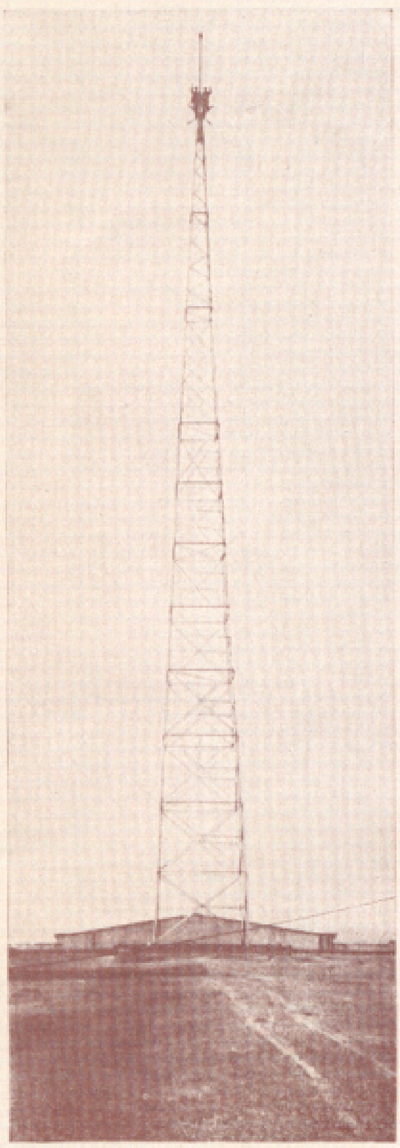


FIG. 2. OSCILLOGRAM

At the left, Sergt. Lawrence W. Bock at Fort McPherson "listening in" on the concert. Out of the way military posts will no longer be lonely for the men, for by means of the radiophone they will be able to get the musical entertainments which are broadcasted, and also immediate news of the outer world.

Below Assistant Secretary of the Navy Theodore Roosevelt has also caught the radio fever. This instrument is a high power navy radiophone which has been installed in his home in order that he and his family may enjoy the nightly concerts by the various bands aboard the warships far out at sea.



The giant aerial tower of the broadcasting station of the General Electric Company, Schenectady, New York, which sends out entertainment and music for thousands of operators. The tower is 183 feet high and supports the aerial.

Bear in mind now what I have explained regarding the production of sound and we will trace through from the beginning each step necessary for the human ear to receive the sensation of sound.

Imagine that you are in my office and I am talking to you. Each word that I speak causes my vocal cords to vibrate, this vibration disturbs the surrounding air, setting it into a wave motion which contains every irregularity of the vibration producing it. The wave motion then carries to your ear and strikes the ear drum and, since it contains the same irregularities as the vibrations, it starts the ear drum to vibrate in exactly the same manner as my vocal cords did and the auditory nerve, which is attached to the ear drum, carries this sensation to your brain and there records the sound.

Fig. 1A shows a cross section of the ear (a) represents the external ear which is the collector of waves, (b) is the ear drum which is a membrane or diaphragm so constructed to be easily set into vibration by waves of air, and (c) is the auditory nerve connecting the ear drum to the brain over which the sensation caused by the vibration is transmitted, and the brain records the sound.

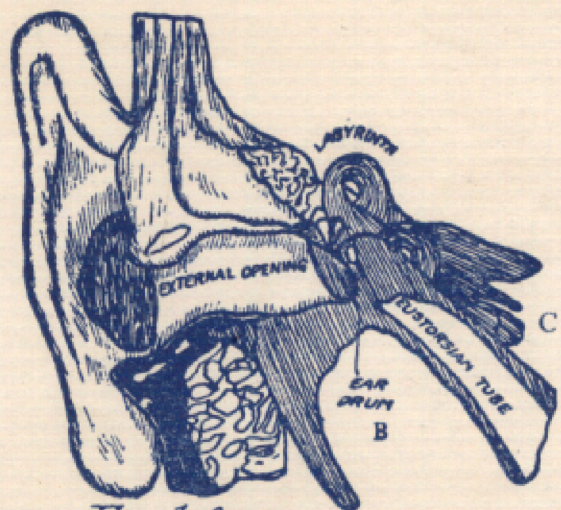


FIG. 1A

Communication by telephone or radio is identical in its principles to what you have just learned regarding ordinary sound transmission. When you speak into a telephone your voice wave sets the diaphragm into vibration, this vibration causes an electrical wave motion which is transmitted either by wire or wireless, whichever the case may be, to the receiver. The receiver also contains a diaphragm and is set into vibration by the electric wave. As this diaphragm is exposed, the surrounding air is set into motion and therefore the ear at the receiver is able to hear the voice spoken into the transmitter.

The wave form caused by voice vibration is very irregular and complexed. Fig. 2 shows an Oscillogram of wave motion caused by voice vibrations. The problem in radio telephony is to transmit this wave form exactly as it comes from the vocal organs. I have stated that the period of speech vibrations is too slow for radio transmission, the sending is therefore accomplished by retaining the true form of the voice wave, but making it up of many waves of a more rapid period of vibration, as illustrated in Fig. 3.

Air is the medium through which voice waves are transmitted. The electromagnetic waves of radio are transmitted through ether. Ether is found everywhere, it cannot be shut out. Performing the same experiment with the electric bell in the jar and using the vibrating contacts of the bell as a miniature radio transmitter as an electric spark occurs there, which sends out electromagnetic waves. A radio receiver would pick up the oscillation of the spark equally as well before or after the air had been extracted.

CATCHING THE CRIMINAL BY WIRELESS

Larger picture shows police officers at headquarters, sending instructions and receiving messages from the men in the field.

"Daniel," a famous police department horse, "stands by" while his master picks up a message from headquarters.

Picture in circle is of police department automobile apparatus for sending and receiving.

Wireless is rapidly taking first place as the greatest means yet adopted to aid the police department in catching criminals. All police automobiles and patrols in the larger cities are being equipped with both receiving and transmitting outfits so that they may be in communication with headquarters at all times. Each policeman on patrol duty carries a miniature wireless telephone, from which he will be able to receive messages, but cannot send. The instrument is small enough to be held in his hand and can be tuned to receive the instructions from headquarters. The receiving antenna, or aerial, is made of a network of wires placed in the lining of the policeman's coat.

Stop and consider for a moment the great advantage attached to such a system of communication. Supposing that a bank is held up and robbed and that the robbers leave the bank in a large black touring car, headed north, we will say, on Western Avenue. This information is broadcasted from headquarters and every police automobile and patrolman in the neighborhood of the bank are on the job immediately. See the time that is saved in picking up the trail of the robbers. Also while the police cars are in pursuit they are not only in communication at all times with each other, but with headquarters, receiving additional instructions and advising headquarters of their progress, or maybe asking for additional help.

ART OF WIRELESS COMMUNICATION.

In order to clearly understand the principles of signal or voice transmission by wireless, it is necessary for you to have a good idea of wave motion and its conducting medium.

We will take, for example, a pond of water, 25 ft. in diameter. If a stone is thrown into the middle of the pond, waves radiate out in all directions starting from the point where the stone breaks the surface of the water. Corks placed on the surface of the water around the edge of the pond, bob up and down responding to the wave motion caused by the stone striking the water. By varying the rapidity with which the water is struck and also by varying the force of the impact, it can be clearly seen that different lengths and sizes of waves will radiate out in all directions and the floating corks will respond to each varying motion. In making the comparison to wireless, the stone striking the water is the transmitter; the corks are the numerous receiving stations, and the water is the conducting medium.

In the actual wireless instrument, the transmitter is a device containing a diaphragm (thin metal disc) which is set into vibration by the voice wave and in turn transforms, through its mechanism, the voice to electrical waves which are transmitted to the receiving end. I have mentioned that the frequency of the voice wave is approximately 800 to 1000 cycles per second which is not rapid enough for satisfactory radio transmission; however, the human ear will respond to sounds of 10,000 cycles per second and for that reason it is used as a convenient dividing figure. It is, therefore, of immediate importance to remember the following definitions:

(A) Electric currents at frequencies below 10,000 cycles per second are called Audio frequencies.

(B) Electric currents at frequencies above 10,000 cycles per second are called Radio frequencies.

ELECTRIC WAVE TRANSMISSION.

Radio messages are conducted by means of electric waves, which are generated by alternating currents. The wave lengths are easily determined when the frequency is known. The velocity of electricity is computed as 186,000 miles per second which equals in round figures to 300,000,000 meters per second, then dividing 300,000,000 by the frequency will give the wave length in meters. Or conversely by dividing the velocity of electricity by the wave length, the result obtained will be the frequency. For example, amateur wireless stations are limited by the U. S. Government to 200 meter wave length for transmitting. The frequency then for generating these waves is $\frac{300,000,000}{200} = 1,500,000$ cycles per second.

Ether is the conducting medium and the electromagnetic waves are the means of communication. Little is understood about ether at the present time; it is found everywhere in space, in the pores of all substance, wood, stone, concrete, etc., in fact every available spot that is not occupied by another substance.

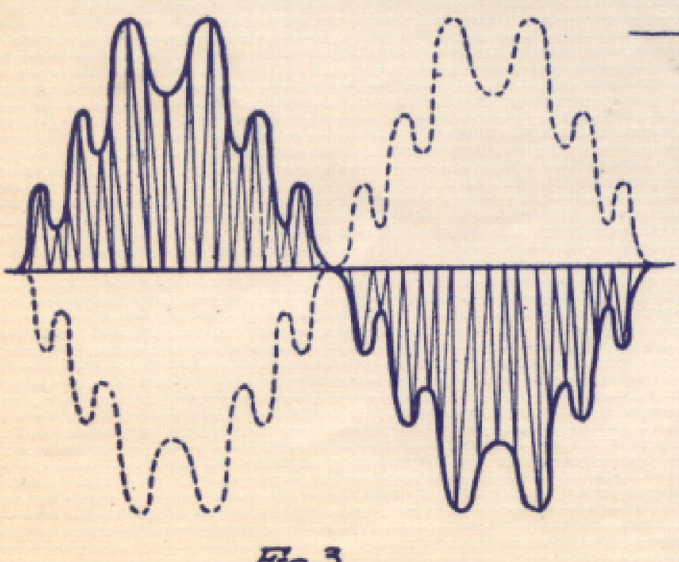


FIG. 3.

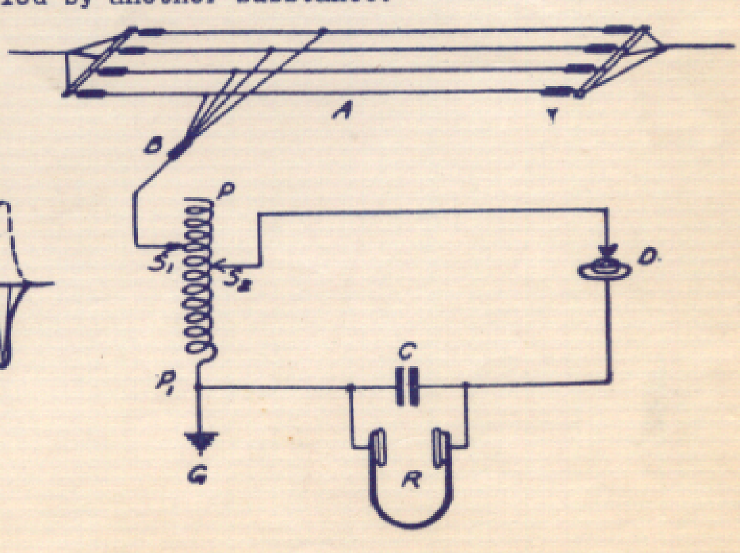


FIG. 4.

RADIO RECEIVING APPARATUS.

In general, the radio receiver is a device designed to intercept the electromagnetic waves, which are being transmitted by the sending station and convert them into audio frequency vibrations of such a character as will cause a response in the telephone receiver. This is accomplished in the following manner: Figure 4 shows the layout of a simple receiving set, all of which, with the exception of the head telephones can be constructed by the beginner. A set of this description will afford excellent practice to one just starting in to study wireless as it is suitable to receive code signals from nearby transmitters. A is the Antenna or Aerial, which is constructed of four lengths of No. 14 B. & S. gauge bare copper, each length approximately 35 ft. long and insulated from the spreaders at each end. For good reception the antenna should be from 40 to 50 ft. above the ground. The usual place for installation is on the roof of a house or suspended from the roof to a tree, making sure that the wires have at least one foot clearance from the branches or other obstacles. B is the lead in wire which is common to all four antenna wires and is of No. 14 weatherproof insulated copper wire. The tuning coil P may be constructed by winding very closely a single layer of No. 26 silk or cotton covered copper wire on a cardboard tube 3" in diameter and 8" long. The wire may be bared for the slider contacts S 1 and S 2 by a sharp pointed knife. D is a mineral detector usually a crystal of galena fastened in a cup container and with a flexible pointer applied to the surface at a sensitive spot. The function of the detector will be fully explained in a later paragraph. The other terminal of the tuning coil P is connected to the ground, a water pipe or a steam radiator.

The condenser C may be constructed by using 12 sheets of tin or lead foil 3"x4" separated by paraffined paper, 6 sheets of the foil are connected in parallel.

R is a high resistance receiver, the ordinary telephone receiver will not do because of its low resistance. For satisfactory results, a radio head receiver should have at least 1000 ohm resistance. The present day radio receiver has a resistance as high as 3300 ohms.

In lesson 2 I am giving you a brief explanation and review of the elementary principles of electricity and magnetism. Study these over very carefully, also if you find that some of these points need to be more fully explained go over and carefully review the main points brought out in lessons 1 to 17 of my general course. Do not slight this review as you will find that knowing the elementary principles of electricity and magnetism are absolutely necessary for the study of wireless.

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Radio Lesson 2

Modern Radio Communication

The operation of all wireless telegraph and telephone apparatus depends upon very simple laws of electricity and magnetism. There is absolutely nothing mysterious about wireless, and anyone who understands the simple laws of electric circuits will have no difficulty in adapting the application of these simple laws to radio communication.

I will, therefore, first take up in brief form some of the more common and elementary facts about electricity and magnetism, and then show you how wireless circuits employ these facts. Of course, elementary electricity and magnetism are taken up in very complete form in the early lessons of my regular course in Practical Electricity, which, I am sure, is the most fascinating subject that any man can take up at the present time, for it is electricity that has made the twentieth century what it is today.

THE NATURE OF ELECTRICITY.

A simple electrical experience that practically all of us have had, is to rub a hard rubber fountain pen on our coat sleeves and then pick up tiny bits of paper with it. We say that there is electricity on the fountain pen and that it was produced by friction. A similar effect can be produced if we comb out hair on a cold dry morning with a celluloid comb. Such electricity which rests on an object that has been rubbed is called static electricity (meaning stationary electricity).

The electricity that is produced by a dry cell or storage battery differs in that it moves or flows very rapidly through the wire connected to the battery. Such electricity is called dynamic electricity (meaning moving electrically. The movement of electricity through a wire is called an electric current. All electricity used for commercial purposes is in the form of electric currents. It is the electric current flowing through an electric lamp which causes the lamp to give off light, just as it is the electric current flowing through the motors that causes a street car to move along so rapidly.

We want to bear in mind, then, that there are two kinds of electricity, static and dynamic, and that it is dynamic electricity in the form of electric currents which is used so extensively commercially. Electric currents can be produced by means of dry cells or storage batteries, and in larger quantities by means of machines called electric generators or dynamos.

ELECTRIC CIRCUITS

Electricity cannot always be used at the place it is produced but must often be sent long distances. For carrying or transmitting electricity some materials are better than others, and we therefore classify them as conductors and insulators. A conductor is a substance through which electricity can flow very freely, while an insulator will not allow electricity to flow through it. The metals, especially copper, are good conductors, while such materials as glass, hard rubber, fiber (pressed paper), porcelain, etc., are good insulators.

In order that an electric current can flow, a wire must be used for conducting it from the place it is generated to the place it is consumed, and another wire to carry it back again. This complete conducting path through which the current flows is called the electric circuit. In order that the current can flow there may be no gap or break in the circuit, that is, the circuit must be closed. By opening the circuit we break the continuous path and thus prevent the circuit from flowing. Switches of different kinds are used for opening and closing circuits.

The flow of electricity through a wire can be compared to the flow of water through a pipe. In order that the current can flow there must be an electrical pressure. This electrical pressure is often called electromotive force and is measured in volts. The rate at which the electricity flows through the wire is measured in amperes. As the current flows through a conductor it experiences a certain amount of electrical friction called resistance. Electrical resistance is measured in ohms. The current used in the electric lighting circuits in our homes is under a pressure of 110 volts.

The amount of current taken by the average size lamp is about 1/2 ampere, while the resistance of the lamp is about 220 ohms. We thus say that a current of 1/2 ampere flows under a pressure of 110 volts, and in flowing through the lamp it experiences a resistance of 220 ohms.

MAGNETISM.

Nothing is more interesting than to buy a small horseshoe magnet for a nickel and to experiment with it. We find that the magnet will attract and pick up only small pieces of iron or steel, but nothing else. It is for this reason that only iron and steel are used in the construction of electrical machinery. An interesting experiment is to lay a magnet flat on a table and put a piece of paper over it, and on this paper sprinkle some iron filings. Iron filings are tiny particles of iron obtained by filing. If the paper is gently tapped with a pencil, the iron filings will arrange themselves along definite lines, called magnetic lines of force. The magnetism is said to act along these lines. They can be seen to come out of one end of the magnet and enter at the other end. The end at which the lines leave the magnet is called the North pole and the end at which they enter is called the South pole. My lesson No. 5 on Magnetism tells you more about magnets and magnetic poles, and you surely will find it most interesting reading.

ELECTROMAGNETISM.

Whenever we have an electric current flowing through a wire, another peculiar condition results, namely, the wire is surrounded by magnetic lines of force. We can have magnetism without having an electric current (as with the little horseshoe magnet we experimented with above), but we cannot have an electric current without also having the lines of force surrounding it. These lines of force surround the conductor in the form of concentric circles, that is, circles all having the wire as a common center. Such magnetism, established by means of an electric current, is known as electromagnetism. Electromagnetism is taken up fully in lesson 12 of my course in practical electricity.

The number of lines of force around a conductor depends upon the strength of current (number of amperes) flowing through the conductor. If the current flowing is increased, the lines of force expand and spread outward and new lines are formed, while if the current is decreased the lines of force shrink together and a smaller number remain. If the current stops flowing altogether, the lines of force collapse completely and disappear within the conductor. Thus as the current within the conductor varies, the lines of force around the conductor also change—they either expand or collapse accordingly as the current increases or decreases.

ELECTROMAGNETIC INDUCTION.

In the previous paragraph we learned that whenever an electric current flows through a wire, that wire is surrounded with magnetic field. The magnetic field, therefore, is a result of the current flowing through the conductor. Now it happens that the reverse also is true, that is, if we can establish a magnetic field around a conductor there will be flowing an electric current within the conductor. The process of establishing a magnetic field around a conductor is very simple, for whenever a conductor moves through a magnetic field so that it cuts the lines of force, the lines will wrap themselves around the conductor with the result that there is flowing within the conductor an electric current. Such a current produced by having a conductor cut lines of force is called an induced current, and the process of producing the induced current is called electromagnetic induction. Electromagnetic induction is taken up in lesson 17 of my regular course.

Instead of having the magnetic field stationary and the conductor moving through the field, it is also possible to have the conductor stationary and the magnetic field moving. A moving magnetic field can easily be established by sending a pulsating current through a conductor, this pulsating current will then create a pulsating magnetic field around the conductor. If, then, another conductor is near the first one, the lines of force in expanding and collapsing will cut the secondary conductor and induce in it an electric current. This principle is illustrated in Fig. 2, in which a pulsating current is caused to flow through the circuit A. This pulsating current creates a variable magnetic field which cuts the turns of the coil in circuit B, and in doing so induces in it an electric current. This principle of current induction is used very extensively in wireless circuit. Lesson 17 of my course in practical electricity tells you a great deal more about current induction and induction coils.

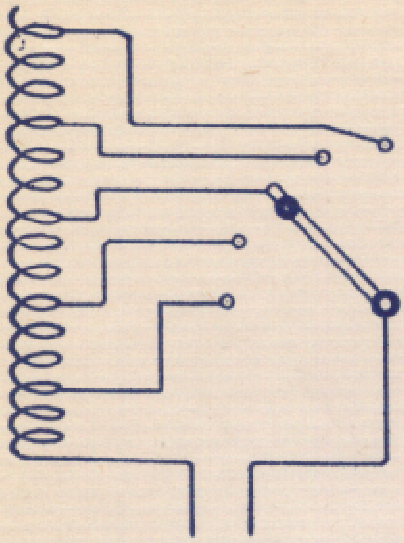


FIG. 1.

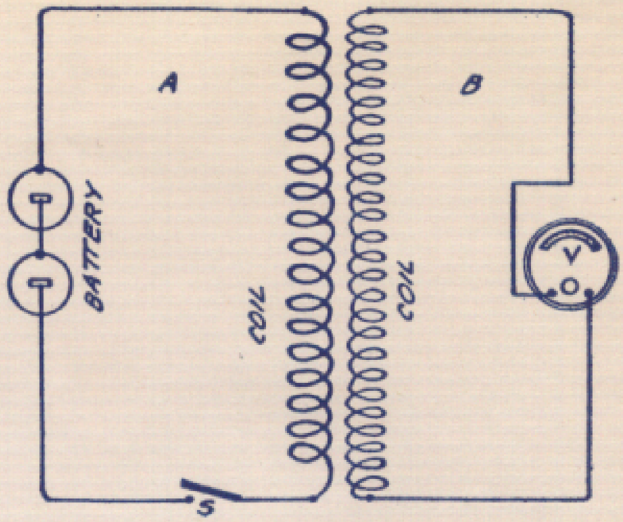


FIG. 2.

SELF INDUCTANCE.

Self inductance is that property of an electric circuit which prevents any sudden or instant change in current flow, in other words, it always tends to maintain a current flowing at the same value. If a switch is closed and an electromotive force impressed across the circuit, the current cannot instantly rise to its final value, due to a counter-voltage which it experiences. Similarly if a current of a given strength is flowing in a circuit and the switch is suddenly opened, the current cannot instantly decrease to zero, for the inductance of the circuit again develops a voltage which tends to keep the current flowing at its former strength. Due to this inductive effect, a spark or flash occurs at the opening of the switch. This is especially noticeable when the field switch of a large generator is opened.

The amount of inductance in a circuit depends upon several conditions. If the conductor is wound in the form of a coil, the inductance is much greater than if it is in the form of a straight wire or single loop. Also the greater number of turns in the coil, the greater is the inductance. If it is desired to have an inductance of variable value, a coil is generally wound with taps brought out at every fifth or tenth turn by means of which the coil can be connected to the external circuit. By thus changing the number of effective turns by means of a dial switch as is illustrated in Figure 1, the amount of inductance in the circuit can be changed. The inductance of a coil also depends upon the nature of the core. If the coil is merely wound on a hollow form, having an air core, then the inductance depends only upon the number of turns of wire in the coil. If, however, the coil is wound around an iron core, then the inductance of the coil is very much greater, and depends not only on the number of turns but also on the magnetic condition of the iron—the more permeable the iron, the greater the inductance.

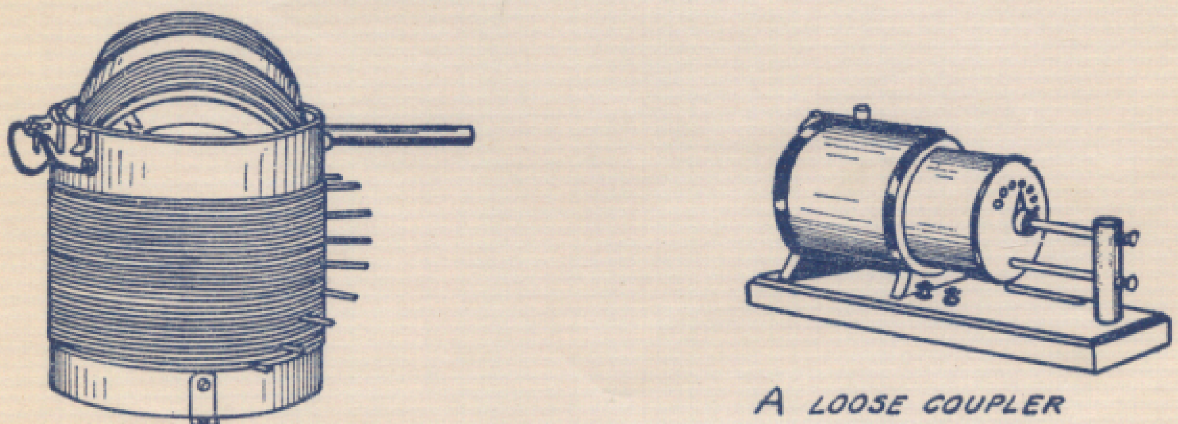
Self inductance, it is to be remembered, takes place only in a single coil or circuit, and may be looked upon as a sort of electrical choking effect. Self inductance is measured in Henrys and is always represented by the capital letter L.

MUTUAL INDUCTANCE.

Mutual inductance is the relation existing between two nearby circuits due to which a current is induced in one circuit when the current in the other changes or varies. Mutual inductance thus always involves two coils or two individual circuits. In Figure 2 we have two circuits inductively related, that is, we have two coils with one wound on top of the other. In circuit A we have one coil connected to two dry cells in series with a switch S. In circuit B we have the other coil connected to a voltmeter. If we now close the switch S, current at once begins to flow in circuit A, but it cannot reach its final value instantly, due to the inductive or choking action of the coil. As the current gradually builds up, lines of force spread out around coil A, and as these lines expand, they cut the turns of coil B and induce in them a voltage which is indicated by the voltmeter. Also, whenever there is any change in current flow in coil A, there is a variation in the magnetic field surrounding it; and this change in the magnetic field causes a current to be induced in coil B. Hence, no change can take place in either circuit without producing a corresponding change in the other circuit.

This principal is used extensively in wireless circuits, in which we always have two or more circuits inductively related, so that when a variable or pulsating current flows in one circuit there will be a corresponding change in current flow taking place in the other circuits. It is also generally desired in wireless circuits to be able to vary or change the amount of influence that one coil has upon the other. This is accomplished in one of two ways. The simpler arrangement is to wind one coil on a suitable support that it can slide into and out of the other coil. The greatest influence is then obtained when the movable coil is entirely enclosed by the stationary coil. As the coil is gradually moved out, the influence or mutual inductance decreases until when the coil is completely removed the inductance effect is zero. Such a pair of coils are illustrated in Figure 3A.

Another method of producing a variable mutual inductance is by mounting one coil on a shaft so that it can be rotated within the other. When the axes of the two coils are parallel or in the same line with each other, then the inductive influence of one coil upon the other is maximum; but when the one coil is rotated so that the axis of the two coils are at right angles to each other, then the inductive influence is zero, that is, one coil will have absolutely no effect on the other coil. A form of loose coupler of this type is illustrated in Figure 3B. It is also called a variocoupler because it has a number of taps brought on the primary winding.



"B" VARIOCOUPLER

A LOOSE COUPLER

FIG. 3.

Two coils constructed in this manner so that their inductive relationship can be varied, are commonly called a loose coupler in wireless language. Another term often used for the same apparatus is variometer, which suggests the possibility of varying the inductive relationship between the two coils. An important point to bear in mind is that inductance is effective only as long as the current is changing; for as soon as the current is steady, the magnetic field becomes stationary and no further influence is produced.

CAPACITANCE.

Capacitance is another electrical effect that is present in many electrical circuits; and just like inductance, capacitance also plays a most important part in wireless circuits. Capacity effects are generally obtained in wireless circuits by means of a condenser. A condenser consists of two sets of parallel metal plates, each set insulated from each other, but the plates of each set are electrically connected. A condenser is illustrated in Figure 4A.

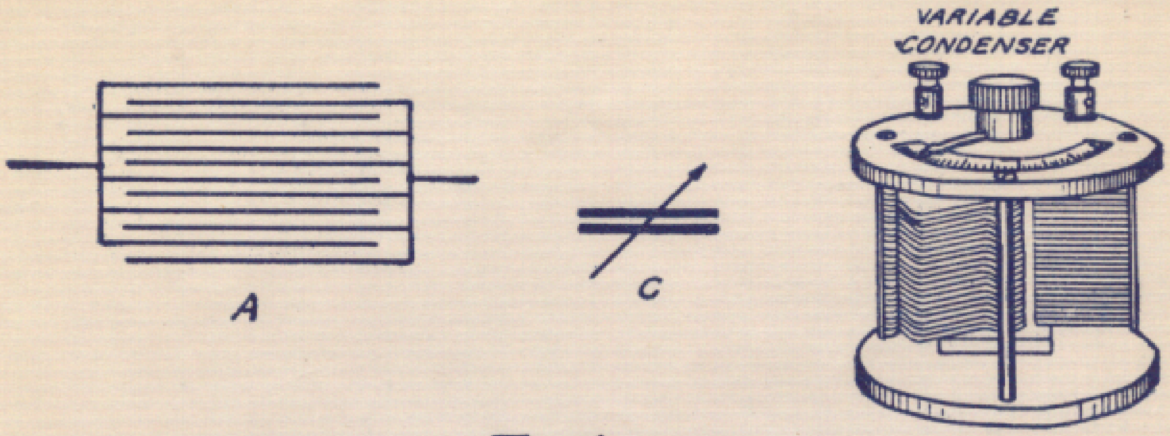


FIG. 4 B

The chief purpose of a condenser is to store up electrical energy. Thus, if in Fig. 4A, we connect the two sets of plates to the terminals of an electrical circuit, one set of plates will become positively charged while the other set will become negatively charged. Enough electricity will accumulate on the plates until the electrical pressure on the condenser will be the same as that of the electrical circuit to which it is connected. If the circuit leads are then disconnected from the condenser and the two sets of plates are connected by means of a wire, the condenser will discharge at once; that is, an electric current will flow from the positive plate of the condenser around through the wire to the negative plate. This movement of electricity or current flow will continue until both sets of plates are at the same potential or pressure.

The capacity of a condenser depends upon several factors, such as the area of the plates, the distance between them, and the nature of the insulating material between the plates. The greater the area of the plates, the greater is the capacity of the condenser; also the closer the plates are together, the greater will be the capacity of the condenser. Most condensers used for wireless work merely have air as an insulating material between the plates, but for some purposes, mica condensers are used. If mica is used, the capacity of the condenser is greater than if air is used. The insulating material is commonly called the dielectric. The capacity of a condenser is measured in Farads and is always represented by the letter C. Since the Farad is a very large unit, the microfarad is more commonly used for commercial purposes. One microfarad is one-millionth of a Farad.

If a condenser of variable capacity is wanted, it is constructed so that one set of plates can be shifted in and out between a set of stationary plates as is illustrated in Figure 4B. When the movable plates are set so that they are completely covered by the stationary plates, the capacity of the condenser is maximum. By rotating the movable plates, so that they are only partially covered the capacity can then be reduced to any desired value. A variable condenser is always represented by two straight lines with an arrow passing through them at an angle, as is shown in Figure 4C.

NATURE OF THE DISCHARGE.

A charged condenser can be compared to two vertical tanks, A and B, connected at the bottom with a pipe containing a valve V, as is illustrated in Figure 5. One tank is filled with water to a certain height and the valve is closed. The height of the water level in tank A, above the bottom of the tank B may be compared to the difference in electrical pressure existing across the two sets of plates of a condenser. Connecting the two sets of plates with a wire is equivalent to opening the valve so that the water can rush into tank B until it stands at the same level in both tanks.

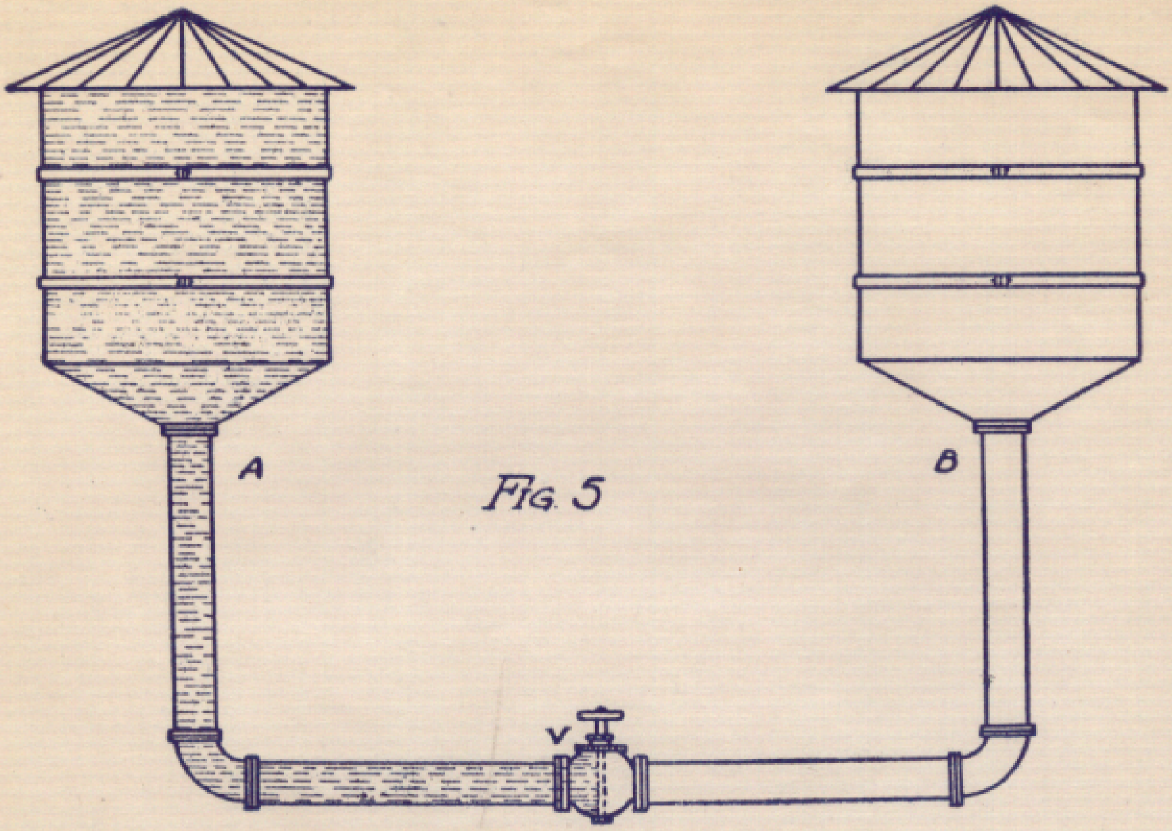


FIG. 5

However, as the water rushes from A into B, it gains such velocity and momentum that it does not stop at the instant both columns are at the same height, but moves some distance beyond. After the water stops, some of it rushes back into A again, and this surging back and forth continues until the water finally comes to a rest and stands at the same height in both columns. The same is true with the discharge of a condenser. The discharge does not consist of a single rush of current from positive to negative plates, but consists of a rapid back and forth surging until both plates are at the same electrical potential. The discharge is thus said to be oscillatory in character, that is, it oscillates back and forth. Due to the energy consumed in overcoming the resistance of the wire, each surge or wave becomes less and less until they die out completely. The waves or surges are thus said to be "damped" and are represented diagramatically as is illustrated in Fig. 6. The amount that each wave or surge is less than the preceding one, is known as the damping factor. These electrical waves or surges take place at an enormous rate, equivalent to several million per second. However, they diminish very rapidly, and hence a condenser discharge lasts only a small fractional part of a second.

OSCILLATING CIRCUITS.

If an inductance coil and condenser are connected in series, a very peculiar type of circuit is obtained. In Figure 7 we have a circuit consisting of an inductance coil, a condenser, and a spark gap connected in series. The spark gap merely consists of two small metal balls separated a short distance. If the condenser is now to be charged with electricity from some high potential source, the pressure across the two sets of plates of the condenser will gradually rise as the charge collects, until the pressure across the spark gap becomes so great that the insulating qualities of the air breaks down and a spark jumps across the gap from sphere to sphere. The passage of this spark renders the air between the two metal balls a very good conductor and permits the condenser to discharge through the circuit.

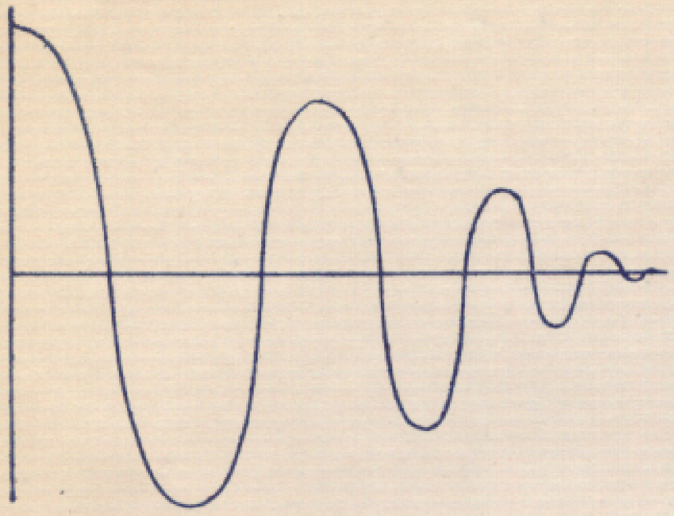


FIG. 6.

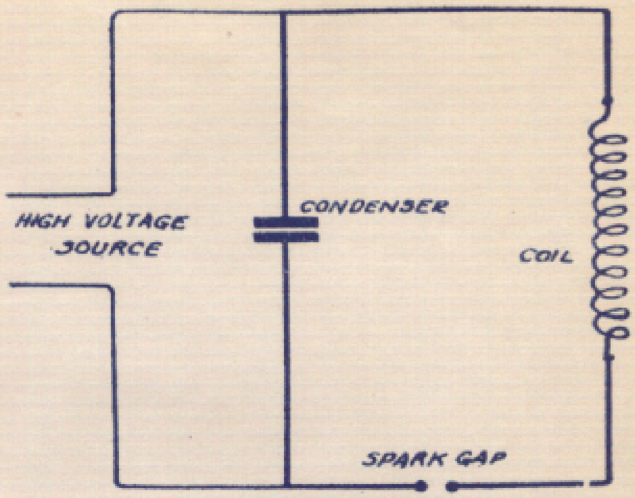


FIG. 7.

As the condenser begins to discharge, the inductance of the coil prevents the discharge current from reaching its final value instantly. Likewise when the current surges back in the opposite direction, the coil helps the surge along and causes it to flow beyond the point at which both plates are at the same electrical potential. This surging back and forth continues until all the energy has been expended in the form of heat in overcoming the resistance of the wire.

These surges take place at an enormous frequency, several million cycles per second. The time required for one complete back and forth surge or wave is known as the period, and is expressed in fractional parts of a second. The period can be accurately calculated from the following formula, in which T is the time in fractional parts of a second, L is the inductance in Henrys, and C is the capacity in Farads.

$$T = 2\pi \sqrt{LC}$$

The value obtained from this formula is known as the period of one oscillation or as the period of the circuit. If it is desired to calculate the frequency of such an oscillating circuit, it is necessary only to find the reciprocal of the period, that is, divide 1 by the period. Thus, if the period of a circuit is 0.000025 second, then the frequency is obtained by dividing 1 by 0.000025, which gives a result of 40,000 cycles per second.

TUNING.

Oscillating circuits used in wireless telegraphy are generally so arranged that the frequency can be varied through a wide range of values by having a variable inductance and a variable condenser. The method of obtaining a variable inductance is by bringing out a number of taps from the windings of the coil as was explained in a previous paragraph. To obtain a variablecapacitance, the condensers are built so that one set of plates is fixed while the other set is movable and can be shifted in and out between the stationary plates. Varying the inductance and capacitance of an oscillating circuit by manipulating the dial switches connected to the coil and condenser so that the circuit will have a definite frequency, is known as tuning the circuit. The usual method of mounting a variable inductance and condenser is illustrated in Fig. 8.

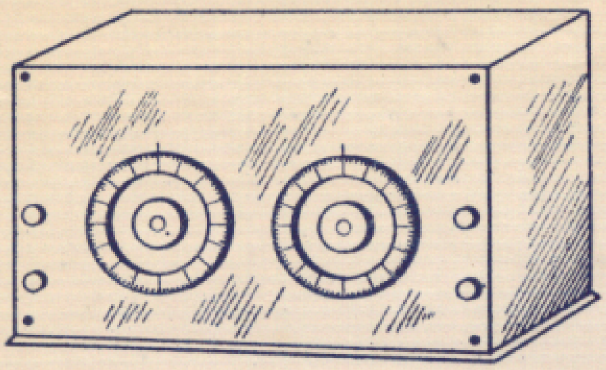


FIG. 8.

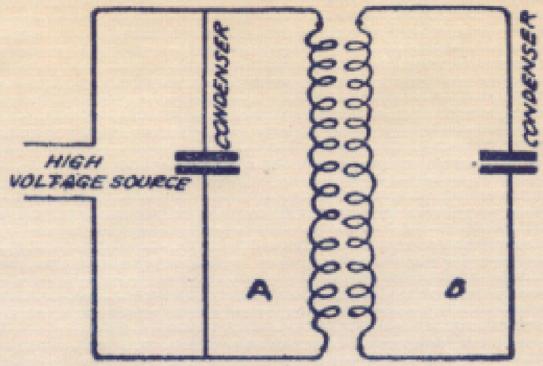


FIG. 9.

COUPLED OSCILLATING CIRCUITS.

One oscillating circuit may be coupled through a mutual inductance to another oscillating circuit as is illustrated in Fig. 9. If a high potential is impressed across the condenser plates to charge the condenser, a spark will jump across the spark gap as soon as the pressure in the circuit has become high enough. This will cause an oscillating current to be set up in circuit A. This oscillating current will induce a similar current in circuit B, due to the mutual inductance of the two coils. If the inductance and capacity of circuit B are such that the period of both circuits is the same, then the two circuits are said to be in resonance. In order that two circuits may be in resonance it is not absolutely necessary that both have the same inductance and the same capacitance, but their periods as calculated from the above formula must be the same. Two circuits can easily be put into resonance by tuning them, that is, adjusting the inductance and capacitance of circuit B so that it will have the same period as circuit A.

OPEN AND CLOSED OSCILLATING CIRCUITS.

In wireless work two types of oscillating circuits are used, known as closed and open circuits. Circuit B, illustrated in Fig. 9, is a closed oscillating circuit because it forms one continuous electrical path. An open oscillating circuit consists of an inductance coupled to an oscillating circuit and a condenser in the form of an antenna and ground, the antenna forming one plate of the condenser and the ground the other. If some means are used to charge the antenna, it will be found that the electrical oscillations are set up in this circuit, just as they were in the previous case, but with one difference. When connected to an antenna and ground of proper characteristics, it will be found that energy is radiated into the space surrounding the antenna as electromagnetic waves, whose length and amplitude depend on the particular values of the inductance L and the capacity C, as well as the resistance of the circuit. These electromagnetic waves travel through space until they reach the receiving or detecting device. There they are caught and their effect recorded.

CHICAGO ENGINEERING WORKS
CHICAGO, ILLINOIS

Radio Lesson 3

Principles of Radio Transmission

Since the invention of the telephone in 1876 the possibility of radio telephony has been evident due to the marvelous sensitiveness of this instrument which will give audible responses when less than one millionth of a volt of electromotive-force is applied.

Anyone accustomed to using a telephone has experienced the sensation of hearing voices other than the one to whom they are directly connected. These interfering voices sound very distant, but nevertheless they are audible. In telephone language this interference is spoken of as a cross-talk and is directly related to wireless transmission, as there is no metallic connection between the transmitter and the receiver of the one hearing these interfering voices. Cross-talk is caused by electromagnetic induction between two parallel telephone lines. A small portion of the wave form which is conducted along the metallic circuit radiates out into space and is cut by the nearby paralleling telephone line in which an electric current is induced having the same frequency and containing the same general wave shape, therefore these responses caused by the induced currents are heard in the telephone receiver. The more sensitive the telephone receiver, the more audible the sound. In wireless work the head receiver must necessarily be very much more sensitive than the ordinary telephone receiver.

RADIO TRANSMITTER.

The transmitter is the portion of the radio circuit and apparatus which creates a disturbance in the conducting medium (the ether) setting up electromagnetic waves which are intercepted by the antenna wires of the receiving station and are there transformed into audible signals at the sensitive head receivers.

HERTZIAN WAVES.

Experiments conducted in 1888 by a young German scientist, Heinrich Rudolf Hertz, showed that by connecting the terminal of a spark coil to two brass balls separated by a small gap, Fig. 1, that the spark caused a disturbance which produced electromagnetic waves. This apparatus is known as the Hertz Radiator or Oscillator, and these waves have since been called Hertzian waves.

When the spark coil is connected to a source of electricity a discharge will pass between the two brass balls. If a loop of heavy wire, as shown in Fig. 2, is brought near to the discharging coil tiny electric sparks occur at its air gap, G, showing that Hertzian waves have been generated. These waves may be deflected or intercepted by using metal screens, but will penetrate wood, stone or concrete, in fact, any non-

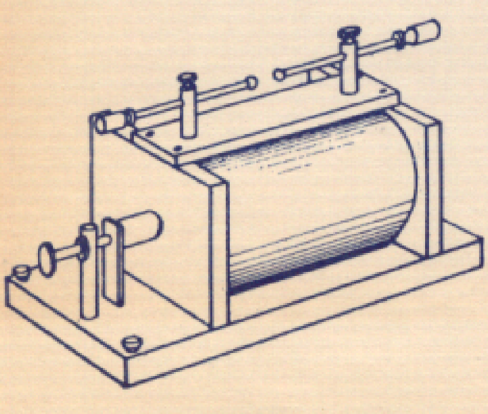


FIG. 1.

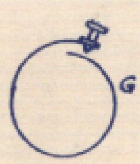


FIG. 2.

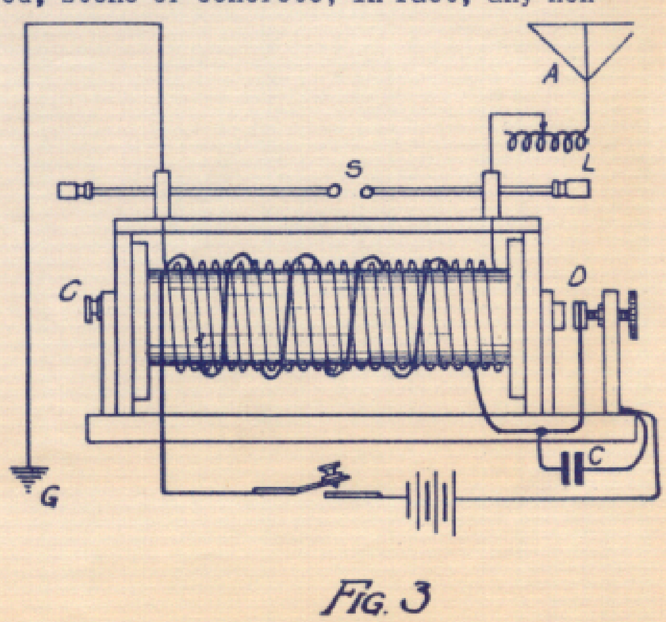


FIG. 3

metallic substance, proving that they are conducted through ether as a medium and with the proper equipment these waves can be intercepted and used as means of communication.

MARCONI TRANSMITTER.

One of the earliest types of radio transmitters developed by Marconi is shown in Fig. 3. The circuit from aerial to ground includes a loading coil, L, which consists of a few turns of copper wire of low resistance (see lesson No. 2 on self induction) a spark gap S and ground G. CD is an induction coil designed to supply at least 30,000 volts across its secondary terminals with an impressed voltage on the primary of about 24. An automatic interrupter is mounted on the end of the coil so that when key K is closed a high voltage current will be induced in the secondary coil due to the rising and falling current wave in the primary circuit. The high voltage current charges the antenna, the stored-up energy discharges across the spark gap and thereby produces oscillations of radio frequency. The wave length of the system can be increased or diminished by cutting in or out the number of turns on the loading coil L.

It is important to explain at this time that spark sets containing no loading coils are not adaptable to a sharp degree of tuning and their use is prohibited by the U. S. Government because of the broad wave form which is sent out and causes a good deal of interference with other stations.

Induction coil sets were used a great deal in the early days of wireless, but today they are mainly used by amateurs for experimental purposes for short distance transmission. They are also sometimes used in a commercial way as auxiliary sets in cases of emergency when the generating equipment is out of order or shut down for repairs.

In lesson 2 you learned the general principles of an oscillating circuit containing inductance and capacitance. I am now going to take up these qualities in connection with wireless transmitting apparatus.

FREQUENCY AND WAVE LENGTH.

I told you we use different frequencies in radio work. Sometimes the frequency is low, around 750,000 cycles per second; and again it may be very high, several millions of cycles per second. But no matter what frequency we are producing in the oscillating circuit, the waves travel through space at the same speed. Each cycle produces one radio wave and that wave starts away from the aerial traveling at 186,000 miles per second. The length of time that elapses before the next wave follows depends on the frequency. At a frequency of 500,000 cycles there will be 500,000 waves leave the aerial every second. At a frequency of 1,000,000 cycles there will be 1,000,000 waves leave the aerial every second. Now it is perfectly plain that with 1,000,000 waves leaving each second they are twice as close together as when only 500,000 leave in a second. That is the same as saying that with only 500,000 waves in a second each wave is twice as long as if there were twice as many or 1,000,000 in a second. The more waves we get into a second the shorter each one must be. The higher the frequency the shorter the waves must be to get them all in.

So far we have been talking about the speed of radio waves in miles per second; but the number 186,000 is not convenient to work with so we make our radio measurements in meters, one of the units of length in the metric system of measurements. We know that 186,000 miles is a distance equal to 300,000,000 (three hundred million) meters. This number, 300,000,000, is much easier to make calculations with then the same measurement expressed in miles

Now we will see how long some of the radio waves are when measured in meters. We know the waves travel at 300,000,000 meters per second (186,000 miles) so the first wave leaving the aerial will be 300,000,000 meters away at the end of a second. The space between that first wave and the aerial is filled with all the following waves. Supposing the frequency is 500,000 cycles or 500 kilocycles. There must then be 500,000 waves in the space of 300,000,000 meters. So we simply divide the 300,000,000 meters by 500,000 and find that each wave is 600 meters long. We call this frequency of 500 kilocycles a wave length of 600 meters. Supposing we had 1,000,000 waves in the 300,000,000 meters. Then, dividing again, we would have a wave length of 300 meters. The frequency of radio waves may then be expressed in meters of wave length, and that is the measure that you will hear used most generally.

TUNING.

It is by means of the various frequencies that we are able to receive only the signals we want to hear and reject those we don't want to hear. If we could not control the frequency at which transmitters and receivers operate it would not be possible to operate more than one sending and one receiving station at a time. As it actually is, there may be scores of sending stations operating at one time, each one using a frequency different from all the others, and there will be no interference or confusion between them. Then, by "tuning" our receiver to receive only a certain wave length or frequency, we will hear only the particular station operating at that one wave length.

The unit for measuring capacity is the farad. This unit is too large for use in radio work so we make our measurements of capacity in millionths of farads called "microfarads" or in the one-millionth part of a microfarad, called a "micro-microfarad." The unit for measuring inductance is the henry. In radio work we often wish to use a smaller measure of inductance than the henry so we generally use the microhenry which is a millionth of a henry or else we may use the millihenry which is the one-thousandth part of a henry. The symbol for capacity is the letter "C" and the symbol for inductance is the letter "L". These are two symbols you should remember in this work.

EFFECT OF INDUCTANCE AND CAPACITY.

When we multiply the number of microfarads capacity in an oscillating circuit by the number of microhenrys inductance in that circuit it gives us a number called the "LC" value of the circuit. This "LC" value determines the frequency at which the circuit will oscillate.

Say we have a circuit with a coil having 375 microhenrys inductance and a condenser with 0.0004 microfarads capacity. Multiply 375 by 0.0004 gives us an LC value of 0.1500 for this circuit. From a table of these values we would find this circuit would oscillate at a frequency of 411 kilocycles or 729+ meters. Suppose we had another circuit whose coil has 300 microhenrys inductance and whose condenser had 0.0005 microfarads capacity. Multiplying 300 by 0.0005 gives us an LC value of 0.1500; just the same as before. So this second circuit would oscillate at the same frequency and wave length as the first. While we decreased the inductance we increased the capacity and it amounts to the same thing. Take a third circuit with 500 microhenrys inductance and 0.0003 microfarads capacity. Multiplying 500 by 0.0003 again gives us 0.1500 so this circuit would also oscillate at the same frequency and wavelength as the first two.

You see, by adjusting or changing the capacity, the inductance, or both capacity and inductance, we can control the frequency at which a circuit will oscillate. We may keep the inductance (the coil) at one value and change the capacity, or we may keep the capacity the same and change the inductance with the same result in the LC value. The process of changing either inductance or capacity or both to make a circuit oscillate at a certain desired frequency is called "tuning" and it is just this that we do when we "tune" a receiver or a transmitter.

CONDENSERS.

In order to construct a condenser of a certain capacity it will be necessary to use the following formula:

$$C=\frac{KA2248}{tx10^{10}} \text{ or } \frac{KxAx2248}{tx10{,}000{,}000{,}000}$$

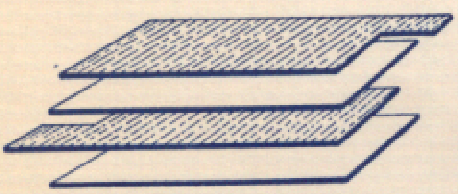
K=a constant for the dielectric which is different for various insulating materials as given in the following table:

TABLE DIELECTRICS

Dielectric	Value of K
Air at ordinary pressure (standard)	1.00
Glass	6.00 to 10.00
Porcelain	4.40
Mica (pure sheet)	6.00
Paraffined paper	3.65
Rubber	1.60

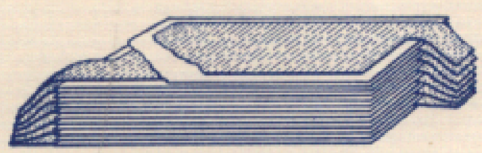
A=the area of the condenser plates in square inches
t=thickness of dielectric in inches
10^{10}=10,000,000,000

For amateur transmitting sets operated from a 60 cycle source with power supply of 250 to 500 watts, .008 mfd capacity for the condenser has been found to be a good average.



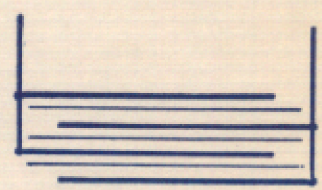
Method of Assembling Plates and Dielectric

Fig. 4A



Condenser Assembled

Fig. 4B



Showing Method of Connecting Condenser Plates

Fig. 4C

Fig. 4 shows the assembly and method of connecting the plates of a fixed condenser.

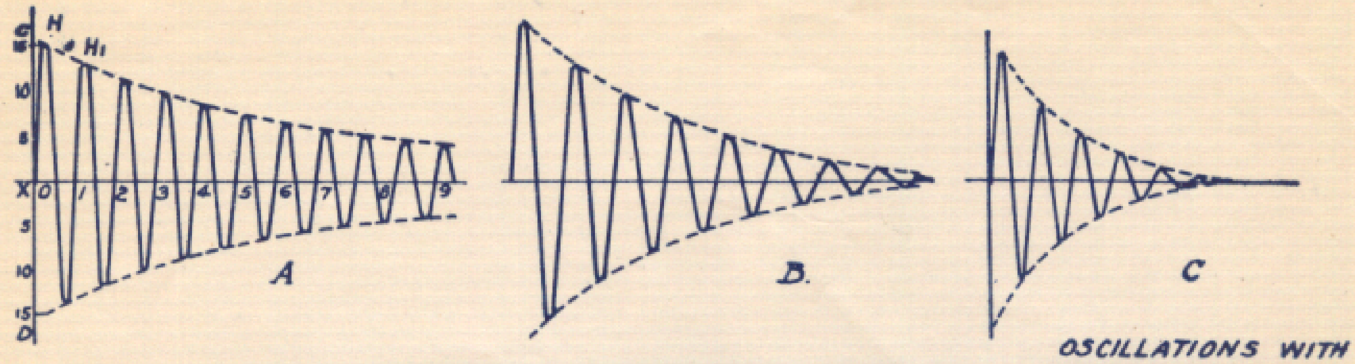
THE WAVE METER.

The method of tuning described above will enable you to bring both circuits into resonance but the question is asked, what is my wave length? It would be a tiresome job to go through the above calculations every time you wished to determine the wave length at which you are transmitting or receiving and furthermore every transmitting set must be licensed by the U. S. Government and assigned a wave length that it must transmit at, there fore, tuning in practice for transmitting is carried on by means of a wave meter. A wave meter is simply a miniature wireless set having a very accurate inductance and capacity either one or both of which may be varied. The wave meter is inductively coupled to the closed circuit and set at a definite wave length, L and C are then varied until the ammeter reads a maximum. L and C are then left at these values and L-1 and C-1 varied until resonance is obtained, then the set is ready to transmit at the desired wave length.

DAMPING DECREMENT.

In order to comply with U. S. Government wireless regulations it is necessary that the transmitting set radiate what is called pure waves, which make it necessary for sharp tuning and, therefore, cause a minimum interference with other stations. The law requires that the oscillations of the antenna circuit shall not exceed a decrement of 0.2 per complete cycle. This means that each spark discharge in the closed circuit L C S, Fig. 4, must cause not less than 23 complete oscillations in the antenna circuit A L-1 C-1.

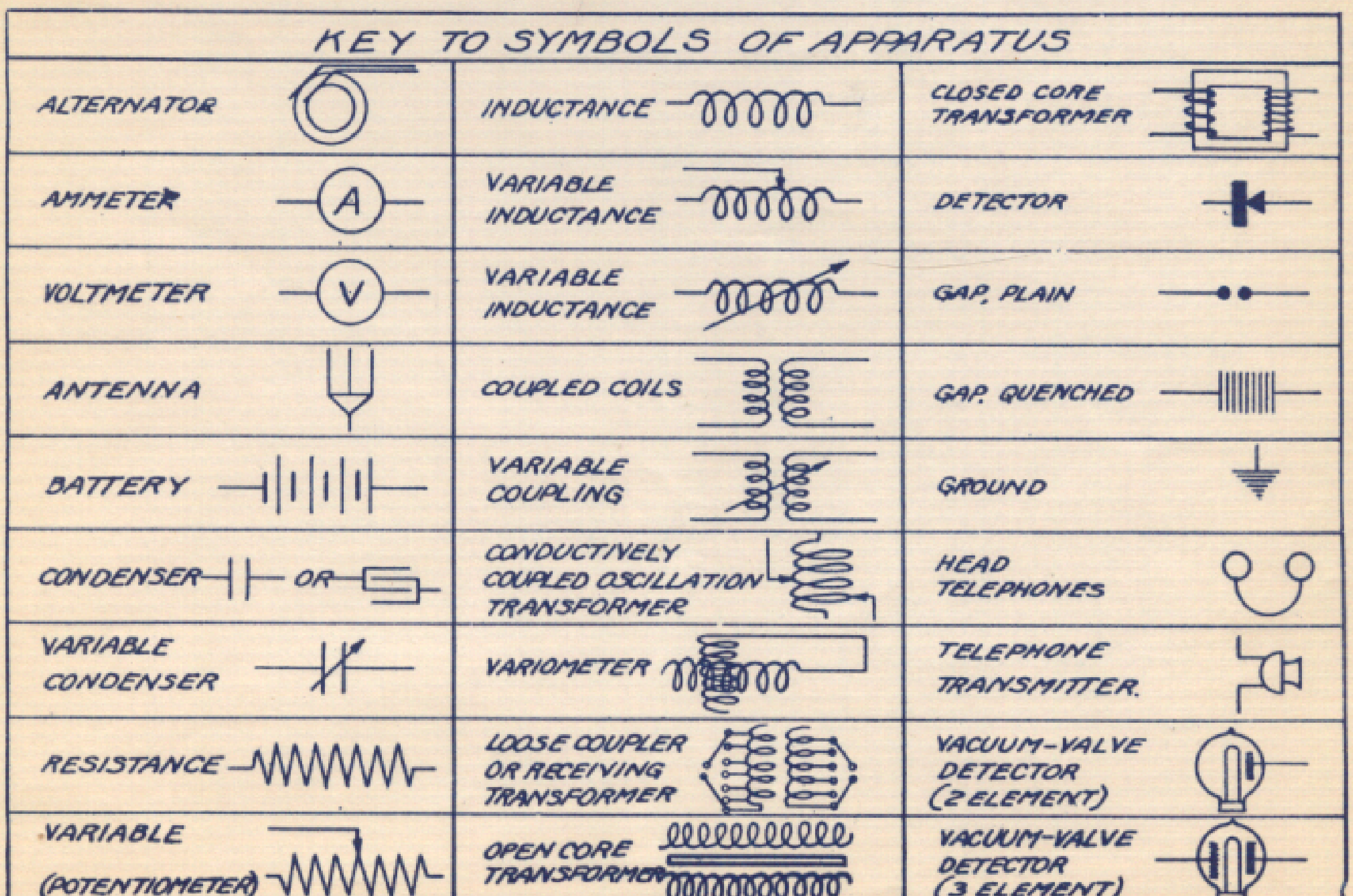
Fig. 5 shows a succession of damped wave trains. C is very highly damped and would not be permitted under Government regulation.



FEEBLY DAMPED OSCILLATION — HIGHLY DAMPED OSCILLATIONS — OSCILLATIONS WITH EXCESSIVE DAMPING

FIG. 5.

The heighth of a wave such as OH is called the amplitude and the horizontal distance x-1 is complete cycle of the wave form. It can be seen that each successive cycle is proportionally less in amplitude than the preceding one. Thus the amplitude of one cycle may be 0.7 of the amplitude of the other and this proportion will be fixed until the wave has entirely died out. But instead of expressing this decreasing amplitude in a numerical proportion, it is expressed in the terms of the logarithm of the ratio as in this form it is more easily handled. Therefore, it is spoken of as the logarithmic decrement. In Fig. 5 suppose the ratio of $\frac{0\,H}{1\,H1}=1.223$ then referring to a table of Naperian logarithms we find that 1.223=0.2 which is the logarithmic decrement of this particular wave train. The logarithmic decrement in practice is ordinarily determined by means of a decrementor and it is very important that the decrement does not exceed 0.2 as



anything above this figure is termed a broad wave and will cause considerable interference in tuning at the receiving and where selectively and good signals are dependent upon sharp tuning.

SYMBOLS.

I have explained in an elementary way the important parts of the radio circuit and their relation to each other. Every radio set whether transmitting or reciving is based upon these principles and contains the various apparatus as described, only connected together in different ways to produce the various desired results. The lessons from now on will contain many circuit diagrams and in order to clearly understand them I am giving you the following table of standard wireless symbols which I want you to study very carefully so that you will recognize them immediately in studying the circuit diagrams.

SPARK GAPS.

I have described to you the simpler form of spark gap as shown in Fig. 6. This represents the earliest type of spark gap used in wireless telegraphy and has many disadvantages. It becomes overheated in continuous operation and has a tendency to arc which causes the air between the two points to remain a conductor which will not permit the condenser to build up to its maximum charge, thereby discharging at a lower potential than desired and the oscillations in the closed circuit are not quickly quenched but continue after the open circuit has started radiating its waves which superimposes waves on the original wave form greatly reducing the efficiency of transmission.

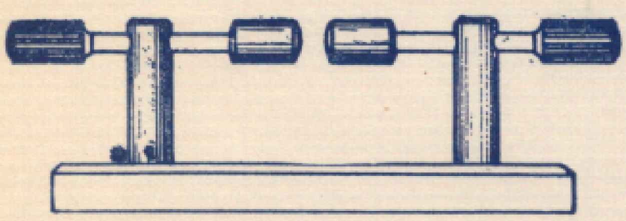


FIG. 6. SIMPLE SPARK DISCHARGE

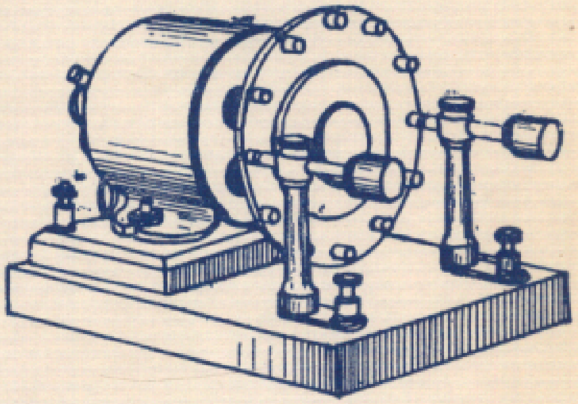


FIG. 7 ROTARY SPARK GAP

NON-SYNCHRONOUS ROTARY SPARK GAPS.

The rotary spark gap as shown in Fig. 7 is more nearly ideal than the one described above. It consists of a small high speed electric motor running from 1700 to 3000 revolutions per minute with a metal disc mounted on the shaft. This disc contains eight or ten electrodes which pass between stationary electrodes directly connected in the closed oscillating circuit. With this arrangement the spark occurs when the electrodes are opposite each other and the resistance of the spark gap becomes greater as the electrodes get farther apart. In this way when the resistance is greatest the condenser is charging and when the resistance becomes a minimum the spark takes place, but the discharge is immediately quenched as the resistance is increased rapidly due to the electrodes becoming farther apart. This type of spark gap described is known as the non-sychronous discharger because the speed of the motor bears no relation to the frequency of the charging current. However, the discharges are uniformly timed, and produce a musical note of a pitch which is more easily read than that produced by the simple gap.

SYNCHRONOUS ROTARY SPARK GAP.

In order to make the rotary gap synchronous the disc containing the electrodes must be mounted on the shaft of the alternator which supplies the power to the oscillating circuit. There also must be the same number of electrodes on the disc as there are poles on the alternator. Fig. 8 shows a synchronous rotary spark gap used on a 3 KW. 500 cycle marconi ship set. In addition to the adjustment for the length of gap, screw R is an adjustment for moving the stationary contacts through an arc so that the discharges can be made to occur at the maximum amplitude of each alternation.

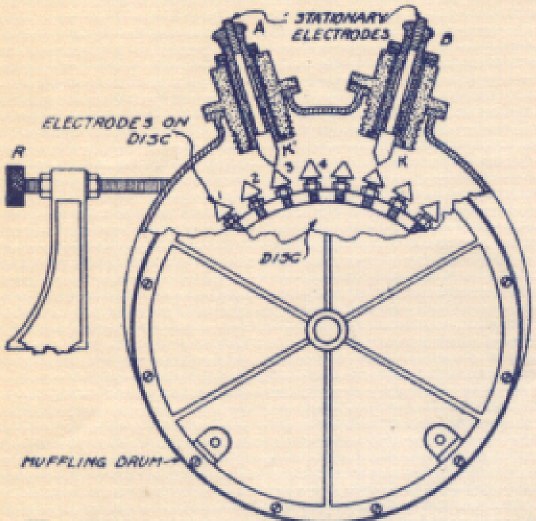


FIG 8 3 K.W SYNCHRONOUS DISC DISCHARGER OF THE AMERICAN MARCONI COMPANY.

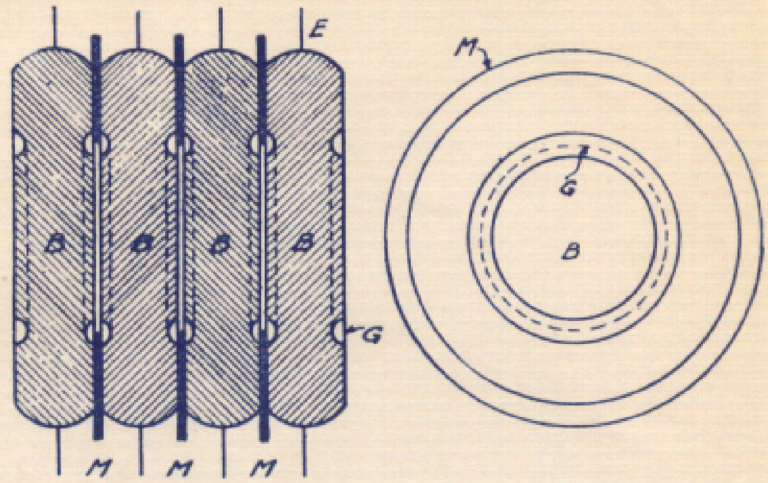


FIG. 9 SECTIONAL AND END VIEW OF QUENCHED SPARK GAP.

QUENCHED SPARK GAP.

The quenched spark gap consists of a number of electrodes of large surface connected in series with a very short gap between each electrodes. I have found this type of gap to be very efficient. It will produce one discharge per alternation of the charging current and can be made synchronous; also it quickly stops each oscillation of the closed circuit, allowing the open or antenna circuit to oscillate at its natural frequency, thereby radiating waves of but one length. In Fig. 9 a quenched spark is shown which consists of a number of copper discs separated by insulating washers and the whole drawn very tightly together to prevent air from entering the discharging surfaces. This type of spark gap is little used by the amateur as its construction requires very accurate machining, the sparking surfaces between plates not exceeding 0.01 inch. It also does not give a very good tone on 60 cycle charging current.

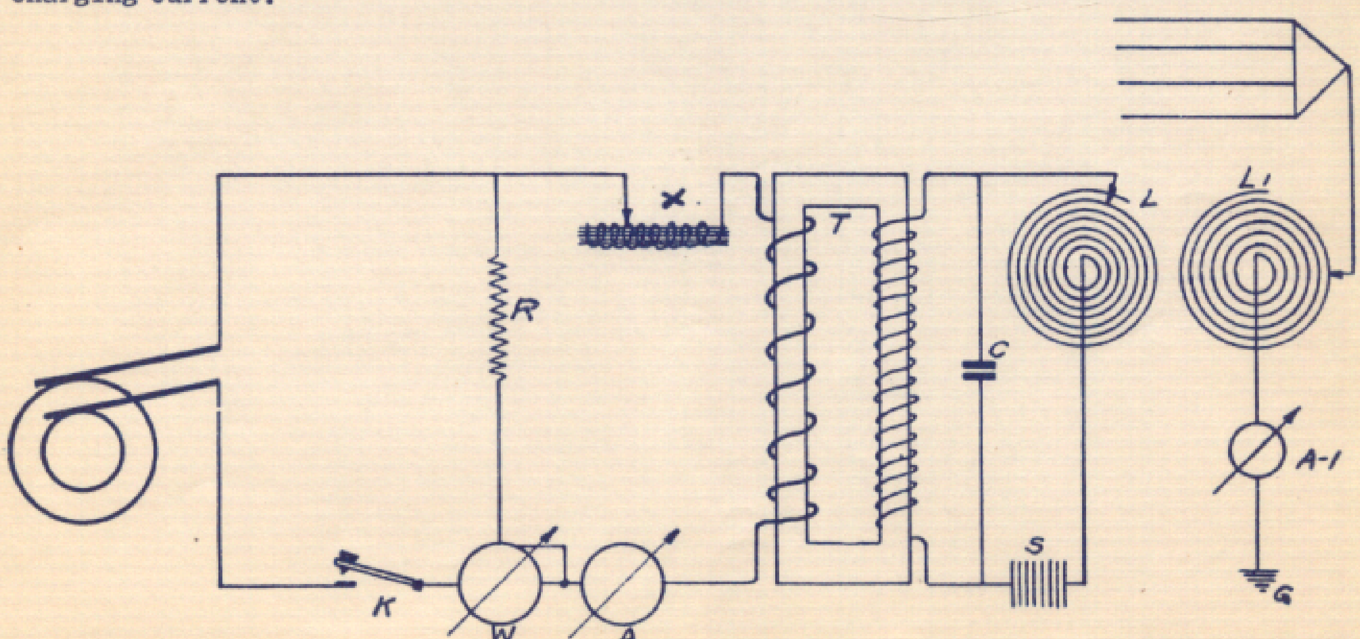


FIG. 10

MODERN TRANSMITTERS.

A modern transmitter circuit is shown in Fig. 10. As you will note, the circuit is very similar to the one shown in Fig. 4, and its operation is identical. The only difference being that certain pieces of apparatus have been added in order to get more efficient operation and also to obtain more exact control.

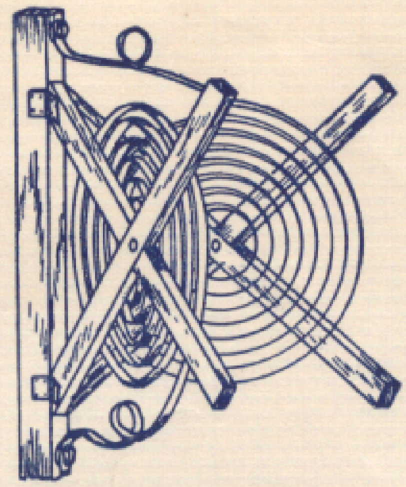


FIG. 11 HINGED TYPE PANCAKE OSCILLATION TRANSFORMER.

W is a wattmeter, x is a variable reactance to control the power input and s is a quenched spark gap. L and L-1 are the primary and secondary coils of the pancake type oscillation transformer. This type of oscillation transformer is now ordinarily used in spark sets in order to reduce the mutual inductance. The variable effect may be obtained by either moving the coils apart in the same plane or mounting the secondary on a hinge as shown in Fig. 11, so that it can be swung out of line with the primary.

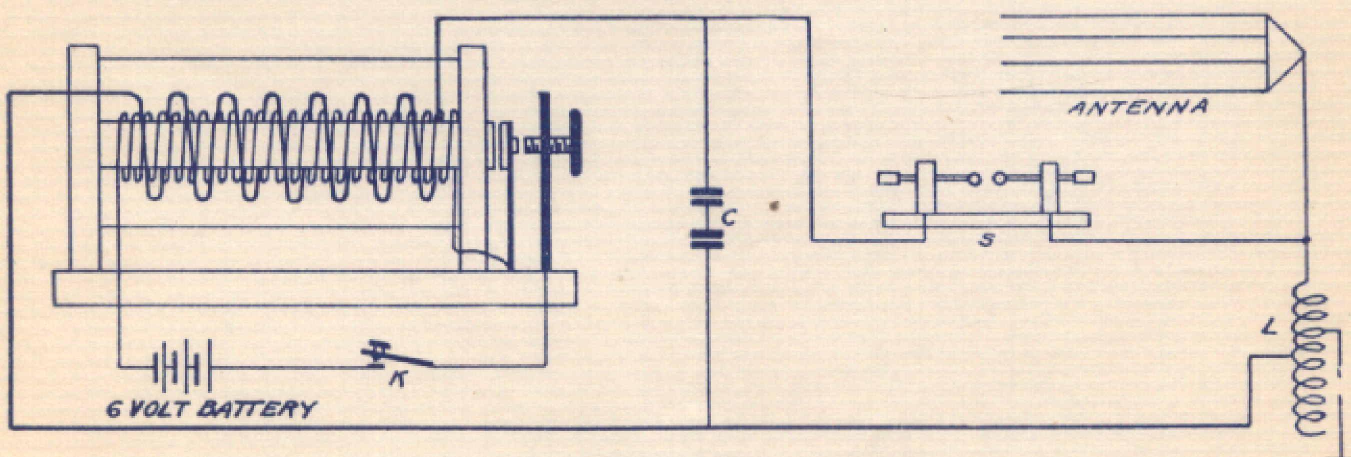


FIG. 11 a

TRANSMITTER DESIGN.

One of the simplest transmitters for the beginner to build himself is shown in Fig. 11A. It consists of a spark coil capable of discharging a spark ½" long. On inductance, a high voltage condenser and a hot wire ammeter.

I would advise that you buy the spark coil as it is a very tedious job to construct, however, for those who wish to build the coil, the following table gives its dimensions and winding data:

2 Coil ends.	2¾" Diameter.	¼" Thick fiber.
1 Coil core.	¾" Diameter.	6½" Long #20 or #22 soft iron (wire).

The primary coil is wound with two layers of #18 silk covered copper wire and the secondary coil contains 1 pound of #40 insulated copper wire.

To build the high voltage condenser C take 20 pieces of ordinary window glass 15x15" and cover each piece on one side with lead foil 12x12". The plates are then stacked, one on top of the other, making two stacks of 10 plates each. Every other plate of lead foil of one stack is connected in parallel to every other plate of the other stack and the two stacks are connected in series as shown in Fig. 11-A. In other words it is simply a parallel series connection.

The inductance L is built by winding 12 turns of #4 bare copper wire on a frame as shown in Fig. 12. The frame is 4" in diameter and the turns must be spaced ¾" apart The transmitter described above is suitable for short range transmission and is the advisable one for the beginner to learn on. In lesson 6 I will give you the layout and the circuits of transmitters in use today for long distance telegraphy work and also for the broad casting of the voice and music.

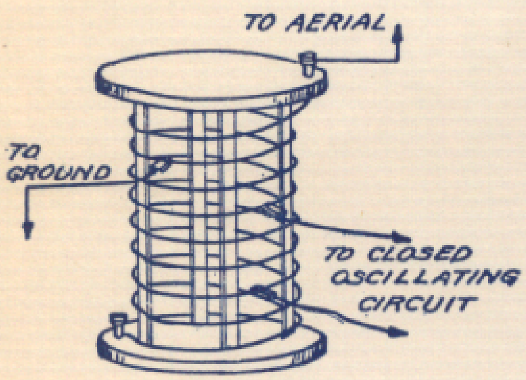


FIG. 12 HELIX

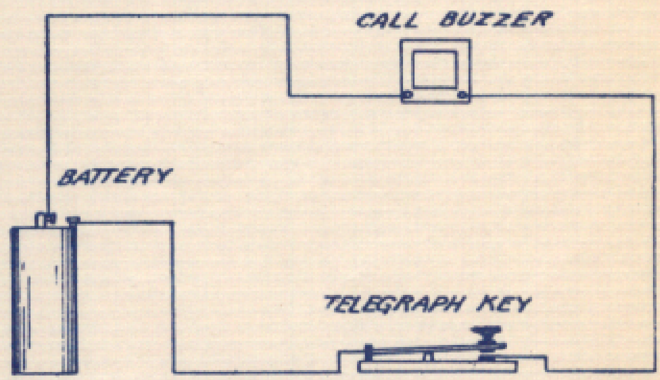


FIG 13

GOVERNMENT REGULATION.

All transmitting stations must be licensed by the U. S. Government and must be operated by a government licensed operator. In order to obtain a license the applicant must pass an examination covering the essential points in the construction and theory of radio receiving and transmitting. He also must be able to send 20 words per minute and receive at the rate of 10 words per minute. Examinations are held at all navy yards and most custom houses. In any case the student can find out the nearest examination point to him by writing the Bureau of Navigation, Washington, D. C.

The table below gives the values in per cent as the various branches of the work are classified on the examination.

Experience (sending and receiving)	20 per cent.
Diagrams of transmitting and receiving apparatus	10 per cent.
Theory of transmitting	20 per cent.
Theory of receiving	20 per cent.
Care and operation of storage batteries	10 per cent.
Care and operation of motor generators	10 per cent.
Internation regulations and (U. S. Radio Laws)	10 per cent.

LEARNING THE CODE.

Wireless communication is carried out by means of the Continental code which is slightly different than the original Morse code. The chief difference of the two being the elimination of the spaced letters in the Continental, and also having all dashes the same length.

TELEGRAPH CODES.

SYMBOL	AMERICAN MORSE	CONTINENTAL
A	· —	· —
B	— · · ·	— · · ·
C	· · ·	— · — ·
D	— · ·	— · ·
E	·	·
F	· — ·	· · — ·
G	— — ·	— — ·
H	· · · ·	· · · ·
I	· ·	· ·
J	— · — ·	· — — —
K	— · —	— · —
L	———	· — · ·
M	— —	— —
N	— ·	— ·
O	· ·	— — —
P	· · · · ·	· — — ·
Q	· · — ·	— — · —
R	· · ·	· — ·
S	· · ·	· · ·
T	—	—
U	· · —	· · —
V	· · · —	· · · —
W	· — —	· — —
X	· — · ·	— · · —
Y	· · · ·	— · — —
Z	· · · ·	— — · ·
1	· — — ·	· — — — —
2	· · — · ·	· · — — —
3	· · · — ·	· · · — —
4	· · · · —	· · · · —
5	— — —	· · · · ·
6	· · · · · ·	— · · · ·
7	— — · ·	— — · · ·
8	— · · ·	— — — · ·
9	— · · —	— — — — ·
0	———	— — — — —
.	· · — — · ·	· · · · · ·
?	— · · — ·	· · — — · ·

Study the Continental code very carefully so that you know every symbol by heart. Good practice is to have some one read off the letters and you repeat each corresponding symbol.

You are now ready for code practice. Connect an ordinary call buzzer in series with a dry cell and a telegraph key as shown in Fig. 13. Start your practice by first learning to send the individual letter, then make a list of simple words and practice on these until you can send any combination of these words without hesitation. The next step will be to take a newspaper or any printed matter and practice sending different paragraphs.

In learning the code it is of great help for two people to work together, as you can then send each other messages, slowly at first, and then more rapidly when you begin to think of the various buzzer sounds as letters and words.

Care must be taken in the formation of letters and numbers to see that the proper intervals are made between each letter; and between each word, that is, a pause equal to three dots is made between letters; and one equal to five dots between words; otherwise the letters and words will run together forming combinations totally different than they were originally intended.

Radio Lesson 4

CHICAGO ENGINEERING WORKS
CHICAGO, ILLINOIS

Receiving Apparatus

The object of all wireless transmitting apparatus is to set up oscillations (current waves) in the antenna system, such as is illustrated in Fig. 1, so that these oscillations will cause electromagnetic waves to be sent out in all directions in space. Various means of accomplishing this are used, as was explained in the previous lesson.

If at some distant station a similar antenna system exists, but instead of radiating energy into space, it has electromagnetic waves impressed on it that were sent out at some transmitting station, this receiving system will be set into oscillation, provided it has the same oscillating frequency as the impressed waves. These oscillations set up will be of an electrical nature and are not visible or intelligible to any of our physical senses, hearing, seeing or feeling, without the aid of some outside assistance. such as an indicating device which is capable of absorbing these oscillations and in some form rendering them intelligible. For this purpose an ammeter might be inserted in the circuit between the inductance L and the ground G; and if the current oscillating in the antenna circuit is strong enough, the ammeter would move every time the antenna was charged and discharged. This, however, would not be sensitive enough and usually much more delicate apparatus is needed for this purpose.

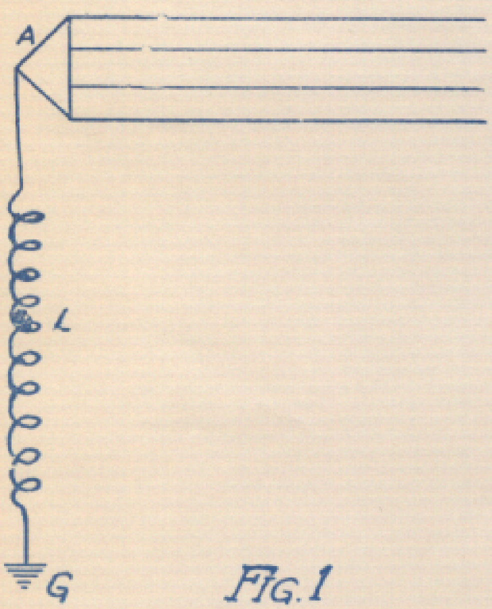


FIG. 1

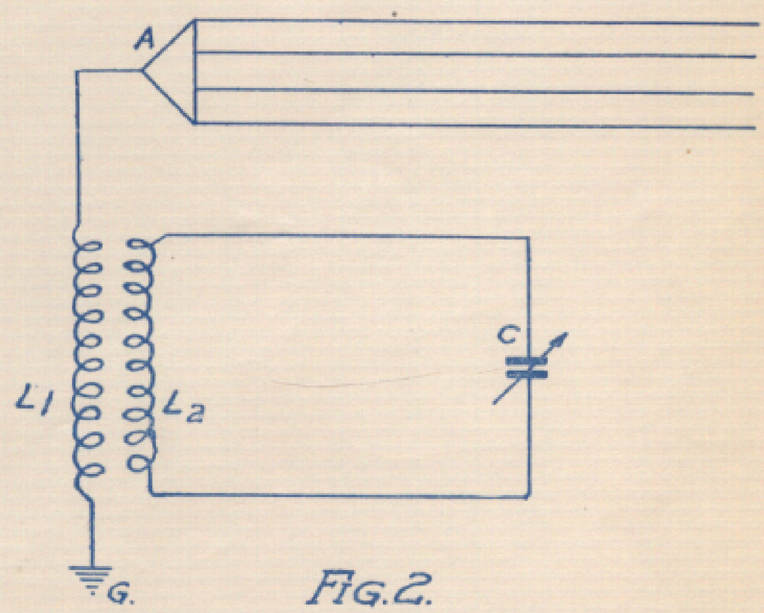


FIG. 2.

In Fig. 2 we have a combination of two circuits inductively related, and both capable of oscillating at their own periods or frequencies. If the electrical oscillations are set up in the circuit AL-1G, the pulsating current in flowing through L will set up a variable magnetic field which will induce a correspondence current in the L-2 C. If these two circuits are adjusted so that they will both have the same period of oscillation, any oscillation which takes place in one will also take place in the other. In other words, if the two circuits are in resonance, harmony—working together—the energy will be transferred from one circuit to the other when oscillations take place. This action is made use of in all radio apparatus, either transmitting or receiving in ways which are modified and adapted to meet the requirements of the particular kind of action desired in the apparatus, as to whether a set is to be used either for sending or receiving.

DETECTORS.

Detectors are used for the purpose of rendering intelligible to the physical senses hearing, etc., the electrical oscillations that are set up in an oscillating circuit, due to the energy received from some distant transmitting station. The detector forms one of the most important parts of a receiving system, for upon its successful operation depends the quality of the signals that are received. Quite a number of different types of detectors have been developed, but only two are used at the present time. One of these is the crystal detector and the other is the audion or vacuum tube detector.

The vacuum tube detector is used where a very sensitive detector is desired and where the receiving apparatus is stationary and not subjected to shocks and vibrations, for these would ruin the vacuum tube. The detailed operation of the vacuum tube will be taken up in the next lesson. The crystal detector is used where a cheaper set of apparatus is desired, and also for portable sets where ruggedness and simple operation are of more importance than extreme sensitiveness. A large number of different minerals have been used for receiving high frequency oscillations. Among these the more common ones are the following: a steel point on a carborundum crystal, a gold or steel point on iron pyrites (fool's gold), a metal or graphite point on galena (lead sulphide), or a combination of silicon and antimony. The one most commonly used today is a copper or steel point and a crystal of galena. The entire surface of a detector crystal is not uniformly sensitive, but there are certain spots which are highly sensitive, while others have very little effect. To get the best results, therefore, it is necessary to move the metal needle around over the surface of the crystal until one of these sensitive spots has been found. On a galena crystal only a very light pressure of the needle is required, and therefore, the crystal is not well adapted for field sets or mule-back sets, where they are jarred considerably. On a carborundum crystal, however, a greater pressure of the steel point is needed, and hence such a crystal is not so easily thrown out of adjustment. Carborundum crystals are therefore extensively used for portable sets that are likely to be subjected to shocks or vibrations.

The general action of a detector is that it permits an electric current to flow through it in only one direction, that is, it acts as a rectifier. Connected in series with the detector is a telephone receiver. The simplest way of connecting a crystal into a receiving circuit is illustrated in Fig. 3. As shown there, the antenna is connected through an inductance to the ground. A variable contact is provided so that different values of inducance can be obtained. Connected in parallel with the inductance is another circuit containing a detector and a telephone receiver in series. A variable condenser is connected in parallel with the telephone receiver in order to make the signals in the receiver somewhat clearer and sharper. Another connection or hook-up is illustrated in Fig. 4. This has an oscillating circuit coupled to the antenna circuit through a variable inductance. connected to this oscillating circuit is the circuit containing the detector and telephone receiver. A condensor is also connected in parallel with the telephone receiver in order to improve the quality of signals heard in them.

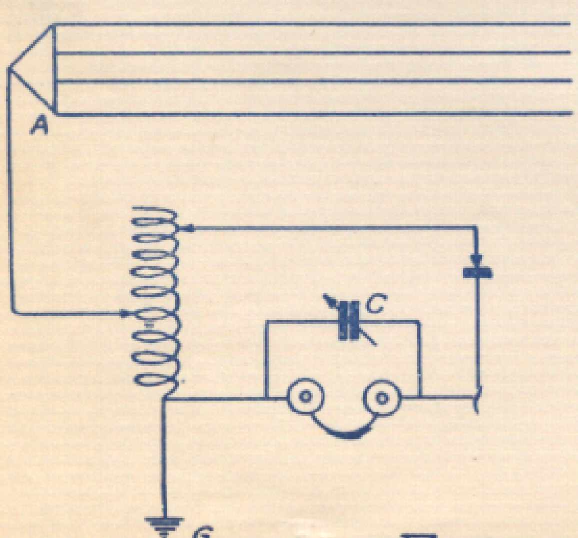


FIG. 3

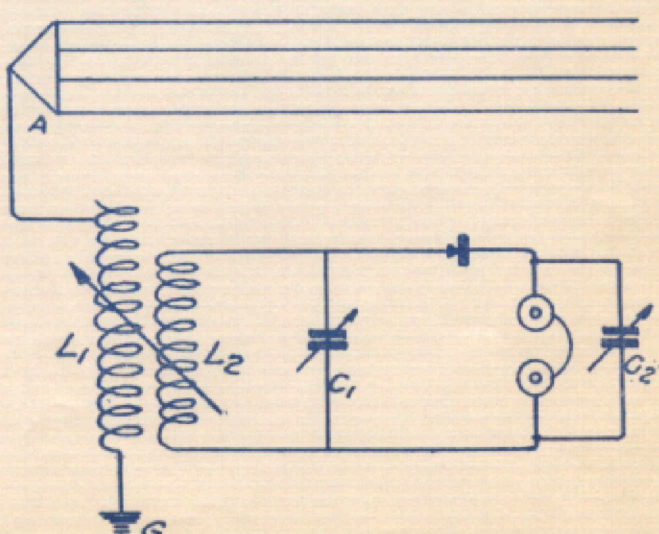


FIG. 4

A set of alternating current waves as come in over the antenna circuit may be represented as is illustrated in Fig. 5. Since the detector permits current to flow through it in only one direction, only one-half of these alternating current waves are effective in operating the receiver. Therefore, the current waves flowing through the detector and the telephone receiver may be shown as in Fig. 6. However, the condenser shunted around the telephone receiver smoothens out the individual wave impulses so that an effect similar to that shown in Fig. 7 is produced. The effect is thus a more uniform attraction produced on the diaphragm of the receiver, and as a result the sounds produced are clearer and sharper. The receiver diaphragm, therefore, vibrates in unison (at the same rate) with the sets of wave trains coming in over the antenna circuit. The vibration of the receiver diaphragm sets up sound waves in the air, and these sound waves are heard in our ear. Besides the hook-ups shown in Figs. 3 and 4, various others are used, but the principles of operation are the same in all.

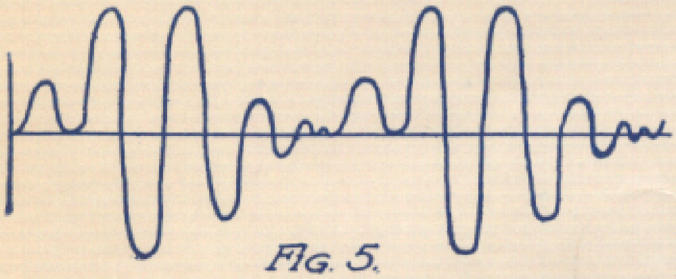


FIG. 5.

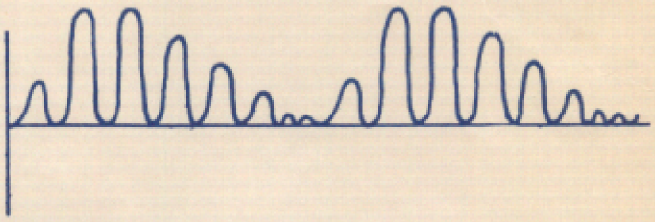


FIG. 6.

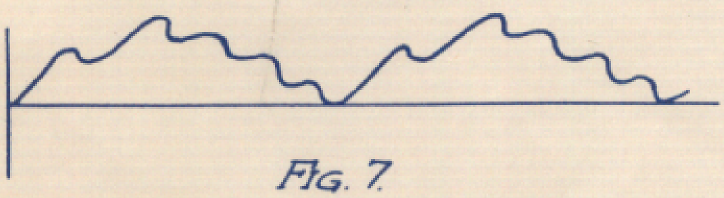


FIG. 7.

SIMPLE RECEIVING SETS.

We are now ready to take up the construction and operation of simple crystal detector receiving sets. The first part of any receiving set is the antenna or aerial, for it is in the antenna that the electrical impulses or waves are first set up. The antenna can be constructed in several ways as will be explained in a later paragraph, but the one thing to bear in mind is to make the antenna sufficiently large. It receives only a small amount of energy as it is, and hence with a small aerial the incoming signals will be very faint.

From the aerial or antenna a wire is run to the receiving set located within the station. The sketch shown in Fig. 4 is probably the best simple hook-up to be used for crystal detector receiving stations. As the impulses or waves come in over the antenna, they flow through the primary of the loose coupler. This primary is provided with a sliding contact so that a variable number of effective turns can be used. The electrical current waves in flowing through the primary induce a corresponding pulsating current in the secondary. The loose coupler is arranged so that the amount of induction can be varied by rotating the secondary within the primary. The secondary circuit is adjusted or tuned so that it has the same frequency of oscillation as the antenna circuit, in other words, the two circuits are brought into resonance. The exact condition of resonance is found when the signals are the loudest. The detector and telephone receiver circuit is then connected to the oscillating circuit in parallel with the condenser C. Another condenser, C2, is connected in parallel with the telephone receiver in order to make the signals sharper.

THE ANTENNA OR AERIAL.

The antenna or aerial consists of a network of wires suspended in the air and serves to catch or receive the electromagnetic waves from the atmosphere. In a transmitting station the aerial serves to radiate the waves out into space. For transmitting purposes it is desirable to have the antenna of special dimensions and design in accordance with the capacity of the transmitting apparatus; but for receiving purposes the aerial may be as large as it is practical, for with a large aerial more energy is received and the signals are proportionately louder.

Various types of aerials have been used and tried out, but the flat top L or T type have been found most satisfactory and are in most common use today. An L type aerial is illustrated in Fig. 8 and a T type in Fig. 9. The wires of an aerial should be run as straight as possible, and should be of good electrical conductivity. Phosphor bronze wire is very satisfactory in that it has a high tensile (tearing) strength and also fairly good conductivity. Aerial wire cable generally consists of 7 strands of No. 19 wire or 7 strands of No. 21 wire. Hard drawn copper wire or aluminum wire may also be used, but iron wire should be avoided, for it has a rather high electrical resistance and hence causes large losses.

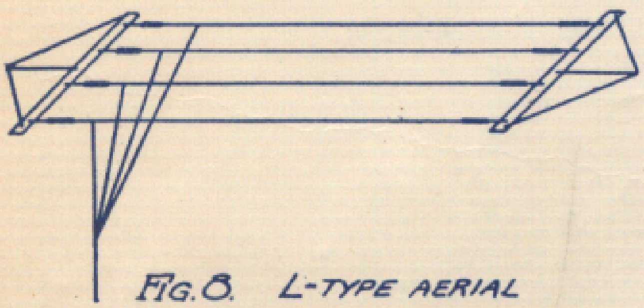


FIG. 8. L-TYPE AERIAL

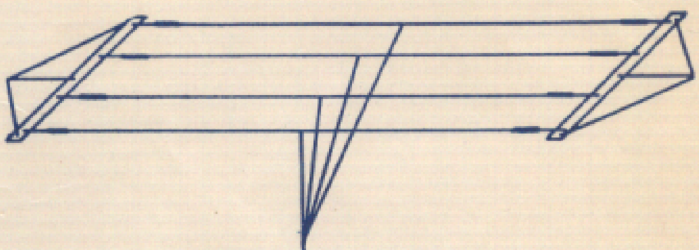


FIG. 9. T-TYPE AERIAL.

For receiving purposes an aerial of four wires spaced about 2 feet apart and about 35 feet in length will give very good results. An aerial of these demensions can be constructed conveniently under almost any conditions. For supporting the aerial either wooden masts can be used or staffs of iron pipe consisting of several lengths of decreasing sizes joined end to end by means of reducing bushings. The masts should be well guyed so that they will stand up firmly when subjected to strains due to wind pressure. All guy wires on either a wooden or iron mast must be broken up into sections of about 15 or 20 foot lengths joined together through tension or strain insulators as is shown in Fig. 10. This is necessary in order to prevent any undue electrical surges being set up in the aerial and to prevent any possible loss of current or electrical energy.

The spreaders which are used for holding the aerial wires in their proper position should be made preferably of bamboo or spruce wood, for this is very strong and light. Each aerial wire should be fastened to these spreaders through porcelain strain insulators in order to prevent any leakage of current to the ground. At the ends of the spreaders, eyebolts are securely fastened to which the bridle wires are fastened for attaching the aerial to the masts. As shown in Fig. 10, each bridle wire should also contain a good tension insulator for it is most important that all current leakage be properly guarded against. The entire aerial can then be raised by means of a block and pully fastened to the top of the mast. A good height at which to have the aerial is about 40 to 50 ft. above the ground. An important point to bear in mind in case an aerial is erected on the top of a building is that the distance from the aerial to the ground is not the total height of the building plus the height of the aerial above the roof of the building, but really only the height of the aerial above the roof. This is because a building is generally equipped with a network of gas pipes, water and heating pipes, and electric light and power wires, and since all of these are in contact with the ground, the effective distance of the aerial to the ground is greatly reduced. Therefore, better results will be obtained if the aerial is stretched between the roof of a building and a post, between two posts, or between two buildings.

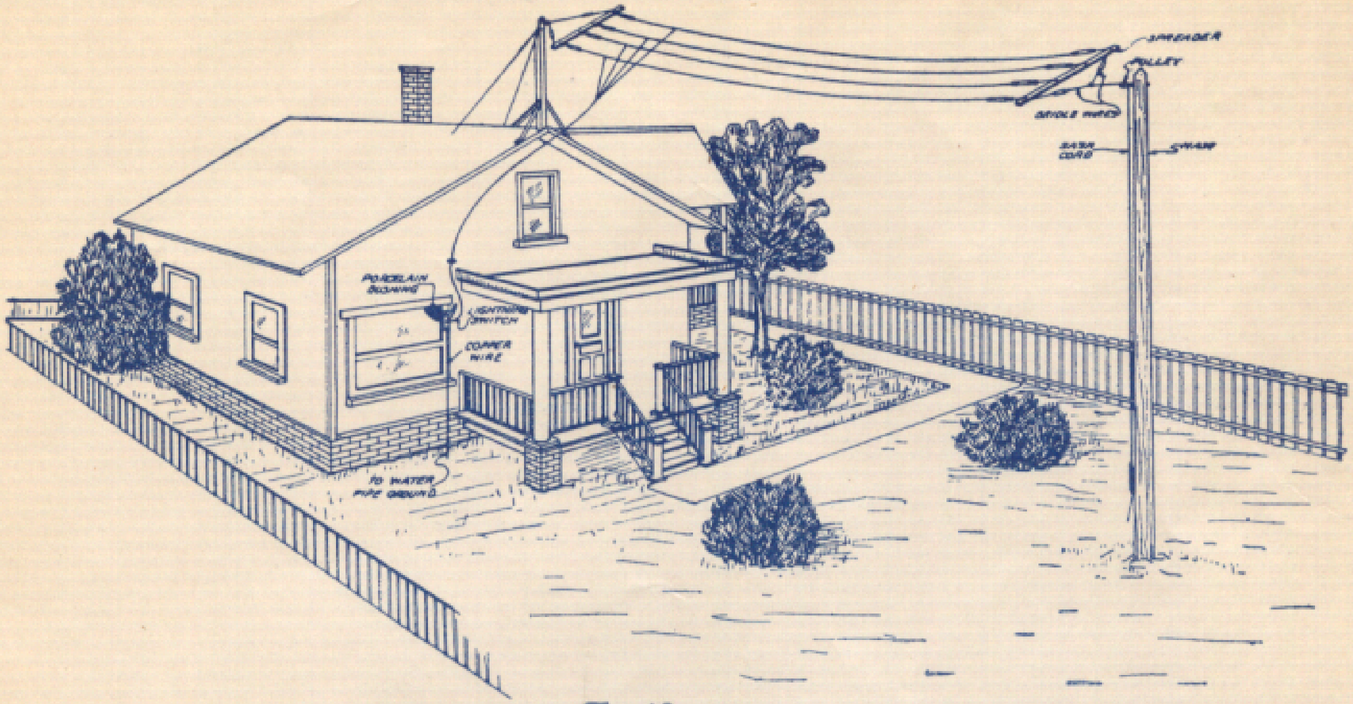


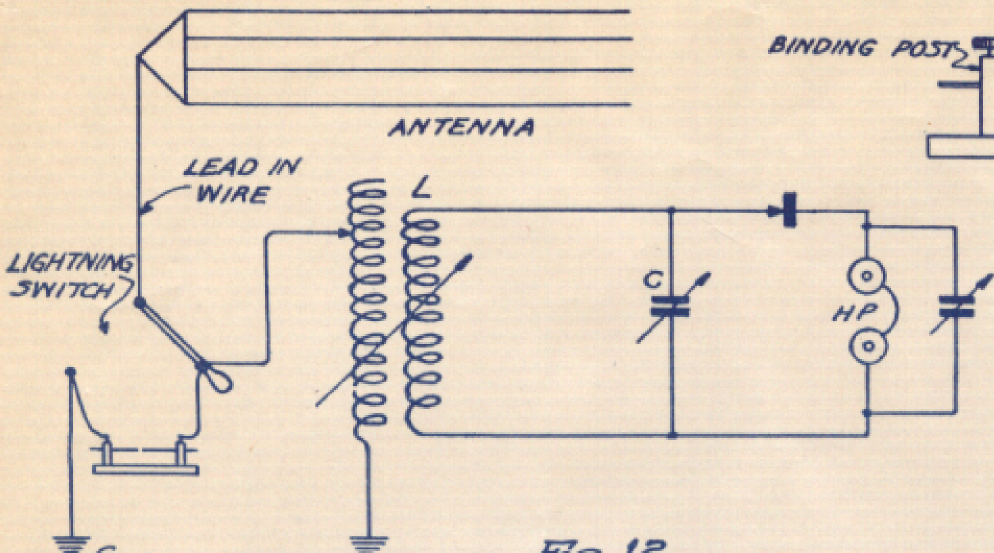
FIG. 10

The most convenient place to attach the "lead-in" wire to the aerial, is at the end of the aerial nearest the place where the lead-in wire is to enter the building or receiving station. The correct way to attach the lead in wires is also illustrated in Fig. 10. Four No. 10 wires should be used, one connected to each of the four aerial wires by means of a running tap splice and well soldered. The loose ends of the four wires are then collected and attached to a No. 4 copper wire which is used for leading into the station or house.

An important point to bear in mind is that aerials have a tendency to gather static electricity from the air, especially during thunderstorms. To prevent any harmful results due to these high voltage charges, or from lightning striking the aerial, the aerial should always be grounded to a good earth connection, a water pipe is best. For the ground wire a No. 4 copper wire should be used, mounted on porcelain knobs in as straight a line as possible and avoiding any sharp bends. The lightning switch should have a capacity of 100 amperes and should be mounted on a fireproof base. It should be placed on the outside of the building.

In order to prevent the possibility of lightning striking the apparatus and injuring the operator while the station is in operation and the lightning switch is open, it is advisable to connect a safety spark gap in parallel with the switch. This safety spark gap will then allow any excess electrical charges at pressures above normal to discharge to the ground. A convenient safety spark gap for this purpose can be constructed by screwing two binding posts about three inches apart into an insulating base (fibre will do), and then supporting two large stiff wires about 1/64 inch apart in these building posts. Any excess pressure will then jump across this gap to the ground. The two binding posts are then connected in parallel with (across) the two switch terminals. A safety gap of this kind is illustrated in Fig. 11.

Inside of the station the apparatus is arranged as is illustrated in Fig. 12. L is a vario-coupler which consists of a mutual inductance. The primary has a number of taps brought out so that a different number of effective turns can be connected between the antenna and the ground. The secondary of the vario-coupler is connected to the variable condenser C with the result that an oscillating circuit is formed. The frequency of this oscillating circuit depends upon the value of the inductance and capacity for which the coupler and condenser are set. Connected across the variable condenser C is the crystal detector D in series with the head phone H. P. Another condenser is connected across the telephone receivers in order to make the signals heard clearer and sharper.



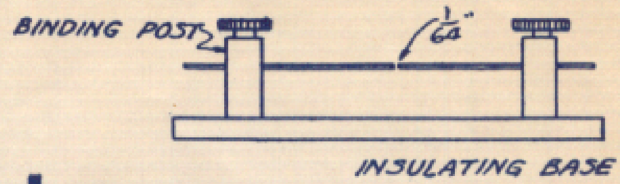


FIG 11

FIG. 12.

In order to receive a message, the receivers are held to the ears and the lightning switch thrown into the instrument side as is shown in the figure. By then changing the number of primary turns in the primary of the coupler and adjusting the position of the secondary and also of the variable condenser, the circuit is thrown into resonance with the antenna circuit and the signals will be heard. It will also be necessary, of course, to adjust the crystal detector so that the most sensitive spot will be used.

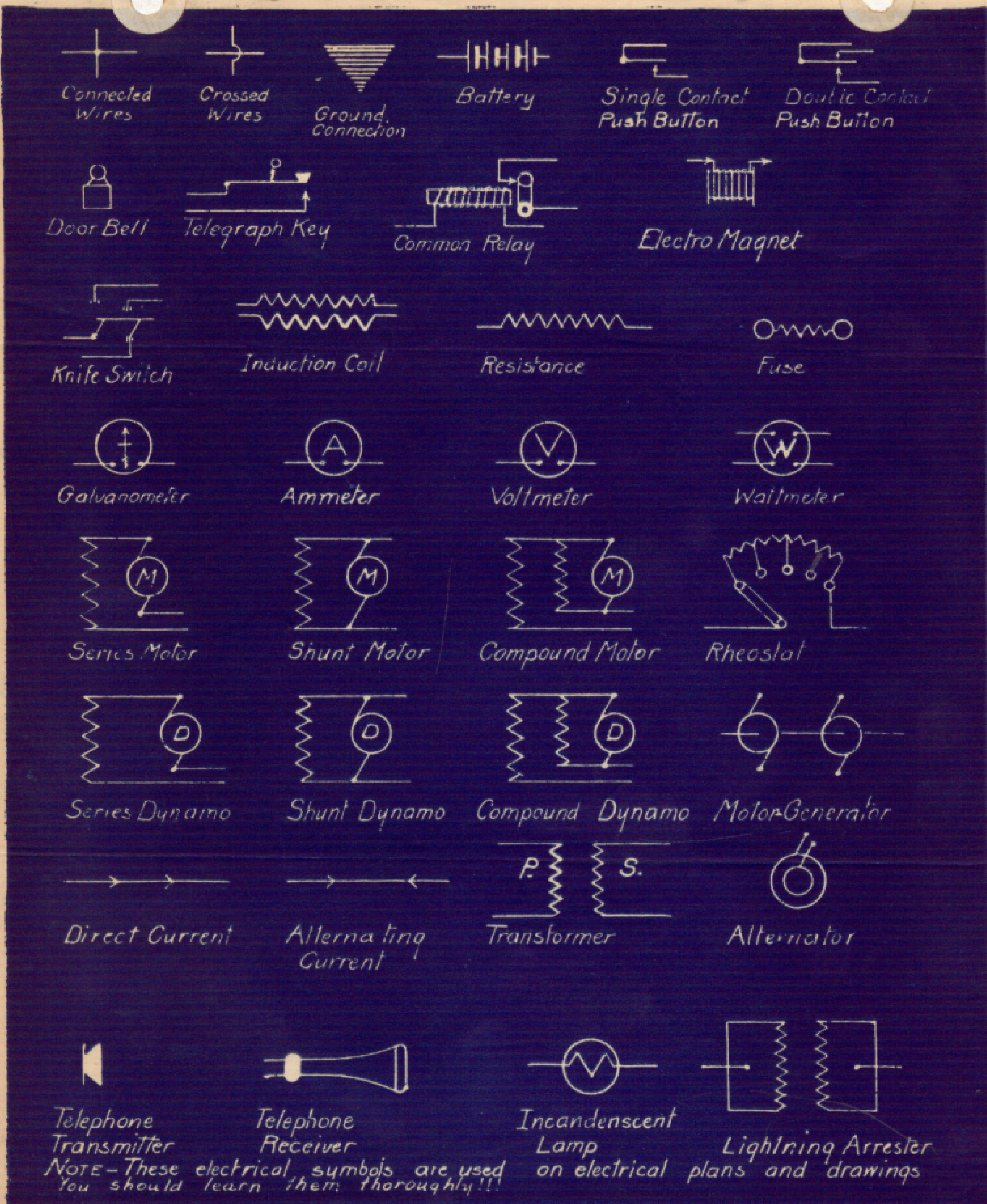
The process of bringing the instrument oscillating circuit into resonance with the antenna circuit is known as tuning. The first step in tuning should be to adjust the primary taps on the vario-coupler so as to set the antenna circuit for the wave length of the signals which are to be received. During this process the coupler should be in the position of maximum inductance and the condenser plates should be completely inserted so that maximum capacity is also obtained. After the antenna circuit is adjusted so that the signals are being heard, the next step is to adjust the condenser until the signals are heard best; and lastly the coupler is adjusted until the intensity of the signals is at the maximum value. When this condition is reached, the circuit is said to be properly tuned.

The vario-coupler can be easily constructed according to the formulas and instructions given in the previous lesson; but to get best results with the condenser, it is advisable to purchase a ready built variable condenser. These ready built condensers have been manufactured by machine processes and are more accurate than one built without the proper tools and equipment. In fact, even well built vario-couplers can be purchased ready to install on a panel at the same cost as the material can be purchased at for home construction. By thus purchasing the various parts ready built, but unmounted, and then carefully assembling and mounting them on a panel as desired, and wiring it up properly, a very good receiving set can be constructed at a small fractional part of the cost that a ready built set could be purchased at.

THE BUZZER TEST.

A buzzer test is often used to aid in finding the most sensitive spot of a crystal detector. Any kind of buzzer will do, but a high-toned one which makes very little noise is best. It is advisable to keep the buzzer in a box with cloth or cotton to smother the noise, so that it will not interfere with the sounds heard in the receivers. If the buzzer is enclosed, the only sound heard comes from the telephone receivers when a sensitive spot on the crystal has been found. The only connection from the buzzer to the radio is a wire running from the fixed contact of the buzzer to the ground lead. The buzzer and container can be placed anywhere within the receiving set where convenient.

The buzzer can be controlled by means of a switch or a telegraph key which can also be used for code practice. To adjust the detector, the test buzzer is set into operation, and the contact moved over the crystal until a regular sound is heard in the telephones. This, however, must not be confused with other notes heard when parts of the set are touched with the hand. When a clear and regular note is heard, the detector is ready to receive signals.


Connected Wires
Crossed Wires
Ground Connection
Battery
Single Contact Push Button
Double Contact Push Button
Door Bell
Telegraph Key
Common Relay
Electro Magnet
Knife Switch
Induction Coil
Resistance
Fuse
A
V
W
Galvanometer
Ammeter
Voltmeter
Wattmeter
M
Series Motor
Shunt Motor
Compound Motor
Rheostat
D
Series Dynamo
Shunt Dynamo
Compound Dynamo
Motor-Generator
P.
S.
Direct Current
Alternating Current
Transformer
Alternator
Telephone Transmitter
Telephone Receiver
Incandenscent Lamp
Lightning Arrester
NOTE - These electrical symbols are used on electrical plans and drawings
You should learn them thoroughly!!!

ENGINEERING DEPARTMENT
CHICAGO ENGINEERING WORKS
2154 Lawrence Avenue
CHICAGO, ILL.

Do Not Write in Space Below

Examination Sheet

"GO TO SCHOOL AT HOME"

Grades

Date ____________________

Name ____________________

Address ____________________

Print Your Name and Address or Use Your Rubber Stamp

Scholarship No. ____________

Lesson No. ____________

What New Lessons have you to work on? ____________

Be Sure Your Correct Name and Address Appears on Each Sheet; Also That You Have Answered All Questions.

"The Cooke Trained Man is the 'Big-Pay' Man"

WORK SHEET METHOD
Trade Mark

L. L. COOKE
School of Electricity
CHICAGO

Outfit Work Sheet "B"

BELL AND ALARM EQUIPMENT

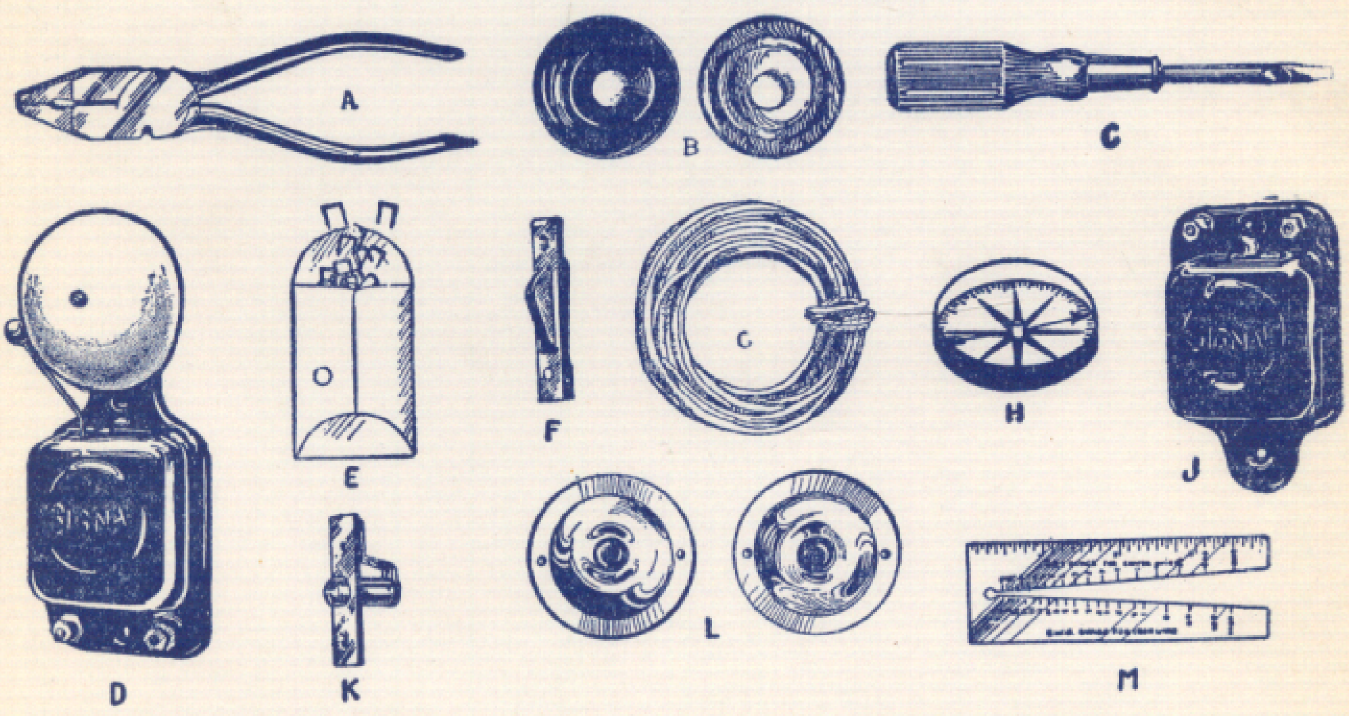
I am sending you in this outfit, the necessary equipment so that you can experiment with the bell and alarm circuits I have explained to you in the work sheet on this subject. I want you to use this equipment and make up as many of the circuits as you possibly can, in order to get the actual experience of making installations of this kind.

You may at first think that these various articles are simple both in operation and construction. True, but it is because of their simplicity that I have chosen them as a part of this outfit.

I havr tried out different kinds of equipment and after questioning hundreds of my studen s, I am convinced that the articles that I send you can not be improved upon for instruction purposes.

The more you experiment along this line, the better acquainted you will be with the equipment and its operation. You can mount this equipment on a board if you wish, although it will work just as well spread out on a table or any flat surface.

Fig. 1



The equipment contained in your second outfit will help you to understand the various uses of the bells, buzzers and the different ways of connecting push buttons. By learning how to connect and install them, it will be a very simple matter to go out and get small jobs.

Now, remember this, if you have not done any of this work before, by all means get every job of this kind that you can. Don't pass up a single one. Your profits in some cases may be small, but you will be getting something which money can't buy--EXPERIENCE. With experience comes self-confidence--knowing that you can take a job and carry it through successfully.

There are too many fellows passing up valuable experience and these same men are the ones you hear complaining when the other fellow is getting the work, and getting ahead.

It is the Go-Getter spirit coupled together with the training I give you that is going to put you on the top. Now, get down to brass tacks -- study this work sheet carefully -- and experiment whenever you can. When you have completed this work sheet and the experiments, try the apparatus on the different systems I have given in my work sheets and see if they work out the way I say they do.

In Fig. 1 I show you the parts of this outfit and each one is lettered, so that from the following explanation, you will know what each one is for.

PLIERS "A".

You will need pliers for cutting wire and tightening or loosening bolts and nuts on parts of your outfit. You should not try to cut hard steel wire or heavy material, other than copper or soft wire, as the jaws may be damaged.

SINGLE CONTACT PUSH BUTTONS "B".

You may use one or two of these buttons in any of the circuits, wherever a single contact button is needed. The top may be removed from the base, by holding the base in the left hand and turning the top to the left with the right hand, as it is screwed to the base. The connecting wires are connected to the button under the heads of the screws you will find holding the contact part to the base.

SCREWDRIVER "C".

The screwdriver will be used for fastening the push buttons and other parts to the boards, also in assembling your motor and other equipment.

BELL "D".

You can use the bell in any of the bell or alarm circuits where a bell is required. If it fails to work remove the cover and examine the contacts, as they may be stuck or out of adjustment. Adjust them properly until you get the bell to operate. The cover may be removed by pressing on the side at the point where you will find a small raised place on the base for holding the cover.

PACKAGE OF STAPLES "E".

Whenever a job of bell wiring has to be done, it is best to fasten the wires securely by using a number of staples all along the run of wire. However, when you are just doing experimental wiring and do not care to have the connections made permanent, the staples are not needed and you can lay them aside until you have some permanent installation to make.

WINDOW CONTACTS "F".

This is the closed circuit contact used in windows. When the window is closed, the contact is closed also and current is flowing continually in the circuit. When the window is opened, this opens the contact and breaks the circuit. This is to be used in closed circuit work as explained in the alarm circuit work sheet.

COIL OF ANNUNCIATOR WIRE "G".

The wire which is most commonly used for bell circuits is called "annunciator wire" because it was first used a great deal for the wiring of annunciators. You will find this wire to be very handy in making up your bell circuits, wiring up your motor and battery connections. This wire is #18 B & S gauge and has an insulation provided which is very strong and resists moisture because of the use of a wax filler.

POCKET COMPASS "H".

This compass is to be used in performing magnetic and electro magnetic experiments, also for making a galvanometer. You will find this very interesting and instructive and I want you to always keep it, as you will find a great variety of uses for this compass in your regular electrical work. It is very useful for finding the polarity of motor coils and other kinds of electrical equipment.

BUZZER "J".

This buzzer is built just the same as the bell except that it does not have the gong or the tapper. It is to be used in the circuit where a buzzer is used, or where 2 bells are used, as its operation is just the same as the bell.

DOOR CONTACT "K".

This is an open circuit door contact to be used in the burglar alarm circuit, in connection with the circuit I give you for alarm protection.

When installed in a door and the door is closed, the contact is opened, so no current flows. When the door is opened, this closes the contacts and allows current to flow which either acts on the relay or directly on the bell or alarm device.

DOUBLE CONTACT PUSH BUTTONS "L".

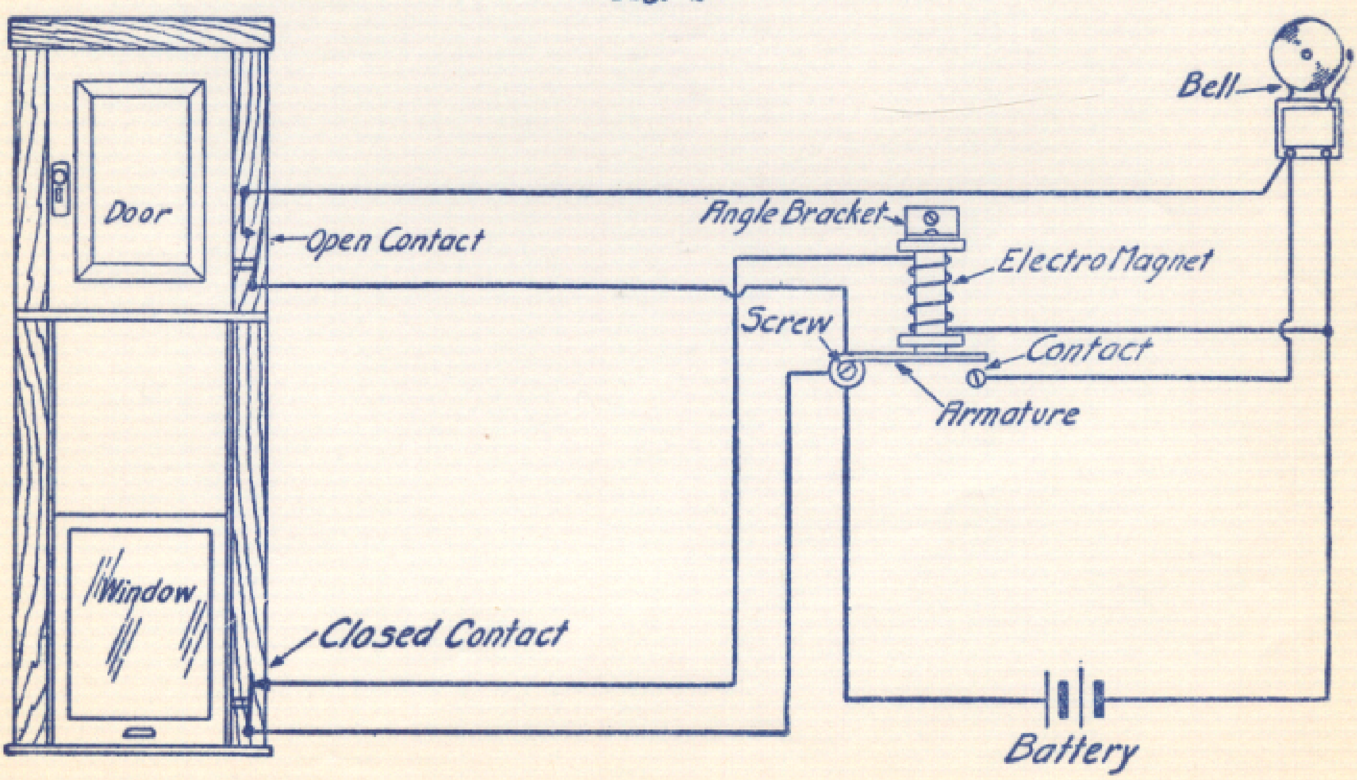
These are to be used in the circuits where double contacts are required. There are three places for fastening the wire and you can easily find them, as three screws are provided. The wires are to be placed under the head of the screws and the screws tightened to hold the wires in place and make contact with the three different contacts of the button.

The base of the button is held firm when the screws are placed in to hold the shell against the wood or the door casing.

WIRE GAUGE "M".

This is a very handy device which can be carried in your pocket and with which you can measure the different sizes of wire. It is accurate and will show the size of wire either in B & S (Brown and Sharpe) or B. W. G (Birmingham Wire Gauge) which is the standard generally used for measuring iron wire. The B & S is standard for copper and the B. W. G. for iron wire.

Fig. 2



After carefully removing all of the insulation from any wire which you wish to measure, place the bare wire in the slot of the gauge and move it down toward the narrow end until it just touches on both sides of the groove. At this point, the wire size can be read off directly from the scale. If it is iron wire read from the B. W. G. gauge, but if it is copper wire, read from the B & S gauge. Magnet wires, that is, wires smaller than #18 B & S gauge must be measured with a micrometer or another type of wire gauge which can be purchased from any hardware store. The micrometer measures it in thousandths of an inch which is in mils and the reading is then obtained directly in mils and the size of wire determined by a wire table. This gives the diameter of all different sizes of wire and I give you a wire table in later work sheets which will tell you how to find the size of wire by this method.

EXPERIMENTAL ALARM CIRCUITS.

In Fig. 2 I show you how to use the electro magnet I sent you in your first outfit. Here it is used as a relay in an alarm circuit, together with your door and window contacts, and the bell or buzzer.

The door contact called the open contact, has one of its terminals connected to the battery by way of the armature screw and the other terminal of the contact is connected to the bell.

As soon as the door is opened, the contact closes and the bell is connected directly across the battery.

The window contact is mortised into the window casing and one of its terminals connects to the battery by way of the armature screw and the other terminal of the contact is connected to the winding of the electro magnet. The other terminal of the electro magnet connects back to the battery so that when the window is closed, the window contact is also closed and current always flows from the battery to the armature screw through the closed contact, through the winding of the electro magnet and back to the other side of the battery.

As long as the electro magnet is energized, it holds the armature up against its iron core and away from the contacts, but as soon as the window is opened, the contact is also opened and the electro magnet is deenergized. This allows the armature to fall on the contact and a circuit is now made from the battery to the armature, through the armature, to the contact, to the left hand terminal of the bell, and back to the other side of the battery.

This system is a combination of open and closed circuit types, in which the open circuit contact is independent of the relay action.

In making your experiments, I would suggest that you not leave the battery in the circuit for any great length of time. In a closed circuit system, it is preferable to use a gravity type battery or a bell ringing transformer for energizing the magnet if the circuit is to be used continuously.

In your next outfit, you will receive a motor, an ammeter for measuring current, voltmeter for measuring pressure or voltage and a switch with which to operate these devices. This equipment will be sent to you just as soon as you have completed Work Sheet No. 18.

It may seem a long way ahead, but if you keep plugging away at your work sheets, you will soon have a number of interesting experiments to perform along with your studies.

WORK SHEET METHOD
Trade Mark

L. L. COOKE
School of Electricity
CHICAGO

Electrical Outfit C

This Outfit is called our "Power" Outfit because it includes such apparatus and measuring instruments as are universally used in connection with the generation and distribution of electricity for power purposes.

You should, therefore, try to get all you can out of this Outfit Work Sheet, and the experiments you will be asked to do. While naturally the apparatus and measuring instruments I am sending you are small, and look like toys -- they are not toys in any sense of the word. For instance, the motor is just as much a motor as the biggest motor built. Used as directed it will enable you to apply in a practical way those fundamental principles of Electro-magnetism taught you in my work sheets. In fact that's all these things are for -- to give you practical experience. Once you have wound the motor and made it run, you'll understand electro-magnetism perfectly, and will be able to handle practically any kind of motor trouble.

And so it is with the measuring instruments, etc. They are all included to make your training more practical, to enable you to do with your hands those things I have tried to teach you to do in my work sheets.

And you really learn more and better from these small or miniature types than you would were you working on real apparatus, because these small pieces have been so designed as to make their working principles easily seen and understood, while on real apparatus everything is so covered up that unless one really understands the principles involved, he can learn little or nothing even when working on such apparatus.

This was proved to me by an electrical construction man who was taking my course, when he said:

> "I have installed and operated a great many large electrical machines, but have obtained more real, practical electrical dope in building your outfit motor than in all of my other work, simply because the construction of this simple piece of apparatus makes it easy to understand the main, underlying principles of operation of larger machines".

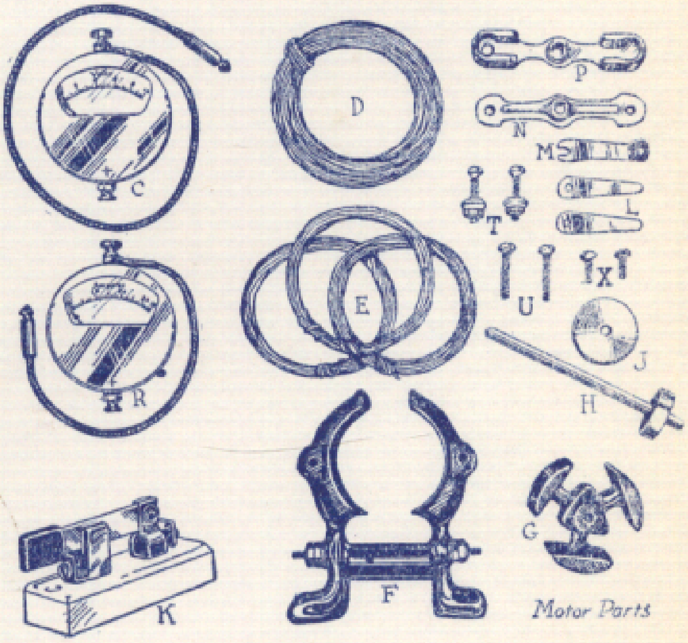


Fig. 1

Instead of sending you this motor wound, and simply allowing you to watch how it operates, I am instead sending it to you unwound, so that you may wind the armature and field coil, and understand exactly how they are connected. This experimental motor is of the series type and is explained in Work Sheet 19. Series type motors are used in electric railway work, and in many other places where a large starting torque is required and the load may be left on the motor at all times.

The motor in this outfit was designed especially for experimental work, and is much more substantial than any other so-called battery motor. In fact, it can be rewound for either 32 or 110 volts, and can be operated on either alternating or direct current, as well as dry cells.

DIRECTIONS FOR WINDING MOTOR.

Before you start to wind the motor, carefully look over the various parts and check them with the parts shown in Fig. 1. There should be one coil of heavy field wire, three coils of armature wire, one back and one rear bearing, one brass connecting

link, two brushes, screws and nuts for holding the brushes to the front bearing, binding posts, which are already assembled with the field frame, two front bearing screws, two back bearing screws, one pulley, one commutator and shaft, and an armature. If any of these parts are missing, let me know at once and designate the missing parts by the letters shown opposite the various parts in Fig. 1.
Before assembling the motor, it is first necessary to wind the armature and the field.

WINDING THE MOTOR ARMATURE.

In winding the motor armature, it must first be removed from the motor frame. This can be done by unscrewing the back bearing. Next, loosen the set screw in the armature and slide it back away from the commutator, so that after the poles are wound, you will have room to make connections to the commutator.
Before winding the armature, it is advisable to wrap a strip of paper around each armature pole. This is to insulate the wire from the iron frame, and thus prevent it from making electrical contact with the frame in case the insulation should wear. There are three coils of fine wire for winding the armature. Take one of these coils and scrape 1/2 inch of insulation from the end, and then wind the wire around the armature pole, as shown in Fig. 2. Wind the wire out over the top and back under the bottom in even layers until all of the coil has been put on. The starting end of this coil is connected to the commutator segment thru one of the small holes, but you should not actually make the connection until the winding has been completed.
Wind the second coil in the same manner that you wound the first one, being careful to wind the coil in the same direction. The third coil is wound in the same way, and when you have finished winding all three of the coils on the armature, twist the finishing end of coil 1, together with the beginning of coil 2. Do the same with the finishing end of coil 2 and the beginning of coil 3, and the same with the finishing end of coil 3 and the beginning of coil 1. Put the two wires thru one of the holes of the commutator segment, and then bring the wires back to the other hole of the same segment as shown in the illustration. Do this with all three of the resulting connections. The wires fit rather snugly and for that reason it is not necessary for you to solder them in order to secure good electrical contact. However, if you have soldering materials on hand, I would suggest that you solder these connections, as it will make a more permanent job.

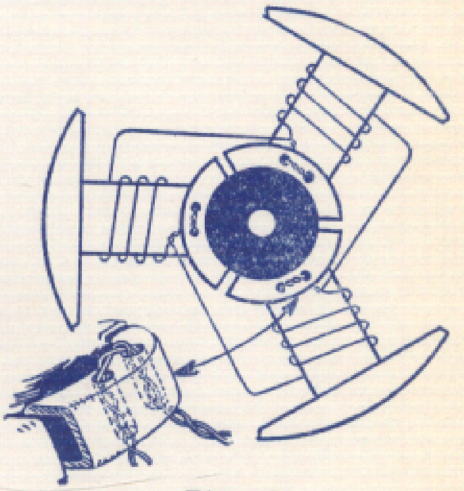


Fig. 2

Great care should be taken not to break the insulation of the wire at any point except at the end connection, as the bare wire must not come in contact with the iron of the armature or any other wire.

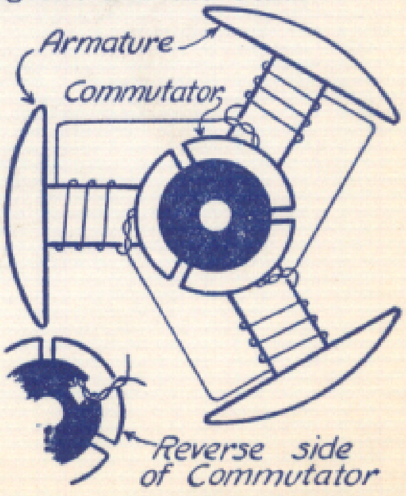
CONNECTIONS TO COMMUTATOR OF OUTFIT MOTOR.

I am now sending two different types of commutators to my students, one type having two small holes drilled through each commutator segment and the other having a projection on each segment on the side next to the armature.

If you have the type with the holes in the segments, follow the instructions as given above.

If your commutator has projections on the commutator segments, twist the two ends of wire around each projection as in the illustration and bend the projection down against the fibre part of the commutator so the wires are held firmly between the fibre and the projection.

Caution: Be sure to bend the projections down toward the middle of the commutator. If you try to bend them up toward the outside, they will break off.



WINDING THE FIELD.

First, remove about 1/2 inch of insulation from the end of the heavy coil of wire and then fasten it to the left hand binding post. This can be done by first loosening the knurled nut and bending the wire around the screw between the next nut and the brass washer. Note how the brass strip is connected to the right-hand binding-post. Now, wind the wire around the field-pole, beginning the winding by carrying it over the core and away from you. Wind the first layer to the right, being careful that the turns are wound neatly and close together. When the winding is completed, there should be about 3 1/2 layers of wire. Leave the finish end of the winding free until the motor is assembled.

ASSEMBLING THE MOTOR.

Place on the front bearing, which is also the brush-holding device. Put the armature in place and screw on the back bearing, but do not tighten the screws until the position is found where the armature will turn freely without binding. Next, connect the free end of the field wire to the left hand brush. This is done by removing about 1/2 inch of insulation and then bending the bare end of the wire around the screw and between the hexagon nut and the brass washer. The brushes should lie flat on the commutator so as to make good contact. Drop a little oil in the bearings, but be careful not to get any on the commutator. If any lubrication is necessary, use a little vaseline which has been rubbed into a cloth. When the motor is assembled it will look like the one shown in Fig. 3.

The motor is now ready to run. Connect two dry cells in series. If it will not start or has dead spots, past which the armature will not turn, loosen the set screw on the armature and turn the armature either way on the shaft, until a position is reached where the motor will run freely.

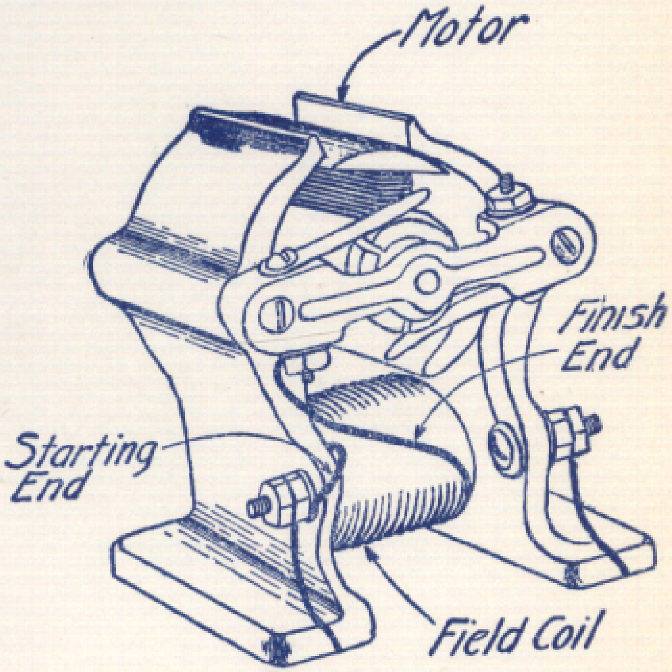


Fig. 3.

OPERATING THE MOTOR.

The motor I sent you in the outfit, is to be operated from 2 or 3 dry cells, and in case that you prefer to operate it from a 6 volt storage battery, simply make connection across two of the storage cells in series to obtain 4 volts. If two dry cells are used, connect them in series with a knife switch and in series with the motor as shown in Fig. 4. Get your motor into proper operating condition and then I will show you how to make another very interesting experiment.

REVERSING SWITCH FOR MOTOR.

I told you in Work Sheet 19 that to reverse the rotation of a direct current motor, it is only necessary to reverse the leads to either the armature or the field windings, but not both. In order to do this, the armature and field must be disconnected from each other. The connection which is changed is shown by the dotted line in Fig 5.

The reversing switch simply changes the direction of current thru the field winding, but the current will always flow thru the armature in the same direction. You will remember in Work Sheet 12, in which I took up electro-magnetism, that in reversing the direction of current through a coil, the magnetic polarity is changed also, and it is this change in the direction of the magnetic field which causes the motor to rotate in the reverse direction.

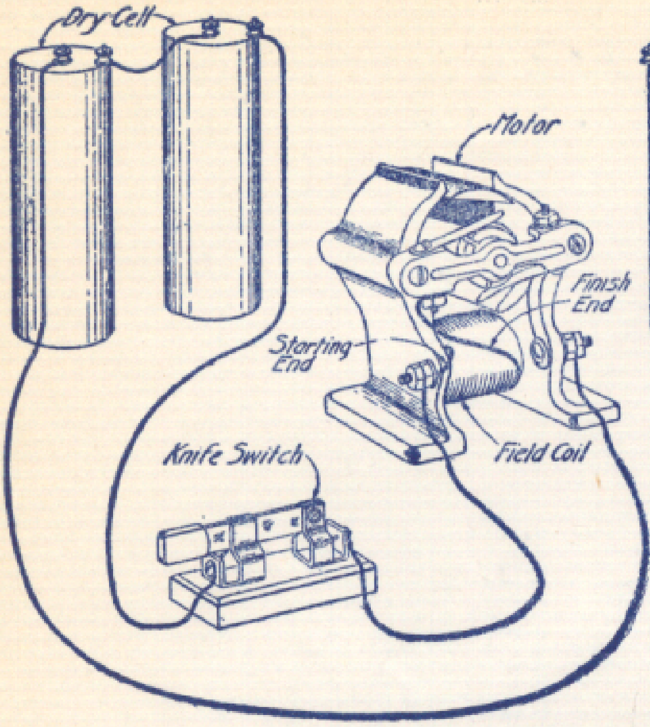


Fig. 4.

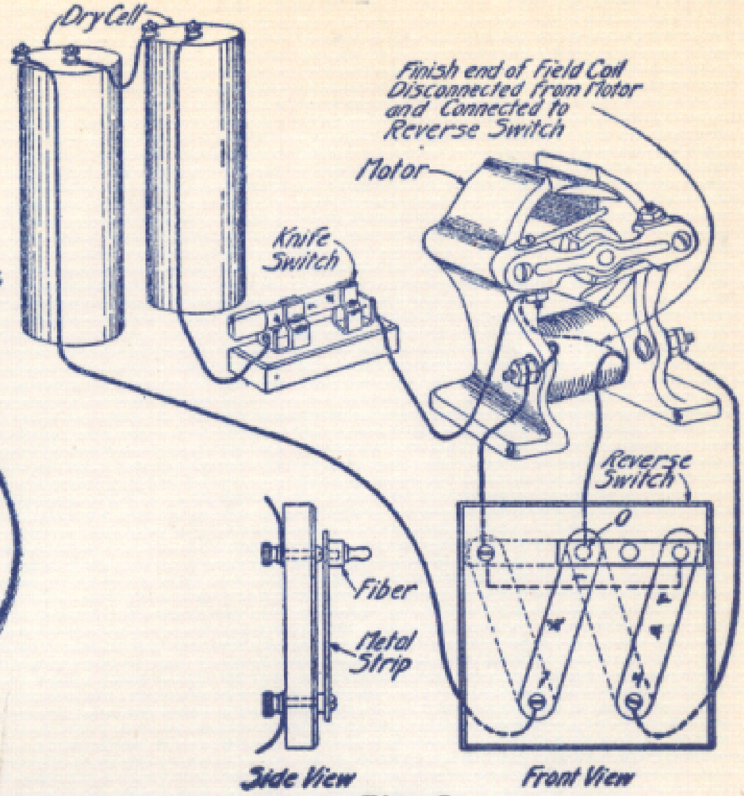


Fig. 5.

You can easily make a reversing switch from a block of wood 4 inches square and about 1/2 inch thick. Two metal strips will be required. These are fastened together by means of a fibre strip. When the reversing switch is completed, the finishing end of the field coil must be connected to the terminal of the reversing switch marked "O" in Fig. 5.

WINDING MOTOR FOR 110 VOLTS.

By using a much smaller wire than that which I sent you with your motor for winding the armature and field coils, and using a great many more turns, it is possible to operate the motor direct from a 110 volt lighting circuit, either D. C. or A. C. The motor will run somewhat slower on alternating current, because of the fact that it is built of solid iron. All A. C. motors will operate best if the field frame and armature are laminated; that is, built of thin sheets of iron. Also, the motor will become somewhat hotter when operated on A. C. than on D. C.

In winding the motor for 110 volts, it is only necessary to wind about 400 ft. of No. 30 enamel covered wire on the field core, and about 125 ft. of the same size wire on each armature pole. The winding and the connections of the coils to the commutator and to each other are done in exactly the same manner as explained in the preceding paragraphs.

Since a great deal more wire must be used in this winding, enameled wire is best, because this form of insulation occupies less space than other insulation. In winding, be very careful not to break or rub off the enamel in any place on the wire, for this injures the insulation and may allow the bare wire to come in contact with the frame of the motor and thus cause a ground or short circuit. The greatest care must be taken when the motor is wound for 110 volts, for at this high pressure, troubles are much more likely to occur than when operating at 3 or 4 volts.

WINDING MOTOR FOR 32 VOLTS.

It is sometimes desired to operate this motor from a 32-volt farm lighting plant. In that case, the motor can easily be wound for this voltage by winding 100 ft. of #24 wire on the field core, and 140 ft. of #26 wire on each of the armature legs. All connections should be made as I have already explained.

VOLTMETER, AMMETER AND KNIFE SWITCH.

Besides the motor, your outfit also contains a small voltmeter, an ammeter and a knife switch. These instruments are small enough so that you can carry them in your vest pocket, in case you care to use them for testing. The range of the voltmeter is from 0 to 10 volts, and it should not be connected to any source of power where the pressure is more than 10 volts, because it may either burn out the instrument or cause the needle to be badly bent.

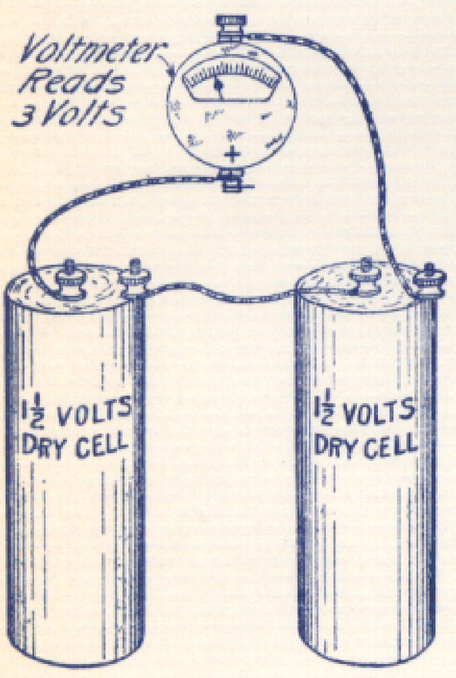
The ammeter looks exactly like the voltmeter, but the construction inside is somewhat different. The voltmeter can be used to measure electrical pressure across any two points in a circuit, while the ammeter will indicate the number of amperes flowing in a circuit.

VOLTMETER EXPERIMENTS.

Here is an experiment which you can perform with your voltmeter by testing the voltage on series and parallel connections. You will need two new dry cells to operate your outfit motor. First, test the voltage of one cell by connecting the positive terminal of your voltmeter to the carbon or center terminal of the dry cell, and connecting the negative to the zinc or outside terminal. The needle will swing to the right. Now reverse the connections and note that the needle swings to the left. The voltmeter can be used to indicate polarity of low voltage D.C. circuits for if the positive terminal of the voltmeter is connected to the positive side of the line, it will give the correct indication, but if the positive terminal of the voltmeter is connected to the negative of line, a reverse reading results.

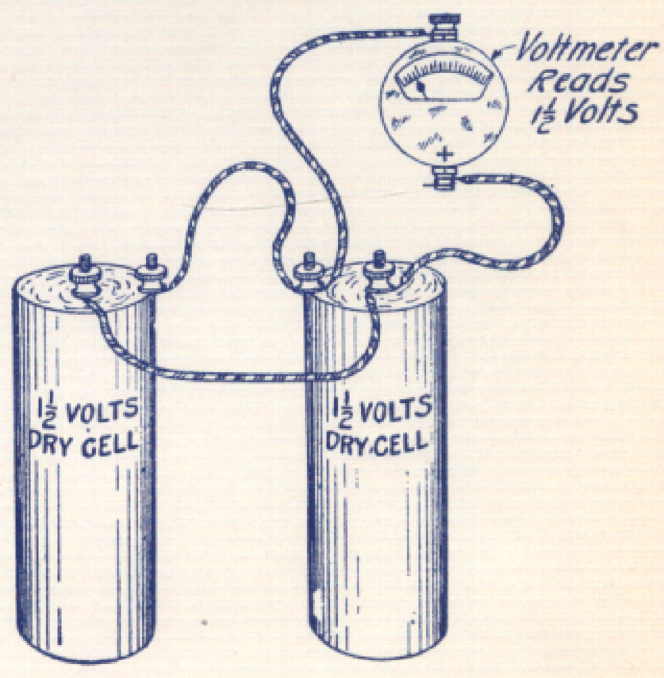
This is exactly the same method that you can use in finding the polarity of a 110-volt or a 220-volt D.C. line if you have a high voltage D.C. voltmeter. This is a mighty good test to remember.

When you first connected the voltmeter to the dry cell, the reading was about 1-1/2 volts. Now connect 2 dry cells in series; that is, connect the positive of one cell to the negative of the other cell and then connect the voltmeter across the



Cells in Series

Fig. 6



Cells in Parallel

Fig. 7

two free terminals as shown in Fig. 6. The reading should be about 3 volts, showing that when two cells are connected in series, the voltage is doubled or the two voltages are added together.

Now connect the two cells in parallel as shown in Fig. 7, and test the voltage. Here you will find that the voltage is the same as that of one cell, showing that the voltage remains unchanged in a parallel connection. This experiment will prove some of the things I told you about in Work Sheet 3.

AMMETER EXPERIMENTS.

Connect the ammeter across the terminals of one dry cell in the same way that you connected the voltmeter, but be sure to hold the connections firm and for a short time only. This reading will indicate the total current that the cells can furnish.

Don't try connecting your ammeter across two new cells in parallel, because the current will be almost double that of one cell and may burn out your ammeter.

Here is another point that you must remember: there is only one condition under which an ammeter is connected across a line and that is, in measuring the current capacity of dry cells. If you try this on any other type of circuit, you are sure to burn out the ammeter or blow out the fuses.

USE OF AMMETER AND VOLTMETER WITH MOTOR.

When an ammeter is used for measuring current in a circuit, it must be connected in series with one side of the line. Now suppose that you will want to measure the current taken by your motor. In your practical work you may quite often want to do this, and here is a chance to make this experiment yourself and thus learn by DOING. In Fig. 8 you will find a sketch showing both the ammeter and voltmeter properly connected in the motor circuit.

When the switch is opened, the voltmeter will measure the pressure of the battery and since no current will be flowing thru the motor, the ammeter reading will be 0. Now close the switch and note what happens; the voltmeter no longer registers the same voltage, but drops considerably because the current flowing in the circuit causes a drop of battery voltage due to this current overcoming the internal resistance of the battery. The ammeter now measures the current flowing thru the motor.

LEARN BY DOING.

Now that I have explained these things to you, go right ahead and connect them up, but remember to place the instruments well away from your outfit motor because its field will otherwise affect the operation of your ammeter and voltmeter which also operate on the principle of electro-magnetism.

This outfit is one of the most important I send you, although it contains only a few electrical devices. The motor, of course, is not large enough to be used for practical purposes, but you should take care of it because we will likely use it again later.

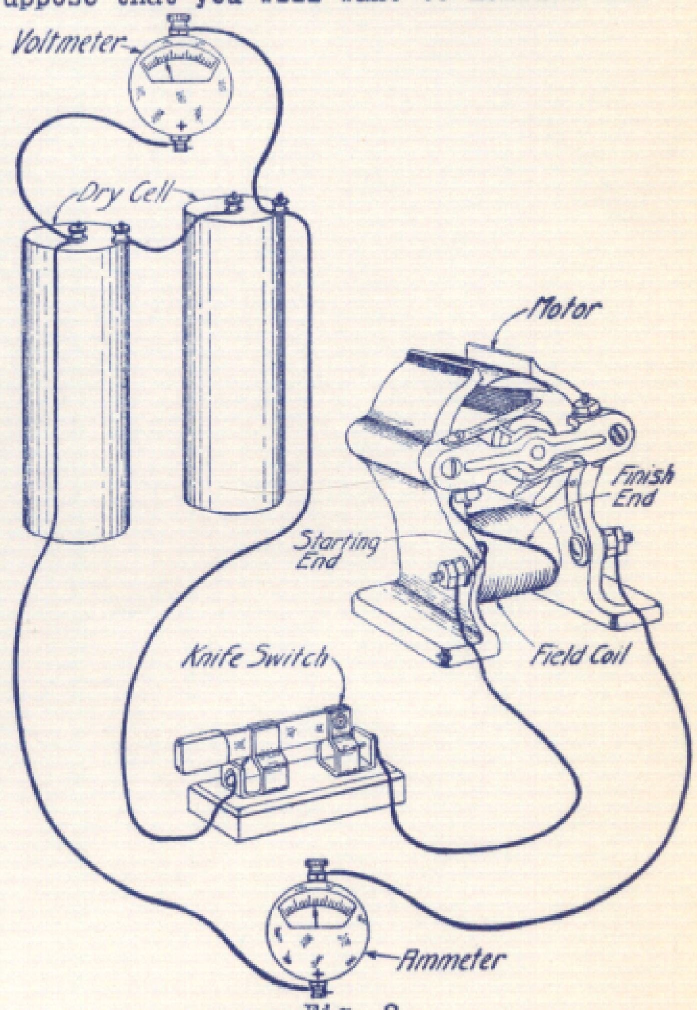


Fig. 8

The Voltmeter and Ammeter can be used with any of your experiments and you will find that they are very handy instruments. You will use both of these pieces again in connection with Outfits you will receive later - so keep them, and take good care of them.

I have not listed all of the experiments you can perform with this outfit, because I didn't know just how much time you had to spend on this kind of work. If you want to do more experimenting, you will find in Work Sheets 18 and 19 many more experiments that you can easily make.

YOUR NEXT OUTFIT.

If you enjoy this experimenting –– actually doing with your own hands the things you are studying about –– then you have something mighty interesting and practical ahead of you. I am referring now to your next outfit, which will be sent to you when you finish Work Sheet 28. A thorough knowledge of the various types of switches and their use in the control of electric circuits is most essential to the Electrical Expert. Your next outfit will give you ample material to work with in mastering this interesting and important phase of Electrical work.

Just about that time you will be studying my work sheets on circuit controls, switches and house wiring and the practical experience you receive by completing the experiments with the outfit I will send you will make you ready to go out and line yourself up some spare time work to do.

You are gradually reaching the top of the hill –– the hard pull will soon be over and you will soon find yourself on the smooth road to success, happiness and big pay. Just keep on studying.

WORK SHEET METHOD
Trade Mark

Outfit Work Sheet "D"

L. L. COOKE
School of Electricity
CHICAGO

LIGHTING CIRCUITS.

Lighting circuits are to be seen everywhere. Every building, every home, every city has its lighting circuit, and every lighting circuit has its troubles. It's to make you familiar, not only with the installation of such circuits, but also in locating trouble when it occurs, that I have added this Outfit to other Outfits I send you. You will need this one especially when studying Work Sheet 29.

Everything in this Outfit is pictured in the illustration marked Fig. 1 on the first page of this Outfit lesson. Examine this picture carefully, and then go over the Outfit itself to make sure none of the items or parts have been left out.

I have sent you one single-pole switch and two 3-way switches, because they are used a great deal more than any others for the control of lighting circuits.

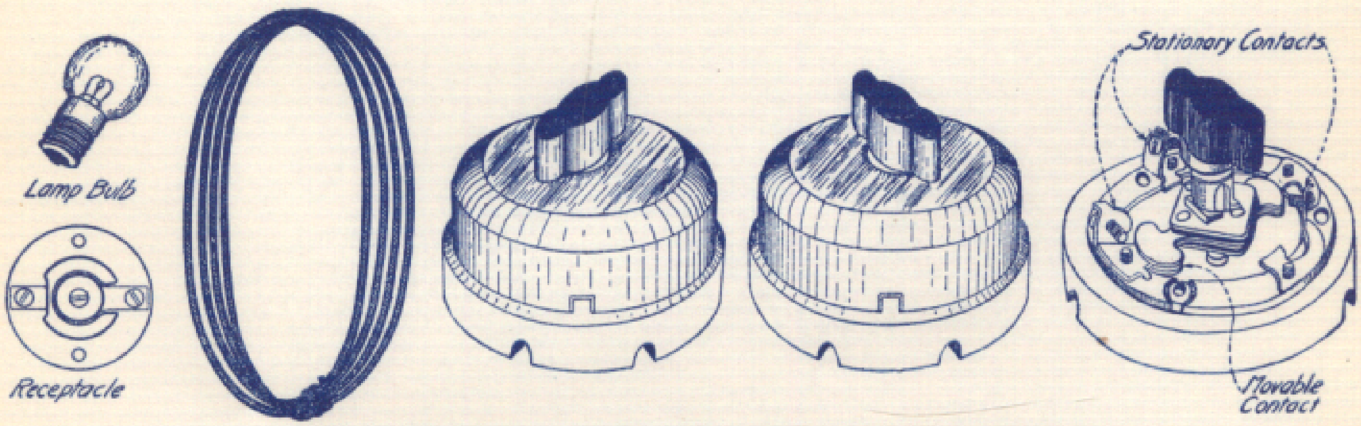


Fig.1

Every home wired for electricity offers opportunities for the use of 3-way switches. Stairways or long hallways are the places where you will see them most frequently used.

Whenever you see an opportunity to install them, call it to the attention of your customer. It will create more work for you and will benefit him by providing convenience which he will learn to appreciate. Besides helping him in this way, you will have a customer who will be ever willing to boost you.

In addition to the switches, I have sent you a miniature lamp and receptacle, and a coil of #14 wire. The lamp may be used to try out the circuits shown in this work sheet and Work Sheet 29 and the wire may be used to make connections.

You will need two dry cells connected in series as a source of current for your lamp.

The circuits which are shown in this work sheet are also shown in Work Sheet 29, except that in this work sheet I have shown two dry cells used as the source of power.

LAMPS AND RECEPTACLES.

The lamp in this part of your outfit is similar in size and construction to a flashlight lamp. In case it should ever burn out, you can easily replace it at any electrical supply store.

The receptacle is arranged so that the construction can easily be seen. Two contacts are provided for attaching wires, and there are two small screw holes in the base to support it wherever desired.

WIRE.

The roll of #14 rubber covered wire is to be used in making the connections for your lamp and switches. This wire is standard and is the kind used for lighting installations. When you begin making the connections for the different circuits you can cut off short pieces of wire as you need them. The method of connecting the wires to the switch contacts is shown in Fig. 2.

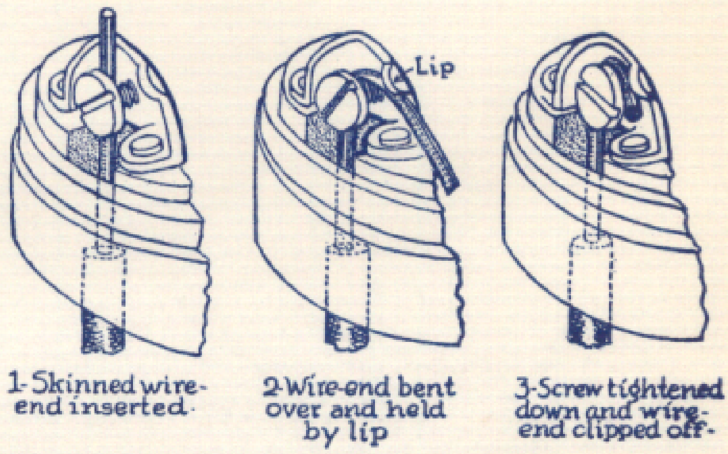


Fig. 2

EXPERIMENT 1.

Using your single pole snap switch, connect it in series with your batteries and your lamp receptacle as in Fig. 3. Do not connect your switch across the battery or in parallel for it will then act as a short circuit and run the batteries down in a very short time.

EXPERIMENT 2.

Connect your lamp to a 3-way switch as shown in Fig. 4. Your 3-way switch is now being made to act the same as a single pole switch by simply connecting and disconnecting the lamp. This is similar to Fig. 8 in Work Sheet 29.

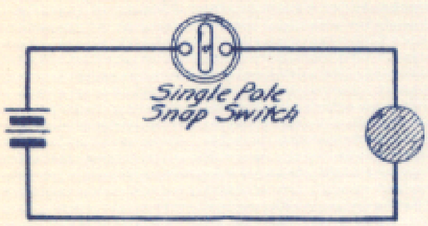


Fig. 3

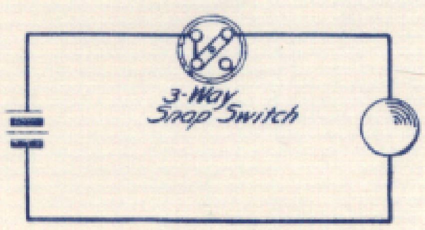


Fig. 4

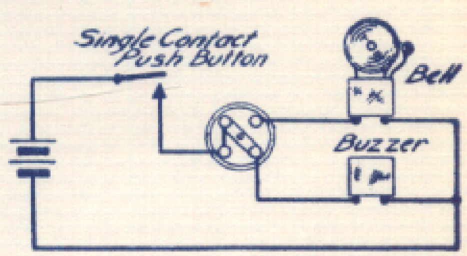


Fig. 5

EXPERIMENT 3.

In your second outfit you have received a bell and a buzzer. Now, I am going to give you an example of restricted control, by combining the use of apparatus which you received in Outfit B and Outfit D. In Fig. 5 the single contact button is used to complete the circuit, but whether it rings the bell or the buzzer, will be determined by the position of the 3-way switch. It will not be possible to operate the bell and the buzzer at the same time because the 3-way switch can only complete the circuit through one of the two.

EXPERIMENT 4.

Fig. 6 is a connection which every electrician must know; namely, the control of a lamp from two places by the use of 3-way switches. When taking examinations for journeyman electrician this question is nearly always asked. You will also find it possible to connect your 3-way switches as shown in Fig. 14 of Work Sheet 29 but this method is not approved as I have already explained in that work sheet.

EXPERIMENT 5.

Very often it is desired to master a 3-way connection so that no one can turn the light off. To do this, it is only necessary to connect the 3-way switches as shown in Fig. 6 and then connect your single pole snap switch across the two traveler wires as shown in Fig. 7. With the master switch in the "off" position, it will be possible to control the light from either of the two 3-way switches, but when the master switch is closed the circuit is always complete and the light will remain "on". As shown in Fig. 7, the master switch is open and the lamp is turned off. Now, turn the master switch on and you will find that current can flow through the first 3-way switch, into the lower traveler wire, through the master switch, to the upper traveler wire, through the second 3-way switch, through the lamp and back to the other side of the line completing the circuit.

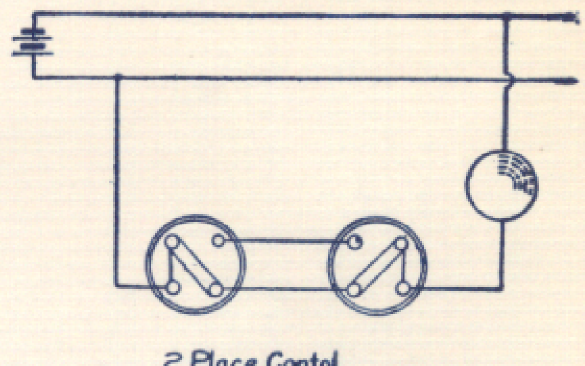


Fig. 6

EXPERIMENT 6.

Another method of mastering a set of 3-way switches is by connecting a single pole snap switch in such a way that it shunts current around the 3-way switches. This kind of connection is shown in Fig. 8. I suggest that you try out this connection as well as Fig. 7. The results are no different.

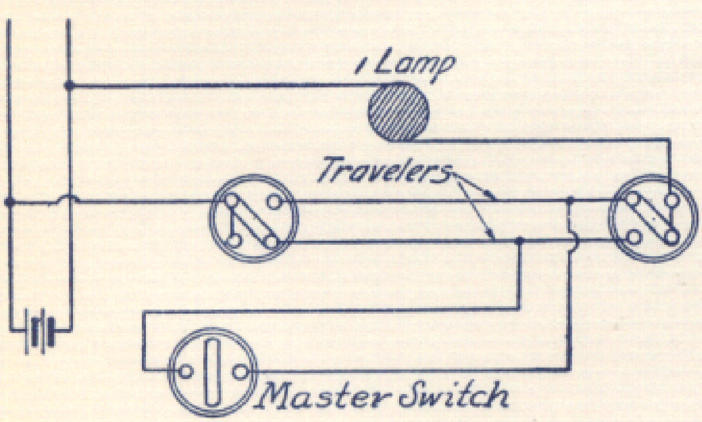


Fig. 7

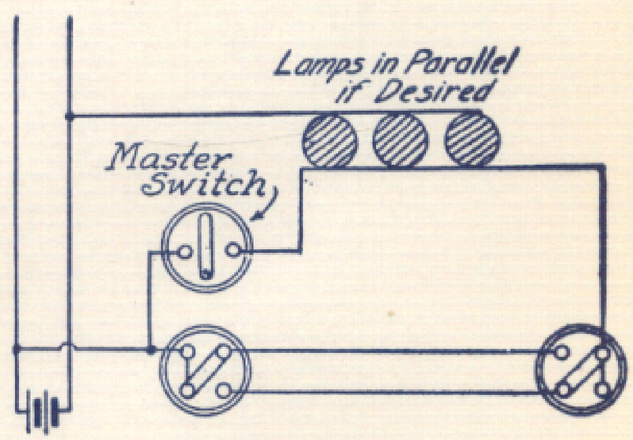


Fig. 8

EXPERIMENT 7.

For this experiment you will need your two 3-way switches, your single pole switch, your bell and your buzzer. This is a master circuit much the same as Fig. 30 of Work Sheet 29. When the master switch is open, the 3-way switches will act like single pole switches in controlling the bell and buzzer, but when the master switch is closed, it will carry current to either the bell or the buzzer through a different path in case that either one is ordinarily shut off. This circuit is shown in Fig. 9.

EXPERIMENT 8.

Fig. 10 shows how you may connect a set of 3-way switches in a stairway. It may be that you will not have an opportunity to perform this experiment but in case that you do, I want you to try it out.

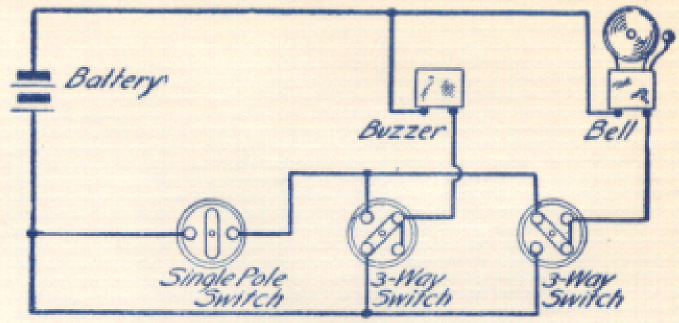


Fig. 9

GENERAL HINTS ABOUT EXPERIMENTS.

When making your experiments with your outfit, I would advise you to lay out your equipment on a table or other flat surface, and make the connections only temporarily. Later on, after you have tried out the circuits shown in this work sheet and in Work Sheet 29, you may mount the equipment permanently wherever you desire, or if you wish you may install the switches permanently in your home.

Your experiments with this part of your electrical outfit will help you, not only in making connections for light circuits, but also in understanding wiring diagrams and blueprints of electrical circuits.

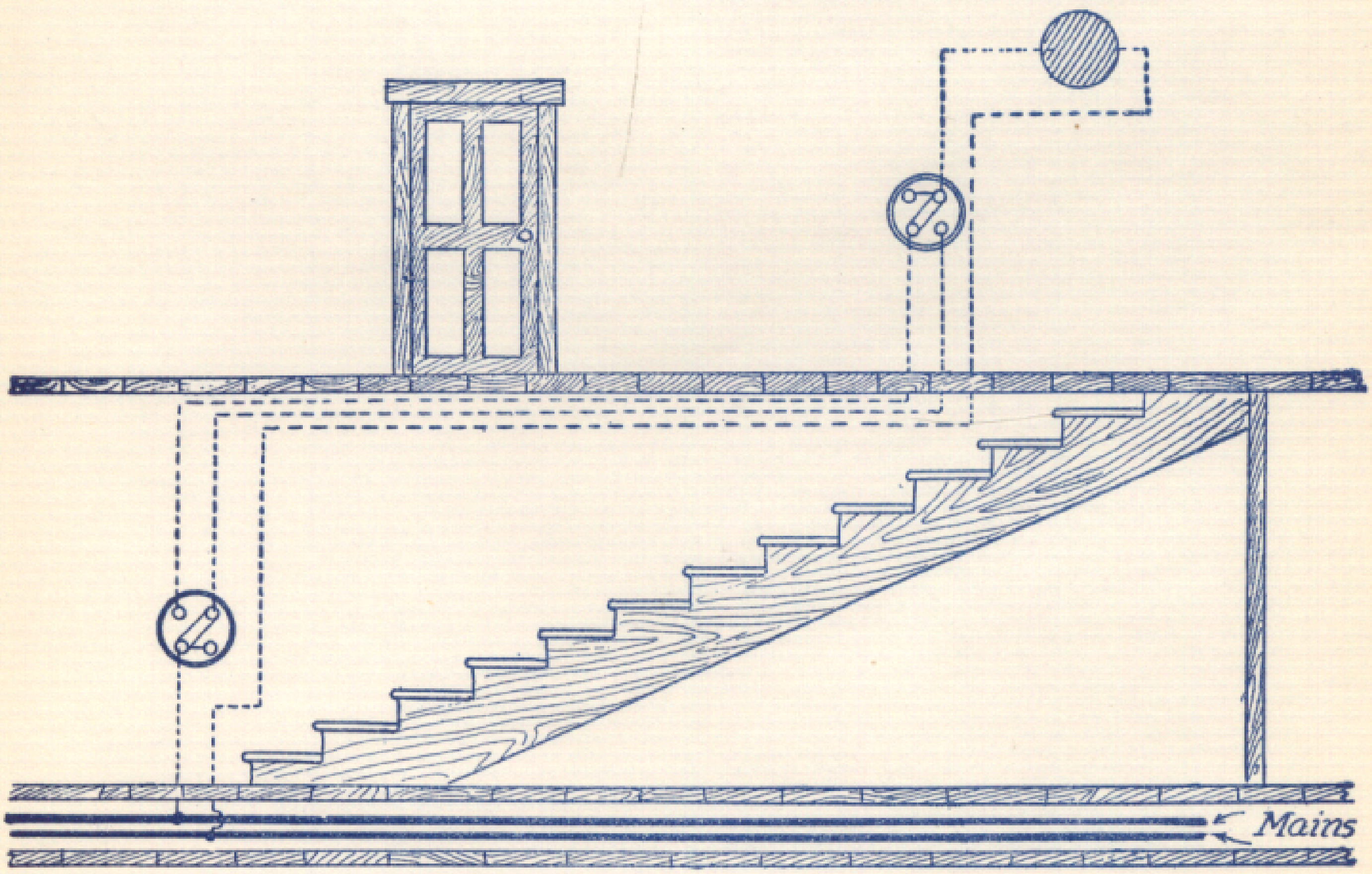


Fig. 10

The switches included in this outfit are standard and approved by the National Board or Underwriters. They can be used to good advantage on any exposed wiring job and need not be confined to experimental work alone. In this outfit I have given equipment that you will have occasion to use often in wiring.

In Work Sheet 29, you will find information concerning switch troubles. Examine all of the parts closely. Note where loose connections are likely to be found and then know where to look for them when they occur. Opportunities come more often to the man who is prepared for them than to the man who is not. This is one of the open secrets of "Success."

For the fellow who expects to go into the Wiring and Contracting profession, there is much to be gained from this experimental outfit.

So many experiments are possible that it will take you quite a long time to perform all of them. Whenever you get an opportunity to experiment, take advantage of it and then many of your problems will be "made to order" for you.

YOUR NEXT OUTFIT.

Part Five of your Electrical equipment will appeal to you in two ways. First, from the standpoint of the practical Electrician, second, from that of the more inventive man -- the man who enjoys to experiment for the purpose of discovering new facts and testing new ideas of his own. In this outfit, which will be sent to you when you have completed Work Sheet 38, you will get all the materials needed for the construction of an instrument used in making various electrical tests and resistance measurements. With it you can do much more than perform experiments I give you in the work sheets. You can make experiments and electrical researches of your own invention.

In the meantime study regularly on your work sheets up to No. 38. They cover subjects you ought to know before you undertake the more advanced experimental work with your next outfit. I am going to take you right into the heart of Electricity in the work sheets ahead of you.

L. L. COOKE
School of Electricity
CHICAGO

Outfit Work Sheet "E"

ELECTRICAL MEASURING EQUIPMENT

This work sheet explains the fifth outfit of your course; namely, the Slide Wire Bridge. In Work Sheet 37 you learned about the operation of resistance measuring devices and now I am going to tell you how you can make one which you can use in your work.

Here you will have an opportunity to do some practical work and I feel sure that you will benefit by your experience and enjoy your studies that much more.

Very few electricians really understand resistance, and only a few of these know how to measure the resistance of a conductor. But with the aid of this slide wire resistance bridge, I am going to show you just how this is done.

All of your outfits have, no doubt, helped you in understanding the principles of electricity, and I feel you will enjoy this one even more, because you are going to build it yourself.

PARTS THAT YOU RECEIVE IN YOUR OUTFIT.

In your outfit you will receive 7 binding posts for baseboard mounting, one brass strip 3" x 1/2", a paper scale 1 meter in length, which is divided off into 100 parts, 60 feet of #24 cotton covered magnet wire, 8 feet of #34 resistance wire and 4 feet of #22 resistance wire.

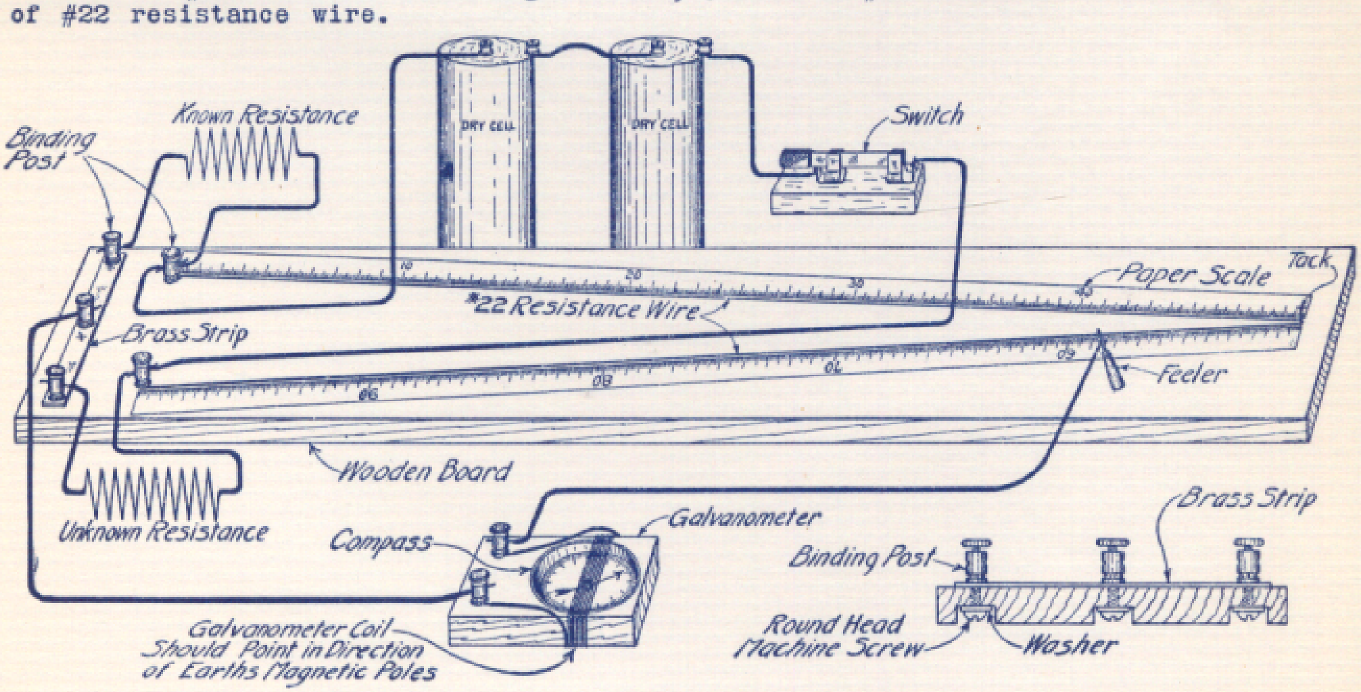


Fig. 1

PARTS THAT YOU WILL HAVE TO MAKE.

You will need several other parts not included in the outfit, but these you can make with very little trouble. First, you will need a smooth board 2 feet long and 4 inches wide and about 1/2" to 3/4" thick. This board is to be used as the base for the other parts.

You will also need a small wooden block of the same thickness as the baseboard and having a length of 4" and a width of 3"

If you have not the tools with which to make these parts, you can have a carpenter make them for you. The small block which will be used as a support for the compass, should have a hole drilled into it, having a diameter of 1-3/4" and a depth of 3/8". You will need an expansion bit and a brace in order to do this. In drilling the hole, set the center of your bit 1-1/2" from the end of the block and in the center between the two sides.

OTHER PARTS NEEDED.

Aside from these, you will need two dry cells which you can purchase from any electrical supply store, a switch such as the one you received in the third outfit, or if you wish, you can use the single pole switch I sent you in the fourth outfit. You will also need a compass which will be used as part of the galvanometer. The compass I sent you in your second outfit will be suitable for this.

BUILDING THE BRIDGE AND GALVANOMETER.

In building the bridge you will first have to make a baseboard of the dimensions given in Fig. 2. While you are sawing off the four inch board to a length of two feet, also saw off a small block four inches wide and three inches long. This block is to be used as a support for the compass.

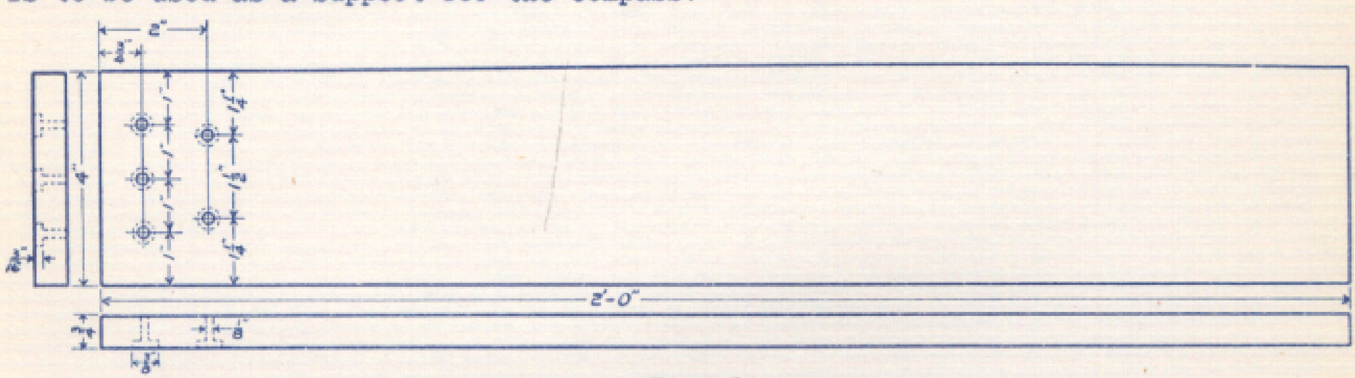


Fig. 2.

The holes for the binding screws are 1/8th inch in diameter and are countersunk on the bottom side so that the heads of the screws will not project beyond the surface of the board where they can scratch the polished surface of a table, or where they can make electrical contact in case the bridge rests on a metal surface.

You will find it a little easier if you will drill the large holes on the bottom of the board first and later drill the smaller ones. The three holes which you see at the left end of the board are one inch apart and to lay them out, you may use the brass strip as a guide. In fact, it is better to do this since this brass strip must be held in place by means of the three end binding posts.

Drill the other two holes 1-1/4th inch in from the outer edge of the board and two inches from the end. The binding posts which are placed in these holes are the ones which must hold the V-shaped resistance shown in Fig. 1.

In order to make the hole which is to receive the compass, you will either have to use an extension bit or a wood chisel. Drill the holes for the two binding posts and when you have finished with this work, sand both the bridge and compass blocks smooth with a piece of #0 sandpaper. The appearance of the wood bases can further be improved by giving them both a coat of shellac.

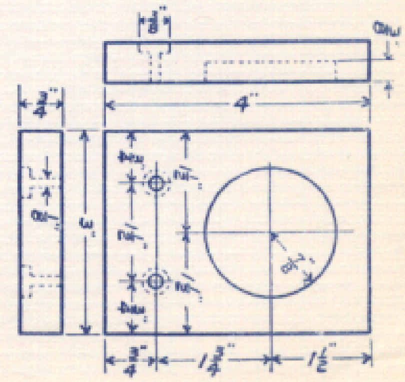


Fig. 3.

Next, mount the binding posts and the brass strip as shown in Fig. 1, but before you tighten the two inner posts, measure off a piece of #22 resistance wire one inch longer than the paper scale. Fasten the two ends of this wire under the binding posts using about 1/2 inch of wire for each connection and then tighten the binding posts by turning the screws from the bottom side of the board.

Now, get a tack or a small staple. Stretch the resistance wire out tight until a long "V" is formed and then fasten down the base of the V with the tack or staple. If the resistance wire is pulled tight, the job will be a neat appearing one. The tack should be driven in midway between the two sides of the board.

Next, cut the paper strip in half and paste it down on the board as I have shown in Fig. 1 with the lines next to the wire.

The first thing to do in assembling the galvanometer, is to insert the compass in the large hole and then wind 10 turns of #24 magnet wire around the block so that the coils come directly over the center of the compass. The turns of wire in the coil should be wound closely together making the coil as compact as possible. A little shellac applied to the coil will help to hold it firmly in place.

MAKING THE KNOWN RESISTANCE.

Before you connect up the battery and various other parts, you will first need a known resistance. In your outfit I included a piece of very fine resistance wire. The size is #34 and has a resistance of 7.4 ohms per foot. For a 10 ohm resistance you will need more than one foot of this wire. A piece of wire 1 ft. 4 in. long has a resistance of 10 ohms, but you will have to allow about 1/4" for each connection to the binding post, so I suggest that you cut off a piece of wire about 1 ft. 4½ in. in length, allowing 1/4" for each connection.

For making tests on wires having high resistance, you will want to use another coil having a known resistance of 50 ohms. To build a known resistance of 50 ohms, first obtain a cardboard tube like the one shown in Fig. 4. If you still have the tube on which the magnet wire in outfit #1 was wound you may use it as a support for the resistance wire, or you can use any other kind of cardboard tube if you wish.

The resistance must be non-inductive, otherwise, with an inductive resistance coil, a choking effect will be produced on the current and the result will be inaccurate readings. To make a non-inductive coil, first cut 6 feet and 8½ inches of #34 resistance wire and double it together.

You will then have the two ends of wire together and a loop at the other end. Fasten the loop to the cardboard tube by means of a staple or a nail and then proceed to wind the two wires around the tube, as shown in Fig. 4. The wires should not touch each other at any point. When you have finished, bring the two ends out through small holes punched in the cardboard tube. In order to hold the resistance wire in place, apply one or two coats of shellac. You now have a non-inductive resistance coil, suitable for measuring high resistances on your bridge.

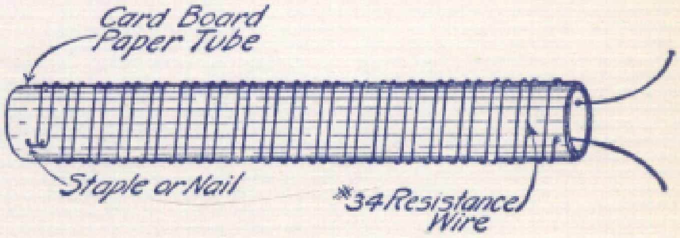


Fig. 4.

6 feet 8 inches of this wire is exactly 50 ohms, so that 1/2" is allowed for making connections to the binding post.

MAKING CONNECTIONS.

The bridge and the galvanometer are assembled and you are now ready to connect the batteries and the other devices in the circuit. The first thing to do is to connect your known resistance to the two binding posts as shown in Fig. 1. To begin with, I would try the 10 ohm resistance, if I were you. Connect one end of the battery to the known resistance at the binding post which holds the bridge resistance wire and connect the other terminal of the battery to the unknown resistance at the other side where the binding post holds the other end of the bridge resistance. Connect your knife switch in series with the battery so as to shut off the current when you are not using the bridge. Connect the unknown resistance opposite to the known resistance and then connect the galvanometer to the middle binding post of the brass strip. The other binding post of the galvanometer is connected to a flexible wire to which is soldered a piece of larger copper and which is to act as a feeler or contact maker.

For an unknown resistance, use any piece of wire you may care to measure, but preferably a piece of magnet wire which has considerable resistance.

OPERATING THE BRIDGE.

Before measuring the resistance of a conductor, arrange the galvanometer so that the coil wound over the compass is directly in line with the compass needle when it is pointing to the earth's magnet poles. Then when current is sent through the coil, the magnetic field established will deflect the magnetic needle and try to arrange it at right angles to the coil. When the current is shut off either by the switch or the feeler, the magnetic needle will return to its normal position in line with the earth's magnetic field. You can readily see from this, that the coil is always acting to deflect the needle at right angles to the earth's magnetic field.

Now that you have the galvanometer properly arranged, close the battery switch and touch the feeler to the resistance wire. Note which way the compass needle moves and then try a point on the opposite side of the resistance wire. If this results in deflecting the needle in the opposite direction, you will know that the point of balance lies somewhere between these two points. For example, first touch the feeler on the wire at 10 and note in which direction the needle is deflected. Then touch the feeler to the resistance wire at 90 and note the direction of deflection. If the needle is deflected in the opposite direction the point of balance lies somewhere between 10 and 90, but if both tests show that the needle is deflected in the same direction, you must try to find the point of balance either between 0 and 10 or between 90 and 100. But suppose that the compass is deflected in the opposite direction when you touch the resistance wire at 90. Now touch the resistance wire with a feeler at 80. If the deflection is the same as it was at 90, touch the resistance wire at 70. As you get nearer to the point of balance, the deflection of the needle will be less violent. Finally you will reach the point where the needle will not be deflected at all and this shows that no current is flowing through the galvanometer and that your resistances are perfectly balanced.

Suppose that the compass needle strikes a point of balance at 75.

Now you will have to use your pencil a bit in order to work out a problem and find the unknown resistance. Subtract 75 from 100 and the result is 25. Now multiply the value of the known resistance by the number of spaces between the feeler and the binding post to which the unknown resistance is connected. 10 multiplied by 25, equals 250. Now you must divide this number by 75 to get the value of the unknown resistance and in working this out, you will find it to be 3-1/3 ohms.

Now here is a point to remember, which I think will stand you in good stead in working out problems of this sort. When the feeler strikes the point of balance on the scale higher than 50, the unknown resistance will be less than the known resistance, but when the feeler comes to a point of balance between 0 and 50, the value of your unknown resistance will be more than the known resistance.

Now, let us take another example; suppose we find a point of balance at 35. You will at once know that the unknown resistance will have a higher resistance than 10 ohms. Let us see how this problem works out. 35 subtracted from 100 is equal to 65. Therefore, 10 multiplied by 65 divided by 35 will be equal to 650 divided by 35 or approximately 18-1/2 ohms.

I want you to be sure you understand the formula for finding resistance with the slide wire bridge and I also want you to become so well acquainted with this device that it will only take you a few minutes to operate the bridge and work out your problem.

YOUR NEXT OUTFIT.

After you have finished Work Sheet 50, you will be ready for outfit F which is a transformer. This device will also be sent to you unassembled and you will have the opportunity of putting it together and making it work.

The success of present-day power plants is largely due to the transformer which can be made to step up or step down alternating current voltages. Just as soon as you have finished twelve lessons more, you will be ready for this interesting piece of experimental apparatus. Therefore, I wish you would get right after your lessons, as you are going to find experiments with alternating current equally as interesting as any you have made thus far.

WORK SHEET METHOD
Trade Mark

L. L. COOKE
School of Electricity
CHICAGO

Outfit Work Sheet "F"

Electrical Transformer Equipment

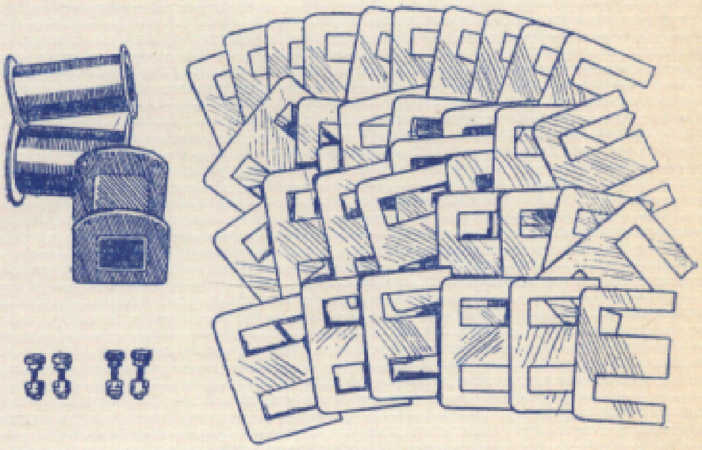
The transformer in this outfit is sent unassembled so you can have the experience of building it yourself. I feel sure that the knowledge you gain by building this transformer is going to help you considerably in understanding both its construction and theory.

In your electrical work, you will often be required to work with transformers. Perhaps you will be called upon to install and connect them, or you might be required to solve transformer problems and locate causes for trouble.

I shall not attempt to estimate the number of transformers in use today, for wherever you find alternating current being used, you will find transformers; in fact, it is the transformer which has made the rapid development of alternating current systems possible.

My work sheet dealing with transformers has, no doubt, reached you by this time and when you combine the knowledge gained from your experiments with the instructions I give you in work sheets 57 and 60, there is no reason why you should not be fitted to take charge of all kinds of transformer equipment.

If you will refer to Figs. 2 and 3 of Work Sheet 57, you will find there, two types of transformer cores. Fig. 2 shows the core type and Fig. 3 shows what is known as the shell type of transformer. The transformer which I give you in this outfit is of the shell type; that is, the iron core is built both in and around the coils.



Transformer Parts

TRANSFORMER PARTS.

The unassembled transformer consists of a number of strips of thin transformer steel or laminations, punched out in the proper size for the core, two spools of wire, one of which is #26 enameled and used for the secondary winding; the other spool is #34 enameled wire, used for the primary winding. There are also four binding posts, a rectangular cardboard tube and two fibre ends. The transformer parts are shown on page 1.

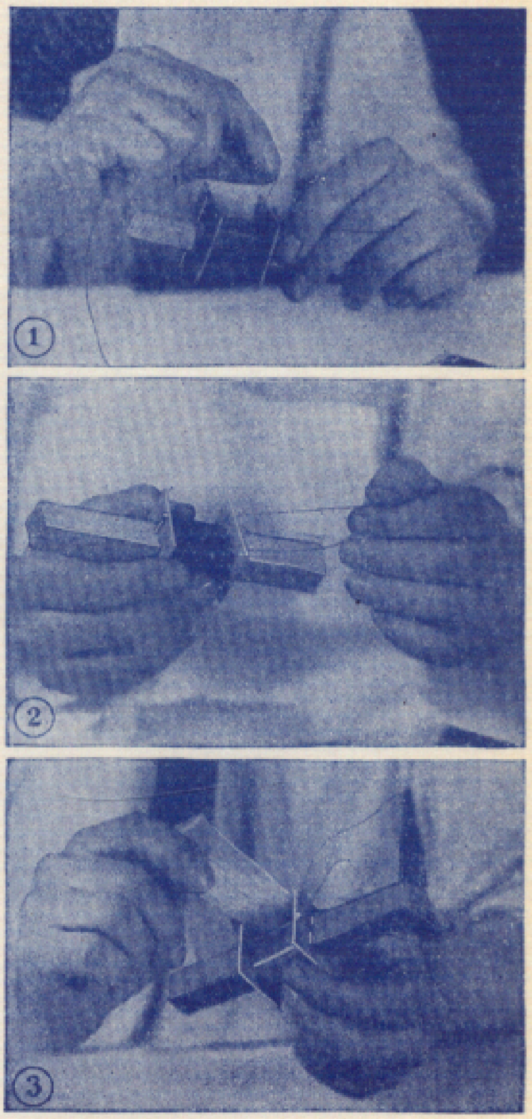
When you receive the unassembled transformer, you will find that a number of laminations are assembled into a rectangular cardboard tube, in order to prevent it from crushing. Take all of these laminations out of the tube.

ASSEMBLING THE TRANSFORMER.

First cut a stick of wood, so that it will fit snugly into the cardboard tube, but be careful that it does not tear it at the corners. It is better to use a stick of wood slightly smaller than the inside dimensions of the cardboard tube, so as to prevent any damage to it. Next, drill two small holes in the stick, 1-5/8" apart, so that when the tube with its fibre ends is pushed onto this stick, small nails or small wooden pegs can be inserted into these holes to prevent the fibre ends from slipping off. This operation is shown in Fig. 1.

Next wind the entire spool of fine wire on the cardboard tube, taking care to keep the turns as smooth and even as possible. Do not pull the wire too tight as it breakes easily. If the wire is wound in neat layers, the construction of the coil will be more compact, although this is not necessary to the operation of the transformer. Leave about 4 or 5 inches of wire on each end of the coil, so that these ends may be brought out and connected to the binding posts which are to be placed in the holes in the fibre ends. The fine wire constitutes the primary winding and is connected to the 110 volt alternating current line. Fig. 2 illustrates this operation.

Cover the primary winding with 2 or 3 layers of waxed paper as shown in Fig. 3. This is very important because in case the insulation on the primary and secondary windings should be damaged in any way, they might make electrical contact with each other and trouble would result. The insulation covering the primary winding may be made by dipping an ordinary piece of writing paper in melted paraffine wax, allowing the wax to soak into the paper thoroughly. After covering the primary winding with the waxed paper insulation, the secondary winding which is the heavier wire, should be put on in smooth and even layers as shown in Fig. 4, leaving sufficient wire in each end, so that the ends may be brought out and connected to the binding posts. After the secondary winding is placed on the spool, it should always be covered with several layers of paper. When the winding is completed, take out the stick of wood and slip in the laminations as shown in Fig. 5. Place the first lamination through from one end of the spool and the next from the other end, and place them alternately until the entire core is built up. Use as many of the laminations as possible, so they will fit snugly, but do not try to force the laminations in, if the space is all filled up. You might break the cardboard tube and since the edges of these laminations are quite sharp, the wire of the primary winding might be cut, or grounds might result.



Figs. 1, 2 and 3

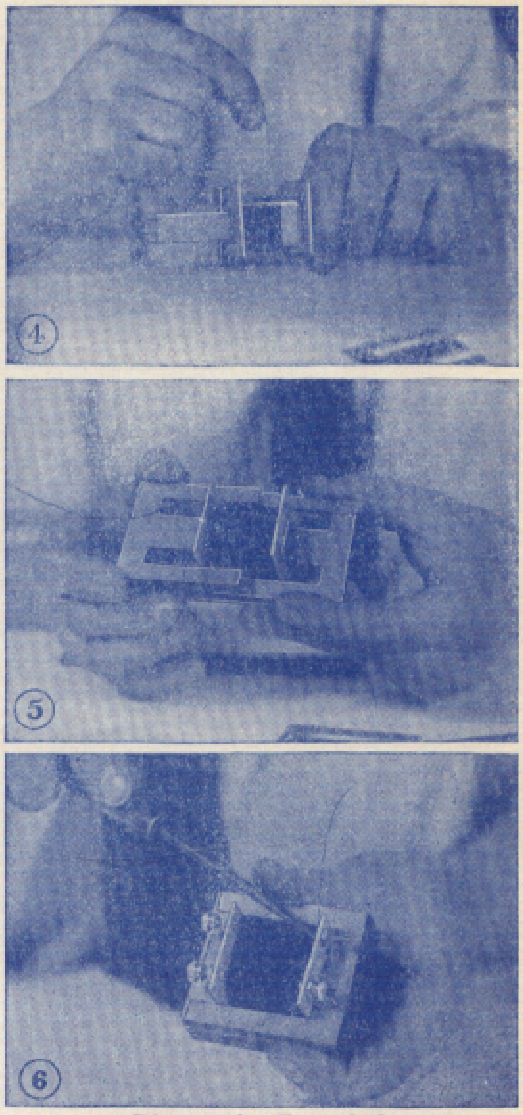
You are now ready to place the binding posts in the holes in the fiber ends. When you have done this, scrape the enamel from the wire where it is to connect to the binding post. This is to insure good electrical contact. One end should be fastened under each binding post, the two ends of the primary winding being fastened to the binding post on one of the fibre end pieces and the two wires leading from the secondary winding being fastened to the two binding posts on the other end.

There are about 1700 turns of the fine primary wire and about 200 turns of the heavy secondary wire, although it does not make any noticeable difference, if there are a few turns more or less on either of the windings.

OPERATING YOUR TRANSFORMER.

Do not, under any conditions, attempt to operate the transformer from a direct current circuit. If you are not sure as to whether the lighting circuit carries direct or alternatiing current, look at the watt-hour-meter name plate. If any reference is made to phase, frequency or cycles, you will know at once that the circuit carries alternating current. D. C. watt-hour-meters are usually labeled prominently on the name plate, so there will be little danger of any mistake. There are several other ways in which you can determine whether a line carries alternating current or direct current. One is as follows; hold a permanent magnet near the filament of a lighted lamp. If the lamp carries alternating current, the filament will be seen to vibrate, but if it carries direct current instead, the filament will be slowly pushed away or drawn toward the permanent magnet. The other method is to bring off two wires from the alternating current line with the lamp connected in series with one of them. Hold the two ends of the wire in a solution of salt water. If direct current flows in the circuit, there will be a large collection of small bubbles on only one wire, but if alternating current flows in the circuit, there will be an equal number of bubbles on each of the wires.

The latter method is not recommended, if it is possible to examine the watt-hour-meter or use a permanent magnet.



Figs. 4, 5 and 6

Another method is to examine the line wires before they come into the house, if you see them coming from a transformer, you will know that the line carries alternating current and is therefore, satisfactory for operating your experimental transformer.

Do not connect this transformer on a 110 volt D. C. line under any consideration. If you do, the primary winding will burn out.

When you have connected the primary winding which is made up of fine wire to the 110 volt 60 cycle line, you can try experimenting with your bell, buzzer and push button which were sent to you earlier in the Course. Try connecting up the apparatus in as many ways as you know how, substituting the transformer for dry cells.

While the transformer can be used for stepping down A. C. voltage it can also be used for stepping up the voltage in a line; that is, if you connected an 8 or 10 volt alternating current supply to the heavy winding which would then act as a primary, you could obtain a much higher voltage from the winding which is made up of fine wire and which in this case would be acting as the secondary.

CONNECTING YOUR TRANSFORMER TO THE LINE.

When connecting your transformer to a 110 volt line, the best method is to use a piece of duplex lamp cord and a socket plug, such as the kind used on electric toaster and irons.

Where you make your connection to the transformer, first remove about 1/2 inch of insulation from each wire. Next, twist the strands of each wire so that they form a compact mass. Otherwise, they will fray out and cause short circuits across the binding posts of the primary winding. Tnen wrap one of the wires around one of the binding posts, taking care that wire is wrapped around the post in the direction that the knurled nut is turned when tightened. If you do not do this, tightening the nut will tend to push the wire out away from the post resulting in poor contact.

When you have made both of the connections you will want to take care of the frayed ends of the insulation. Either wind ordinary string around the end of the duplex cord followed by a coating of shellac, or use friction tape also followed by a coat of shellac.

A transformer used to step 2300 volts down to 230 volts, can be used to step 230 volts up to 2300 volts. In other words, the action of a transformer is reversible.

When you study Work Sheet 57, I want you to refer to this experimental transformer quite often. It works just like any other transformer, the principle of operation being exactly the same as a large one of either the power or distribution type.

I want you to get the most from your experiments. So be sure and let me know if you have any trouble in assembling or operating your transformer.

WORK SHEET METHOD
Trade Mark

Mathematics Work Sheet 3

L. L. COOKE
School of Electricity
CHICAGO

ELEMENTARY ELECTRICAL CALCULATIONS

In the study of Electricity the practical engineer must know how to apply mathematics in figuring out some practical problems. In this course I have cut out all unnecessary mathematics and am only giving you the calculations which you are going to need in your practical work. I am making this part of your work easy to understand and I don't think you will have much trouble in understanding it.

We are now going to take up the study of finding the resistances of circuits which are connected in different ways. You understand there are series circuits, multiple circuits and others as explained in Work Sheet 3. It is very necessary for an electrician to be able to calculate the combined resistance of the different kinds of circuits, because the resistance, in a measure, governs the amount of current maintained in the circuit. In multiple circuits, for instance, there may be connected a number of different kinds of devices, each taking a different amount of current. Now there are times when an electrician must know just how much current each device connected in multiple on a circuit takes when in operation. It takes a very simple calculation to solve this, by the method I use.

There is no perfect conductor of electricity. Every conductor offers some resistance to the flow of an electric current, but some offer more than others. This difference is part of their makeup just as color and strength and weight. Some metals are dark and others are light; some metals are tough and other break easy; and some metals are heavy and some are light. In much the same relation, some metals offer much resistance to the flow of an electric current and some offer very little. The best conductor has the least resistance and the poorest conductor has the most resistance. The resistance of a conductor is fixed in amount without regard to whether current is flowing in it or not, and without regard to the amount of current flowing.

In some work we want conductors which offer the greatest resistance to the flow of the electric current and in other work we want conductors which offer the least resistance. For instance, in the manufacture of electric heating and cooking devices, a very high resistance wire is used, while it is most desirable to employ very low resistance wires for lighting purposes.

RESISTANCE PER MIL-FOOT.

Pure silver is the best conductor and has a resistance of 9.84 ohms per mil-foot. A mil-foot of wire is 12 inches long and has a cross sectional area of 1 circular mil. Its diameter is 1 thousandth of an inch.

The resistances of the different kinds of metals are usually stated as "resistance per mil-foot." This is sometimes called the CONSTANT of the metal and is used to a great extent in wire and wiring calculations. The resistance per mil-foot of copper is 10.79; of aluminum 17.21; of iron 63.35 and German silver 128.29. Compare these different resistances with the conductivity of these metals given in Lesson No. 1 and you will find that as the conductivity increases the resistance decreases.

RESISTANCE GOVERNED BY FOUR THINGS.

The resistance of a metal conductor depends on three main factors; length, cross-section and kind of material; and to some extent on the temperature of the metal. The way the resistance varies can be summed in one statement as follows: "The resistance of a metal conductor varies directly with its length; inversely with its cross-sectional area; it increases as the temperature rises; and depends on the kind of material of of which it is made." (Inversely means that as the cross-section increases the resistance decreases.)

The longer the wire the greater is the resistance. Doubling the length doubles the resistance and reducing the length to one-quarter of the former length reduces the resistance to one-quarter of the original.

By cross-section is meant the actual area seen if the wire is cut directly across. The cross-section is measured in circular mils. Two wires of the same material and length will be found to have different resistances if they are not the same size. The larger wire will have less resistance than the smaller one. The resistance of a metal conductor is inversely proportional to the cross-sectional area, or to the square of the diameter. That is, if one wire has twice the diameter of another wire of the same material and length, it will have only one-quarter of the resistance. A wire with one-half the diameter of another has four times the resistance.

The resistance of metals increases as the temperature rises. The increase in resistance due to rise in temperature is not very much and is not of much consideration when dealing with wiring for practical purposes.

The cross-sectional area in circular mils of any wire may be found by measuring the diameter of the wire in thousandths of an inch and squaring the diameter, that is, by multiplying the diameter by the diameter. Example. A wire 10 thousandths of an inch (.010 inch) in diameter has an area of 10 by 10 = 100 circular mils. A wire 20 thousandths of an inch (.020 inch) in diameter has an area of 20 by 20 = 400 circulars mils. Note that doubling the diameter increases the area "four times." This increase is the same when we double the diameter of any size of wire.

Wires of square or rectangular shape are calculated in the same way, but as the product in this case is in the form of "square mils" it must be multiplied by the constant (1.2733). Example. A wire 10 thousandths of an inch square has an area of 10 x 10 = 100 x 1.2733 = 127.33 circular mils.

SERIES AND PARALLEL CIRCUITS.

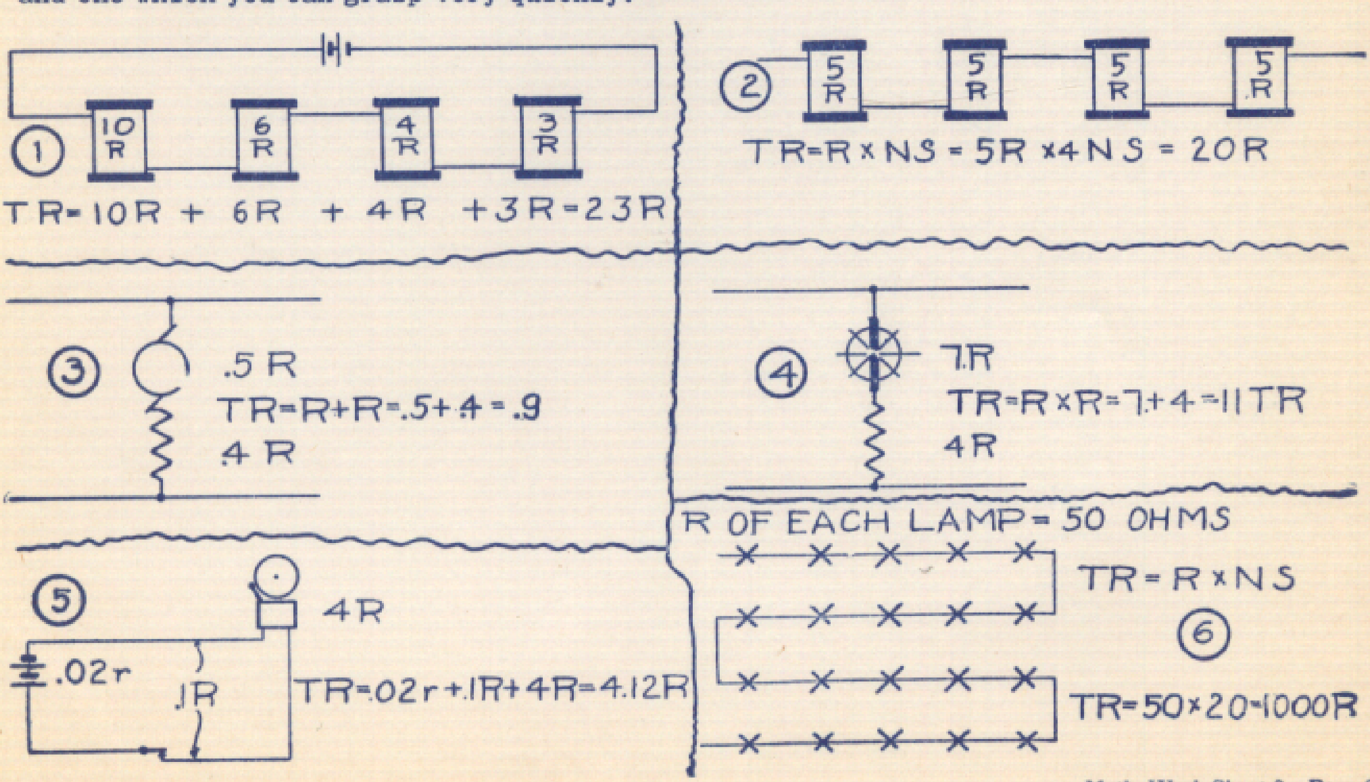
Series and parallel circuits are used more than any other kind. Series-multiple and multiple-series circuits are not in common use and I may say that they are only used in storage battery connections and in devices in which there are resistance coils.

SERIES CIRCUITS.

Series connections are made when cells are connected in the ordinary way. Arc lamps on the streets are usually connected in series. Field coils of multipolar motors and generators are connected in series. Resistance coils are connected in series with any apparatus through which they control the flow of the current such as in arc lamps, motors, etc.

It is often necessary to calculate the combined resistance of circuits of different kinds and it is a valuable thing to know how to do. A good electrical man often runs up against a problem of this sort and there should be no difficulty found in solving such problems.

Calculating the combined resistance of series circuits is a very simple matter indeed and one which you can grasp very quickly.



FORMULA NUMBER 1.

In Figure 1 there is shown a simple circuit which includes four electro-magnets connected in series. The resistance of each magnet is shown to be 10 ohms, 6 ohms, 4 ohms and 3 ohms, respectively. What is the entire resistance of all the magnets, or what is the combined resistance?

You can readily see that since the current has to pass through all the coils, one after another, the combined resistance will be equal to the separate resistances added together. This rule you should remember and follow in problems of this kind.

THE COMBINED RESISTANCE OF A SERIES CIRCUIT IS EQUAL TO THE SUM OF THE SEPARATE RESISTANCES. T. R.=R+R+R+R.

To solve the problem shown in Figure 1, it is only necessary to add the values of the separate resistances.

10 ohms+6 ohms+4 ohms+3 ohms=23 ohms.

FORMULA NUMBER 2.

Figure 2 shows a circuit in which there are four coils connected in series and instead of being different resistances, all have the same value, the resistance of each coil being 5 ohms.

The combined resistance of such a circuit may be found in the same way as the problem in Figure 1 was solved, but there is an easier method and this is the rule to use.

THE COMBINED RESISTANCE OF A NUMBER OF EQUAL RESISTANCES CONNECTED IN SERIES MAY BE FOUND BY MULTIPLYING THE VALUE OF ONE BY THE NUMBER.

To solve the problem shown in Figure 2, it is necessary to multiply 5 ohms, the resistance of one coil, by 4, which is the number connected in series.

5 ohms×4=20 ohms.

A series motor is shown in Figure 3 and the resistance of the armature is given as .5 of an ohm and the resistance of the field as .4 of an ohm. What is the total internal resistance of the motor? Small (r) means internal resistance; large (R) means other resistances.

This problem is solved by using Formula No. 1 and the solution is simply: .5+.4=.9 of an ohm, the internal resistance of the motor.

An arc lamp is shown connected across the line in Figure 4. The carbons are shown in series with a resistance coil. The resistance of the coil is 4 ohms and the resistance of the carbons 7 ohms. What is the combined resistance of the lamp, including carbons and coils?

This problem is also solved by using Formula 1. Simply add the 7 ohms and the 4 ohms and the resulting sum is the combined resistance or 11 ohms.

What is the combined internal resistance of a battery of ten dry cells connected in series if the resistance of each cell is .02 of an ohm?

Use Number 2 Formula in solving this problem. Multiply the resistance of one cell by the number of cells in series. The resistance of each cell is .02 of an ohm and there are ten cells in the battery. Multiply the .02 by 10 and the resulting product of .2 of an ohm is the combined internal resistance.

Figure 5 shows a simple bell circuit with cell, wire, push button and bell. The resistances are cell, .02 of an ohm; wire and connections, .1 of an ohm and bell, 4 ohms.

What is the combined resistance of the circuit?

By Formula 1, all of the different resistances should be added together. This is equal to the combined resistance of the circuit.

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 .02
 .1
4.
----
4.12
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A series arc circuit is shown in Figure 6. What would be the combined resistance of one of the circuits if the resistance of each lamp was 50 ohms?

According to Formula 2, the combined resistance is equal to the resistance of one lamp multiplied by the number connected in series. Multiply fifty ohms, the value of the resistance of one lamp, by twenty, the number of lamps, and the product obtained, 1000 ohms, is equal to the combined resistance.

MULTIPLE OR PARALLEL CIRCUITS.

You understand that in a series circuit the current passes through the different devices, one after the other and the current is the same in all parts of the circuit. In a multiple, or parallel circuit this is not so because the current divides, part passing through each of the different devices.

In calculating the combined resistance of a parallel circuit, there are several methods which may be followed, depending on whether the circuit is a simple one or a complicated one. There is one fact that you should first understand and that is: THE COMBINED RESISTANCE OF A PARALLEL CIRCUIT IS LESS THAN THE RESISTANCE OF ANY SINGLE DEVICE IN THE CIRCUIT.

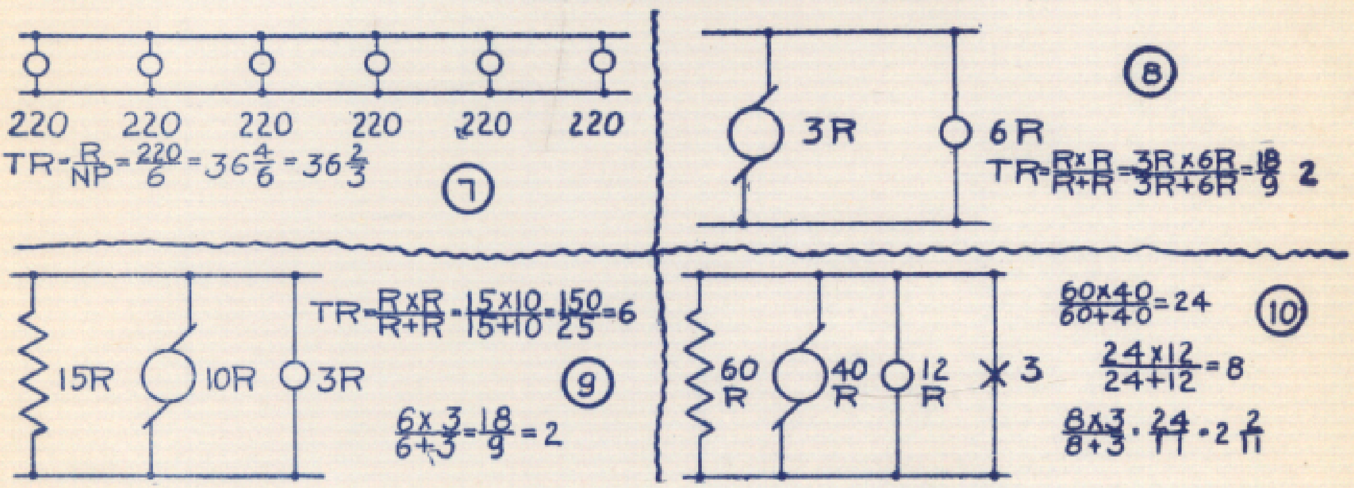
FORMULA NUMBER 3.

When the resistances of all the branches of a parallel circuit are the same, the combined resistance can be calculated in a very simple manner.

The rule is: WHEN THE RESISTANCES OF ALL THE BRANCHES OF A DIVIDED CIRCUIT ARE EQUAL, THE COMBINED RESISTANCE MAY BE CALCULATED BY DIVIDING THE RESISTANCE OF ONE PATH BY THE NUMBER OF PATHS CONNECTED.

In Figure 7 there is shown a circuit including six lamps connected in parallel. The resistance of each lamp is 220 ohms. What is the combined resistance of the circuit?

By Formula 3 the combined resistance is equal to the resistance of one lamp, 220 ohms, divided by the number of lamps, 6, which is equal to 36 2/3 ohms.



DIVISION OF CURRENT.

You can readily see that the total current which is maintained in such a circuit as is shown in Figure 7, would be equally divided among the different paths, each path getting the same amount of current, because each path has the same resistance. Suppose there are twelve amperes maintained in the circuit shown in Figure 7. How much current would each of the lamps get?

The 12 amperes would be equally divided between the six lamps, each lamp getting 1/6th of the twelve amperes, or 2 amperes.

FORMULA NUMBER 4.

In a parallel circuit where the resistance of the paths are not equal, a different method must be used when calculating the combined resistance. Where there are only two unequal paths in parallel, the calculation is rather simple.

This formula should be used when calculating the combined resistance of two unequal paths in parallel. THE COMBINED RESISTANCE OF TWO UNEQUAL PATHS IN PARALLEL IS EQUAL TO THE PRODUCT OF THE TWO DIVIDED BY THE SUM OF THE TWO. It is sometimes called the "R times R" method. In calculating the combined resistance of such a circuit you do just what the formula says. That is, multiply the resistance of each path by the resistance of the other path and then add the two resistances together. Then divide the product which was first found, by the sum of the two resistances and the result is the combined resistance of two paths.

In Figure 8 a motor with a resistance of 3 ohms is shown in parallel with a lamp which has a resistance of 6 ohms. What is the combined resistance of the circuit? By Formula No. 4 you should multiply the two resistances and then add the two resistances; then divide the product found by the sum found and the result is the combined resistance of the circuit. $3\times6=18$ and $3+6=9$; 18 is the product and 9 is the sum; $18/9=2$ ohms, which is the combined resistance.

For practice try the following resistances in place of the 3 and 6 in Figure 8: 6 and 12 ohms; 12 and 24; 20 and 30; 24 and 48. The combined resistance of these couples are, respectively, 4, 8, 12, and 16.

A parallel circuit containing more than two unequal paths can also be calculated in this way in order to obtain the combined resistance, but it is not advised as it makes quite a lengthy problem and when fractions are involved it becomes quite complicated. However, the method of solving a problem in this way will be explained here, but later on in the lesson you will be shown a much simpler method.

Figure 9 shows a parallel circuit in which are connected a resistance coil, a motor and a lamp. The resistance of the coil is 15 ohms, the motor 10 ohms and the lamp 3 ohms. To solve this problem by Formula No. 4, it is necessary to find the combined resistance of the coil and the motor first, and then combine the result found with the resistance of the lamp. The combined resistance of the coil and motor is found by multiplying the 15 ohms by 10 ohms, which is equal to 150. Then add 15 and 10, which is equal to 25. Then divide the 150 by 25 which is equal to 6 ohms. Now, take the 6 ohms and combine with the 3 ohms, the resistance of the lamp. To do this, multiply 6 times 3, which equals 18. Now, add the 6 and 3 which is equal to 9. Divide the 18 by 9 and the result, 2 ohms, is the combined resistance of the parallel circuit, including the 15 ohm coil, the 10 ohm motor and the 3 ohm lamp.

Figure 10 shows another circuit with four devices connected in parallel. The devices are a 60 ohm coil, a 40 ohm motor, a 12 ohm incandescent lamp and a 3 ohm arc lamp. What is the combined resistance? Use Formula No. 4.

First combine the 60 ohms and 40 ohms which equals 24. Next combine the 24 and 12 which equals 8. Then combine the 8 and 3 which equals 2 2/11ths of an ohm, the combined resistance of the circuit.

FORMULA NUMBER 5.

This formula can be used when solving problems which have a number of unequal resistances in parallel, if it is desired to calculate the combined resistance.

The formula is: THE COMBINED RESISTANCE OF A PARALLEL CIRCUIT IS EQUAL TO THE RECIPROCAL OF THE SUM OF THE RECIPROCALS OF THE SEPARATE RESISTANCES.

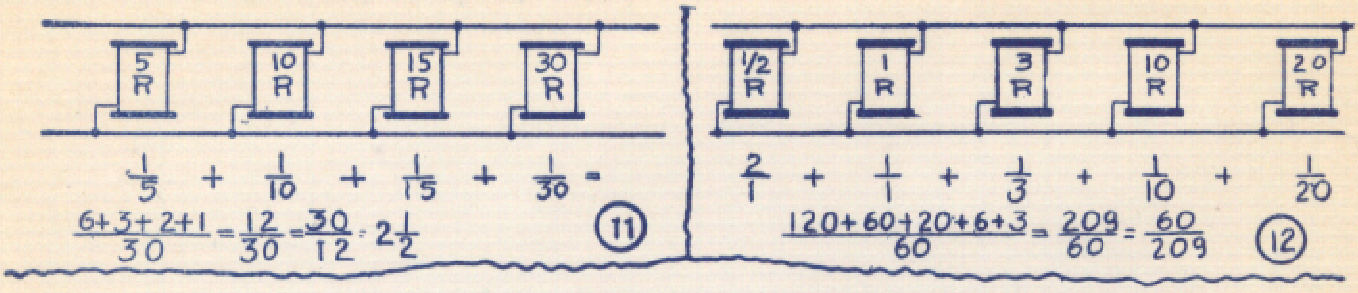
This may seem difficult when you first look at it and it is really much harder to repeat than it is to apply to a problem. It is composed of some long words and it is not possible to use shorter ones without going into considerable detail and possibly complicating matters.

In the first place "a reciprocal of a number is a number divided into the figure one." That is, the reciprocal of 4 is equal to 1 divided by 4, or ¼th; ½ is the reciprocal of 2; 1/6th is the reciprocal of 6 and so on. In electrical calculations we have resistance, which tends to retard the flow of the current; and conductivity, which is the ability with which the current is conveyed from one part of the circuit to another. Remember this, the <u>conductivity</u> of an electrical circuit is equal to the <u>reciprocal</u> of the <u>resistance</u> of the circuit. In other words, if the resistance of a circuit is known, the conductivity may be obtained by dividing the value of the resistance into 1. It naturally follows that the resistance of a circuit is equal to the reciprocal of the conductivity of a circuit.

In solving problems with the use of Formula No. 5, the formula should be worked backwards and in the following steps:

1st: Take the reciprocals of the separate resistances.
2nd: Find the lowest common denominator

3rd: Find the sum of the reciprocals.
4th: Take the reciprocal of the sum of the reciprocals.



In Figure 11 a diagram is shown which includes four coils connected in parallel. Their resistances are 5 ohms, 10 ohms, 15 ohms and 30 ohms. What is the combined resistance of the circuit?

First: Take the reciprocals of the separate resistances. The reciprocals of 5 ohms is 1/5th of an ohm; of 10 ohms, 1/10th of an ohm; of 15 ohms, 1/15th of an ohm and of 30, 1/30th of an ohm. These reciprocals are to be added, but first it is necessary to find a common denominator, which is 30; 1/5th equals 6/30ths; 1/10th equals 3/30ths; 1/15th equals 2/30ths; 1/30th equals 1/30th. Adding these we have 12/30ths which is the sum of the reciprocals and it is also the conductivity of the circuit. Now, the reciprocal of this sum is to be found by dividing it into 1, which is equal to 30/12ths, the resistance of the circuit. Reducing 30/12ths to a whole number we have 2 1-2 ohms as the combined resistance.

What is the combined resistance of the parallel circuit shown in Figure 12 in which five coils are connected across the line?

The resistances of the coils are, respectively, 1/2 ohm, 1 ohm, 3 ohms, 10 ohms and 20 ohms.

This problem is solved with the use of Formula No. 5. First, find the reciprocals of the separate resistances. Second, find the least common denominator. Third, find the sum of the reciprocals. Fourth, invert the sum of the reciprocals. The correct answer is 60/209ths of an ohm.

The calculation of the combined or joint resistance of a divided circuit having a number of branches of unequal resistance, as worked according to Formulas 4 and 5 in the examples No. 7 to No. 12, inclusive, has been performed with "purely mathematical methods," but in problems involving certain fractional quantities this work is tedious and liable to error unless watched closely.

All problems of this sort may be calculated easily by using Ohm's Law Formulas "C=E÷R" and "R=E÷C." This method has the further advantage of "giving the current flowing in each branch" and, as it is usually necessary to know the value of the current in each branch, this method saves considerable time in making such calculations.

FORMULA NUMBER 6.

To find the combined resistance of a divided circuit having branches of equal or of unequal resistance, according to Ohm's Law:

FIRST. FIND THE CURRENT IN EACH BRANCH BY DIVIDING THE VOLTAGE BY THE RESISTANCE OF EACH BRANCH, USING OHM'S FORMULA C=E÷R.

SECOND. DIVIDE THE VOLTAGE OF THE CIRCUIT BY THE SUM OF ALL OF THE CURRENTS IN THE BRANCHES, WHICH WILL GIVE THE COMBINED RESISTANCE, ACCORDING TO OHM'S FORMULA R=E÷C.

We will now work the problem illustrated in Figure 11, by using Formula 6, and as the voltage is not stated, we will "assume it to be 120 volts."

The 1st. coil is 5 Ohms. 120÷ 5=24 amperes.
The 2nd. coil is 10 Ohms. 120÷10=12 amperes.
The 3rd. coil is 15 Ohms. 120÷15= 8 amperes.
The 4th. coil is 30 Ohms. 120÷30= 4 amperes.

The sum of the branch currents is 24+12+8+4=48 amperes. 120÷48=2.5 Ohms, which is the combined or joint resistance of all of the branches.

You will notice that the first operation, using Ohm's Formula C=E÷R, gives us the current in each branch of the circuit, and the second operation, using Ohm's Formula R=E÷C, gives us the combined or joint resistance of all of the branches in the circuit.

Another Ohm's Law Formula, which is "E=R×C," may be used to solve practical problems that are pretty complicated when worked by a purely mathematical method. As an example of this sort:

Take four electro-magnets that are to be used to operate some form of automatic control, and must be operated in parallel to form the branches of a divided circuit. The resistance of the coils are 10, 20, 30, and 60 ohms, respectively. The current available for their operation is limited to 48 amperes.

It is necessary for us to know what voltage is required for maintaining 48 amperes in the group of 4 coils; we also desire to know the amount of current in each coil so that the proper size of wire may be selected for winding them. This proposition looks difficult but it may be solved very easily by Ohm's Law as follows:

We will first get the combined resistance of the coils, and as the voltage is unknown, we will assume it to be 120 volts, which will work out without any fractions to bother us.

120÷10=12 amperes; 120÷20=6 amperes; 120÷30=4 amperes; 120÷60=2 amperes. The sum of the amperes is 12+6+4+2=24 amperes. The combined resistance is R=E÷C, therefore 120÷24=5, which is the combined resistance of the four coils.

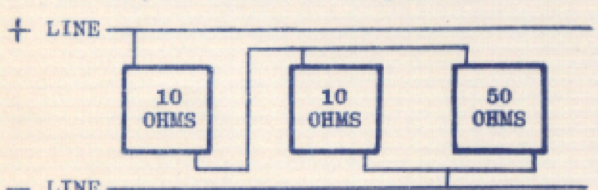
The next operation is to find the voltage necessary, which is "E=C×R," therefore 48 amperes multiplied by the combined resistance of 5 ohms = 240, which is the voltage required.

The current in the different coils is 240÷10=24 amps. 240÷20=12 amps. 240÷30=8 amps. 240÷60=4 amps., which represents the current in the respective coils.

The next detail to be worked out in this example is the proper size of wire to be used for winding each of the coils. In doing this we will allow 1,000 circular mils to 1 ampere, which is a very safe figure, but if the coils were to be located in a cool place, 600 to 700 circular mils per ampere would work nicely.

Now all that is necessary to complete our work is to multiply the amperes in each of the coils by 1,000, which will give the cross-section of the wire required, in circular mils.

The 10 ohm coil with 24 amperes flowing in it, multiplied by 1,000 gives 24,000 circular mils, usually abbreviated "CM." The 20 ohm coil with 12 amperes multiplied by 1,000 gives 12,000 CM. The 30 ohm coil with 8 amperes multiplied by 1,000 gives 8,000 CM. The 60 ohm coil with 4 amperes multiplied by 1,000 gives 4,000 CM. By referring to a wire table the sizes of wire equal in value to the above requirements in CM may be seen at a glance.



$\frac{100}{10}=10.$ $\frac{100}{50}=2.$ $10+2=12.$

$\frac{100}{12}=8.33$ ohms. $10+8.33=18.33$ total resistance

FIG. 13.

COMBINED SERIES AND PARALLEL CIRCUITS.

In Fig. 13 is shown one resistance connected in series with two resistances connected in parallel. The rule for finding the total resistance of this sort of circuits is:

FORMULA NUMBER 7.

TO FIND THE TOTAL RESISTANCE OF A CIRCUIT HAVING A RESISTANCE CONNECTED IN SERIES WITH TWO OR MORE RESISTANCES CONNECTED IN PARALLEL: FIND THE COMBINED RESISTANCE OF THE PARALLELED RESISTANCES AND ADD THIS VALUE TO THE RESISTANCE CONNECTED IN SERIES.

We will now show how easily a complicated circuit of this kind may be worked out by using Ohm's Law. As the voltage is not known, we will assume it to be 100 volts. The combined or joint resistance of the coils connected in parallel is 100÷10=10 amperes, and 100÷50=2 amperes. The sum of these two currents is 12 amperes. 100÷12=8.33 ohms, which is the combined resistance of the paralleled coils. 10 ohms + 8.33 ohms = 18.33 ohms, which is the total resistance of the circuit.

From the working of this example and other examples in this work sheet by means of Ohm's Law, it is plain that the resistance of any divided circuit, or combinations of series and divided circuits may be easily found by the simple application of the three Ohm's Law Formulas, "I=E÷R," "R=E÷I," and E=R×I."
Other work sheets on Electrical Calculations will be given later in the course.

EXAMINATION QUESTIONS -- MATHEMATICS WORK SHEET 3.

1. What is meant by the term "mil-foot"?
2. What governs the resistance of a metal conductor?
3. How does the resistance of a conductor vary with its diameter?
4. Give definitions of a series circuit and a multiple circuit.
5. What governs the division of current in the different paths of a parallel circuit?
6. Is there any division of current in the different parts of a series circuit?
7. What formula is used when calculating the combined resistance of only two unequal circuits if connected in multiple?
8. What would be the combined resistance of three coils connected in series, if the resistance of one is 4 ohms, another 9 ohms and a third 3 ohms?
9. What would be the combined resistance of two lamps, when connected in multiple if one had a resistance of 10 ohms, and the other 5 ohms?
10. What is the combined resistance of six coils connected in multiple if their separate resistances are, respectively, 1, 2, 3, 4, 5 and 6 ohms?

WORK SHEET METHOD

Trade Mark

Mathematics Work Sheet 4

L. L. COOKE
School of Electricity
CHICAGO

TRIGONOMETRY AND LOGARITHMS

In engineering work Trigonometry is used to a large extent in Civil Engineering, but not a great deal in Radio Engineering. In Electrical work it is used principally in the study of Alternating Currents.

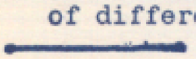
I am going to give you a short practical work sheet on Trigonometry but I am not going to take you into any of its complicated forms, for the reason it is not essential in the Study of Radio.

There are two branches of Trigonometry -- Plane and Spherical -- Plane Trigonometry deals with angles laid out on a flat surface and Spherical Trigonometry deals with angles laid out on a curved surface -- in this work sheet we will consider only Plane Trigonometry.

Trigonometry is that branch of Mathematics which is used in figuring angles and triangles. In this work we use what are called Functions of the Angles. This word Function in Mathematics is used to denote a quantity which depends on some other quantity. For instance, the area of a circle depends on the length of the radius of the circle -- therefore the area of a circle is a function of the radius.

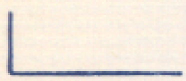
DEFINITIONS FOR VARIOUS ANGLES AND FIGURES.

In starting this work I first want to give the names and definitions of a number of different figures and terms used in trigonometry:



A Straight Line is the shortest distance between two points.

An Angle is formed where two lines meet at a point.

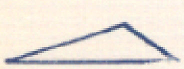


A Right Angle is formed where two lines meet at a point, and one line is perpendicular to the other. This is an Angle of 90 degrees.

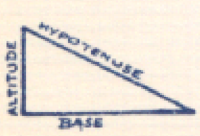
An Acute Angle is an Angle less than 90 degrees.

An Obtuse Angle is an Angle greater than 90 degrees.

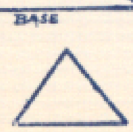
Angles are measured in degrees (°), minutes (') and seconds (") and are written thus, 34° 26' 4". One degree=60 minutes and one minute=60 seconds.



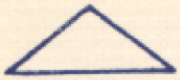
A Triangle is a figure consisting of three sides and three Angles. The three angles of any triangle added together make 180°.



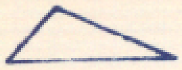
A Right Angle Triangle is a triangle having one right angle (90°). The sides of a right angle triangle are called the Base, Altitude, and Hypothenuse.



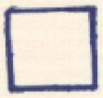
An Equilateral Triangle is one having three sides and three angles equal.



An Isosceles Triangle is one having two sides and two angles equal.



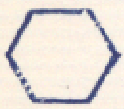
An Oblique Triangle is one having all sides, and angles unequal--no angle is a right angle.



A Square is a figure all sides of which are equal and all angles 90°.

A Rectangle is a figure whose opposite sides are equal, and all angles 90°.

A Rhomboid is a figure whose opposite sides and opposite angles are equal.



A Hexagon is a figure having six equal sides and six equal angles.

RULES FOR FIGURING AREAS.

I will now give you a few rules for figuring the areas or surfaces of these different figures:

Area of any triangle $=$ base $\times \frac{1}{2}$ altitude.
Area of a square $=$ side $\times$ side.
Area of rectangle $=$ base $\times$ altitude.
Area of rhomboid $=$ base $\times$ altitude.

THE CIRCLE.

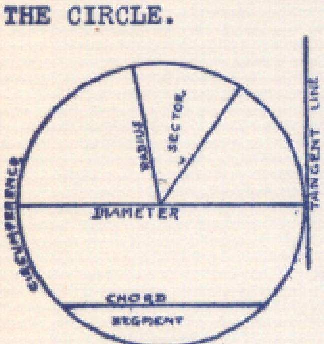


FIG. 5

I will now give you some of the terms and definitions used in regard to a circle. See Fig. 5.

A Circle is a figure bounded by a curved line which at all points is the same distance from the center.

The Circumference is the curved line around the Circle. Every circumference is divided into 360° which is equal to four right angles.

The Diameter is a straight line passing through the center and touching the circumference in two points.
A Radius is a straight line from the center to the circumference (A radius is ½ the length of the diameter).
A Chord is a straight line touching the circumference at two points.
An Arc is any part of the circumference.
A Segment is the part of a circle bounded by a cord and an arc.
A Sector is any part of a circle bounded by two radii and an arc.
A Tangent is a line touching a circle but not passing through it. A Tangent is always 90°, or at right angles, to the radius at the point it touches the circle.
A Semi-Circle is a half of the circle.

MEASURING CIRCLES.

The ratio of the circumference of any circle to its diameter is constant. (For instance, if we double the diameter we double the circumference.) This constant ratio of a circle to its diameter is represented by the Greek leter π, (Pi), which is equal to 3.1416.
The Circumference of a circle $= \pi \times D$ or $3.1416 \times$ Diameter.
The Area of a circle $= \pi \times R^2$ or $3.1416 \times$ Radius square.

MEASURING TRIANGLES.

Every triangle has three sides and three angles. And it is a rule of trigonometry that if we know one angle and two sides or two angles and one side we can find the other angles and sides.

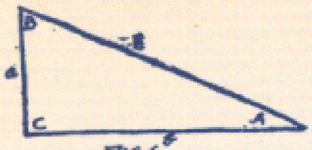


FIG.6

In working with triangles we usually mark the angles with capital letters A B C and the sides opposite with small letters a c b. See Fig. 6.

In a right angle triangle as Fig. 6 the square of the hypotenuse (c) is equal to the sum of the squares of the other two sides (b and a).

This can be written by an Algebra equation thus, $c^2=b^2+a^2$ then $b^2=c^2-a^2$ and $a^2=c^2-b^2$. So if you have two sides of any right angle triangle you can find the third side. It is important to remember that the sum of the three angles in any triangle is 180°. Therefore if you know what two of the angles are, you can find the third angle by subtracting the sum of the two from 180°.

FUNCTIONS OF ANGLES.

The sides and angles of triangles have a certain ratio to each other. Trigonometry is used to show these ratios to each other, and these ratios are called trigonometric functions.

The six trigonometric functions of any Acute Angle are denoted as follows, also their abbreviations:

Sine (Sin) Cosine (Cos) Tangent (Tan)

Cotangent (Cot) Secant (Sec) Cosecant (Csc)

These functions and their applications are the part of trigonometry we use most in alternating current work.

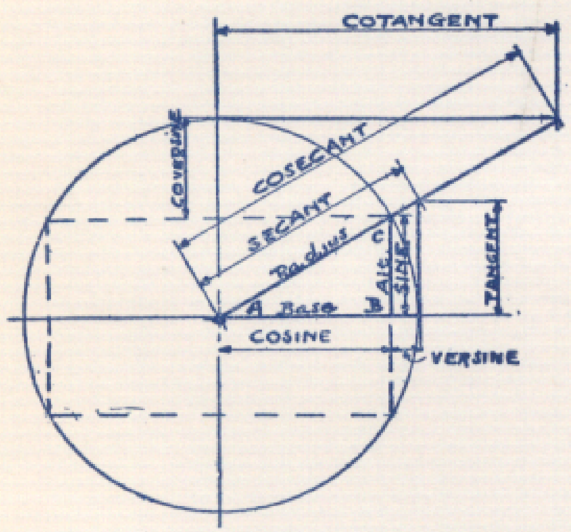


FIG.-1

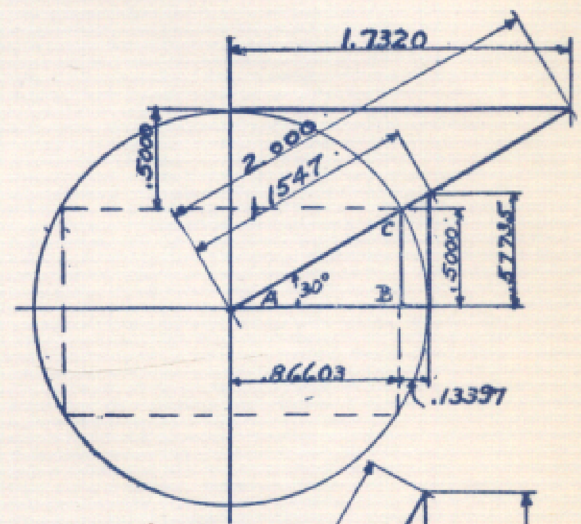


FIG-2

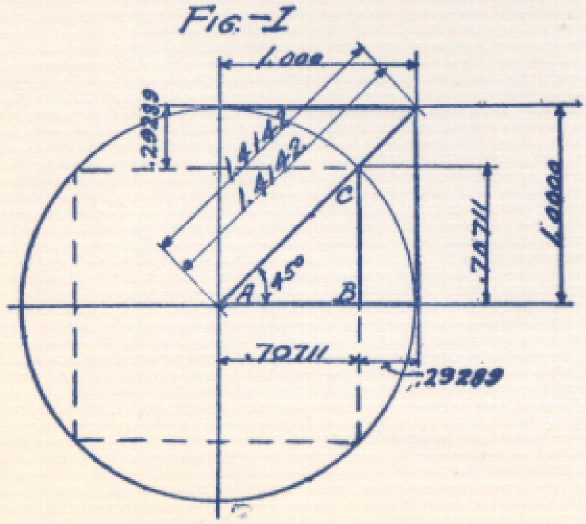


FIG 3

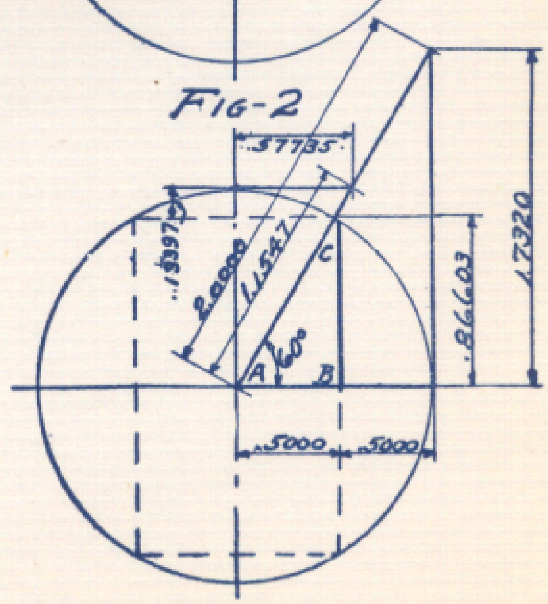


FIG-4

FORMULAE FOR USING THESE FUNCTIONS IN A RIGHT ANGLE TRIANGLE.

Sine $A=\frac{a}{c}$	Secant $A=\frac{c}{b}$	Tangent $A=\frac{a}{b}$
Cosine $A=\frac{b}{c}$	Cosecant $A=\frac{c}{a}$	Cotangent $A=\frac{b}{a}$
Sine $B=\frac{b}{c}$	Secant $B=\frac{c}{a}$	Tangent $B=\frac{b}{a}$
Cosine $B=\frac{a}{c}$	Cosecant $B=\frac{c}{b}$	Cotangent $B=\frac{a}{b}$

The object of these formulae is that when you know the length of any two sides of a right angle triangle you can find the other side and the other angles.

EXAMPLE—For instance you know that in a right angle triangle C is 90°; now you want to find the other angles. We will assume that side c is 2 feet long and side b is 1.73 ft. by the formulae Sine $B=\frac{b}{c}$ then Sine $B=\frac{1.73}{2}$, $\frac{1.73}{2}$=.865= Then looking up in a book of trigonometric tables we find that the angle with a sine .865 is 6°. Therefore B=60°, B plus C=90° plus 60° or 150°, then 180 - 150=30° which is Angle A.

DIAGRAMS SHOWING RELATIONS OF A RIGHT ANGLE TRIANGLE TO ITS FUNCTIONS.

In order to make more clear to you just what these various functions of a triangle mean I have drawn a number of figures showing first just what these functions represent and then how they change as the size of the angles changes.

FIG. 1—Shows the relation of the sides of a right angle triangle to the function of angle A.

FIG. 2, 3, 4 show that when the Angle becomes larger the Sine, Tangent and Secant become larger and the Cosine, Cotangent and Cosecant become smaller and vice versa.

NOTE—In this work sheet on Trigonometry I have not gone into the subject very deeply. I simply wanted to give you the information that you will use in your electrical work. Most Electrical Courses contain a lot of instructions on work that is not at all necessary, but I have written this Course from a practical standpoint, and am giving you only the instructions necessary to make you an Expert Electrical Man.

LOGARITHMS.

Logarithms are used to simplify the solution of difficult problems in mathematics. It is not necessary that you understand them, but if you have a great many difficult problems to work out, they will help you.

The common logarithm of a number is the power to which 10 must be raised to equal that number. For example the second power of 10 = 10 x 10 or 100 and the logarithm of log as it is abbreviated of 100 is 2. The third power of 10 is 10 x 10 x 10 = 1000 and the log of 1000 is 3. The fourth power of 10 is 10 x 10 x 10 x 10 =10,000 and the log of 10,0000 is 4.

Logarithms, consist of two parts, the part to the left of the decimal point which is called the characteristic and the part to the right of the decimal point which is called the mantissa.

The characteristic of the logarithm of any number may be found by inspecting the number itself. If the number is greater than one, the characterictic of its logarithm is always one less than the number of figures to the left of the decimal point in the number. For example the logarithm of 4.7 has a characteristic of 0. The logarithm of 52.4 has a characteristic of 1 and the logarithm of 692.3 has a characteristic of 2. The mantissa of the logarithm of any number must be found by referring to a table of logarithms. The accompanying tables give the mantissas of all numbers from 1 to 999.

LOGARITHMS OF NUMBERS

N	0	1	2	3	4	5	6	7	8	9	N	0	1	2	3	4	5	6	7	8	9
10	**0000**	**0043**	**0086**	**0128**	**0170**	**0212**	**0253**	**0294**	**0334**	**0374**	**55**	**7404**	**7412**	**7419**	**7427**	**7435**	**7443**	**7451**	**7459**	**7466**	**7474**
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
15	**1761**	**1790**	**1818**	**1847**	**1875**	**1903**	**1931**	**1959**	**1987**	**2014**	**60**	**7782**	**7789**	**7796**	**7803**	**7810**	**7818**	**7825**	**7832**	**7839**	**7846**
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
20	**3010**	**3032**	**3054**	**3075**	**3096**	**3118**	**3139**	**3160**	**3181**	**3201**	**65**	**8129**	**8136**	**8142**	**8149**	**8156**	**8162**	**8169**	**8176**	**8182**	**8189**
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
22	3424	3444	3464	4383	3502	3522	3541	3560	3579	3598	67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
24	3802	3820	3838	3856	3874	3892	3909	3927	3845	3962	69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
25	**3979**	**3997**	**4014**	**4031**	**4048**	**4065**	**4082**	**4099**	**4116**	**4133**	**70**	**8451**	**8457**	**8463**	**8470**	**8476**	**8482**	**8488**	**8494**	**8500**	**8506**
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
30	**4771**	**4786**	**4800**	**4814**	**4829**	**4843**	**4857**	**4871**	**4886**	**4900**	**75**	**8751**	**8756**	**8762**	**8768**	**8774**	**8779**	**8785**	**8791**	**8797**	**8802**
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
32	5052	5065	5079	5092	5105	5119	5132	5145	5159	5172	77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
35	**5441**	**5453**	**5465**	**5478**	**5490**	**5502**	**5514**	**5527**	**5539**	**5551**	**80**	**9031**	**9036**	**9042**	**9047**	**9053**	**9058**	**9063**	**9069**	**9074**	**9079**
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	84	9243	9248	9253	9258	9263	9269	9174	9279	9284	9289
40	**6021**	**6031**	**6042**	**6053**	**6064**	**6075**	**6085**	**6096**	**6107**	**6117**	**85**	**9294**	**9299**	**9304**	**9309**	**9315**	**9320**	**9325**	**9330**	**9335**	**9340**
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
45	**6532**	**6542**	**6551**	**6561**	**6571**	**6580**	**6590**	**6599**	**6609**	**6618**	**90**	**9542**	**9547**	**9552**	**9557**	**9562**	**9566**	**9571**	**9576**	**9581**	**9586**
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
50	**6990**	**6998**	**7007**	**7016**	**7024**	**7033**	**7042**	**7050**	**7059**	**7067**	**95**	**9777**	**9782**	**9786**	**9791**	**9795**	**9800**	**8905**	**9809**	**9814**	**9818**
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	98	9912	9917	9921	9926	9930	9934	9939	9943	9041	9052
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

TO FIND THE MANTISSA OF ANY NUMBER.

If the number consists of one or two figures, locate the number in the N column of the table, then read the mantissa opposite the number under the column headed 0. The characteristic of log 2 (logarithm of two) is 0 while the characteristic of log 20 is 1. Therefore, log 2=0.3010 and log 20=1.3010. The mantissa of a decimal number is the same as the mantissa of a whole number having the same figures. For example log 4.7 =0.6721, log 47=1.6721 and log 470=2.6721. Note that the only difference between the logarithms, of these three numbers is in the characteristics.

To find the log of a number having 3 figures, locate the first two figures in the N column and the third figure at the top of one of the other columns. Then read the mantissa in the column under the third figure and to the right of the first two figures. If we wish to find the mantissa of 234 we first locate 23 in the N column, then locate 4 at the top of the table. Follow down the column under 4 until we are opposite 23 in the N column where we find the mantissa of 234 to be .3692. The characteristic is 2 so the complete logarithm is 2.3692.

You have now learned how the logarithms of numbers may be found so I will tell you how they are used.

MULTIPLICATION USING LOGARITHMS.

We may use logarithms when multiplying two numbers together by finding the logarithms of the two numbers and adding them. The result will be the logarithm of the product of the two numbers and by referring to the table we can find the number.

If we wish to multiply 32 by 14 we find the logarithm of 32 which is 1.5052 and the logarithm of 14 which is 1.1461. 1.5052 + 1.1461 = 2.6513 which is the logarithm of the number we wish to find. The mantissa is .6513 se we find 6513 in the table. It is found under column 8 and opposite 44 in the N column so our number is 448.

DIVISION USING LOGARITHMS.

If we wish to divide one number by another, we substract the log of the divisor from the log of the dividend. The result is the log of the quotient and we may find the quotient from the table.

SQUARE ROOT.

To find the square root of a number, find its logarithm and divide the logarithm by two. The result is the logarithm of the square root. To find the square root of 784 find its logarithm which is 2.894 and divided by 2, the result is 1.447 which is the log of the square root. Looking up .447 in the table, we find it to be the mantissa of 28, which is the square root of 784.

CUBE ROOT.

Cube root may be found by dividing the log of a number by 3 and locating the number corresponding to the resulting log. We may also find the square, the cube or in fact any power of a number by logarithms.

To raise a number to any power, find the log of the number, then multiply the log by the power to which the number is to be raised. The result is the log of the power to which the number is to be raised and the power itself may be found by the table. For example, to find the square or second power of a number, find its logarithm and multiply the logarithm by two. The result is the logarithm of the square and the square may be found in the table. To find the 4th power of a number, find its logarith and multiply the logarithm by 4, then look up the corresponding number in the table.

I have shown you only simple examples of the use of logarithms in order to simplify the explanations and make them easy to understand. However, logarithms are generally used only for calculations involving large numbers. Calculations by logarithms are not absolutely accurate for large numbers but the results obtained are accurate enough in most practical problems.