EVERYMAN'S GUIDE TO
RADIO

FIRST PRINCIPLES
THE ELECTRICITY OF RADIO
DIAGRAMS - THE SHORTHAND OF RADIO
THE MECHANICS OF RADIO
THE VACUUM TUBE

EVERYMAN'S GUIDE TO RADIO

A PRACTICAL COURSE OF
COMMON-SENSE INSTRUCTION IN
THE WORLD'S MOST FASCINATING SCIENCE

VOLUME I

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POPULAR RADIO, INCORPORATED
NEW YORK, 1926

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PRESS OF WILLIAM GREEN, NEW YORK

Preface

WHILE radio literature has been added to in great volume during the last few years, the public has hitherto lacked a treatise to which it could turn with confidence and with the assurance that it would find the particular information desired.

Many excellent volumes have been prepared by eminent authorities, but these works either show evidences of hasty preparation or they are so steeped in the technicalities of the art as to be partially or wholly unintelligible to those seeking understandable reading matter. Then, too, it is utterly impossible completely to cover the subject within the confines of one modestly sized volume, so rapidly has radio grown.

Every Man's Guide to Radio in four volumes, is the first attempt to publish a complete and popular exposition of radio in all of its phases. It is designed to serve as a reference library for radio fans and novices at all stages of learning.

Everyman's Guide to Radio is especially dedicated to the young student who is looking forward to sharing in the rich rewards that radio is offering to its followers. There is no field that holds out greater opportunity for young blood. Proficiency in radio may lead to adventure on the seven seas, above the clouds, behind the closed doors of the great laboratories of the country or in the luxuriously appointed broadcasting studios. An honest and conscientious reading of *Every Man's Guide to Radio* will reward the young student in rich experiences and ample compensation.

Due to the simple, non-technical style that has been carefully followed in this work, the casual owner of a radio receiver will not only find much that will be of practical value to him, but he will also find an easily readable outline of one of the greatest scientific romances in the history of man, and he will emerge from the course with a keen understanding of the modern wonders of radio, such, for instance, as radio-dynamics, television, wired wireless and talking motion pictures. Upon completion he will also find himself familiar with certain fundamental facts and practices of the radio art that will make him a more intelligent user of radio apparatus. Instead of being an idle twister of knobs he will become aware of the delicate processes that take place behind receiver panels and he will know what vaccum tube to use, what kind of a loudspeaker is best for this or that kind of a receiver and what "B" battery voltage to employ with a 201-a tube.

In assembling the material for *Everyman's Guide to Radio*, the Editors, in practically every case, have obtained the contributions of specialists each of whom has written concerning his own field of activity. This plan has made the work unique in that no single writer in it has tried to encompass the field as a whole, as in the less conspicuous radio books on the market. Consequently when the subject of vacuum tubes was approached, the editors naturally turned to men like Irving Langmuir, Ambrose Fleming (the inventor of the two-element tube) and William Ballard, Jr. When it came to a discussion of condensers, Sir Oliver Lodge, one of the world's greatest authorities in electrostatic phenomena, was asked to contribute to this department. In every case eminent authorities have been employed and in every case they have couched what they have to say in simple language intelligible to the lay mind.

Nevertheless, the raw recruit may find a slight difficulty in grasping the subject-matter of *Everyman's Guide to Radio* at first reading. But he should not be discouraged, either with himself or the course, for it is rare that a lay mind unaccustomed even to the simplest electrical laws can drink in radio facts as fast as they are presented, no matter how simple the language or how ingenious the explanations may be. Of course the average reader, the reader who still remembers his high school physics, and the reader who has thumbed the pages of some of the current radio magazines and books, will be able to absorb the material here presented practically as fast as he can read. The lay reader, however, may find it necessary to re-read certain portions. The editors hope he will make that slight effort, for they are confident that with very little study the whole meaning will suddenly dawn upon him and the pleasure and benefit he will derive will repay him an hundredfold.

There is, in *Everyman's Guide to Radio*, a vast storehouse of radio knowledge for those who would make use of it. By constant editing and constant rearrangement its material has been kept strictly up to date.

THE EDITORS

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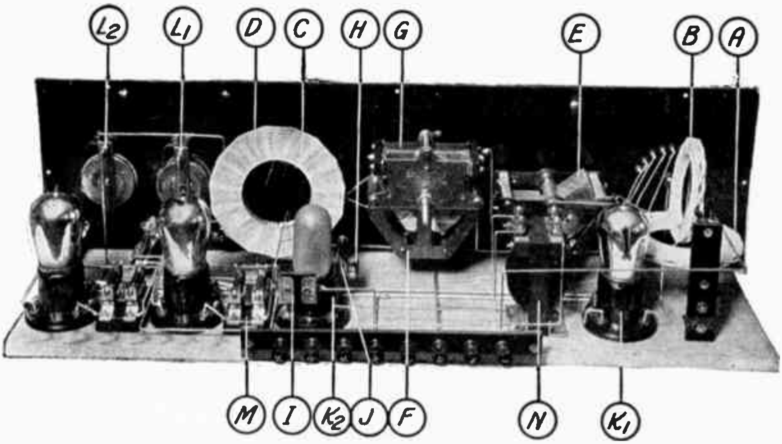


The Sections of the Everyman's Guide to Radio dealing with the various instruments keyed in this illustration may be quickly found by reference to the index below.

ILLUSTRATED INDEX

SECTION I

First Principles of Radio

SINCE radio phenomena are closely associated with the most fundamental precepts of modern physics, it is impossible to gain a penetrating or even intelligent understanding of them without first going to the very bottom of the whole matter. The necessity of this proceeding, however, should not chill the ardor of the practical enthusiast for we will find in such a study a particularly romantic series of facts.

When the subject of radio is approached on this basis it eventually blossoms out into a thing far more fascinating as a study than it possibly could be by a mere consideration of its more practical features. As a matter of fact, nothing but the most superficial understanding can be gained without considering the basic physics upon which the whole art of radio rests. These same physics, incidentally, account for every phenomenon in the world today from the beating of a human heart to the falling of a raindrop.

The Universe, as we know it, has been found to contain only two basic things; *electricity* and *waves*. The most exhausting investigations of science have failed to reveal any other substance. Matter is not the hard substance that our crude senses seem to prove; it is simply made up of tiny particles of a thing that we have arbitrarily called electricity. Our senses do not give us a true conception of the matter about us and it has only been through a long series of scientific investigations carried out by the aid of marvelous instruments that we have learned to look at the world through different eyes.

The chemists of old, unarmed with the delicate devices of modern science, had it that matter was made up of "hard and eternal little particles" called *atoms* and it was not until 1897 that it was found that these hypothetical atoms were themselves made up of still smaller particles called *electrons* and that these electrons were nothing more or less than pure little particles of electricity so small that they were hopelessly beyond the magnifying power of the best microscopes. It was found that these electrons were merely charges of negative electricity and that they possessed the general properties of negatively charged bodies.

If the reader remembers his high school physics at all, he will recall that bodies carrying like charges of electricity repel each other and bodies carrying dislike charges of electricity (positive and negative) attract each other. How, then, can we maintain an atom of matter made up solely of negative particles when it is known that these particles have a natural tendency to part company? It is evident that we must have a positive influence working upon them to keep them within certain bounds.

Perhaps the best way to gain a reasonably intelligent picture of atomic structure is to consider briefly the general architecture of the most simple atom that we have in matter; the atom of hydrogen. Painstaking investigations extending over the last 25 years have shown that the hydrogen atom has but one electron and that this electron is moving at a prodigious speed and in a regular orbit around a positive core or nucleus called the *proton*. We cannot conceive of the negative electron maintaining a definite position in space without having something to hold it there. It is the counter-balancing positive charge of the proton that does this.

All the atoms of matter (there are some ninety different types) are made up from one (in the case of hydrogen) to ninety-six electrons revolving about positive protons in varied and complex systems.

The distance separating electrons from their mothering positive influence or proton is great as compared with the measurement of the particles themselves and what appears to us as very solid matter is in reality but a mere ghostlike structure. In the case of the element copper, the percentage of empty space is 99,999,999,999,8%.

Our solar system, which we ordinarily consider as being made up largely of empty space, has a density six hundred times greater than the paper upon which these words are printed. This is practically equivalent to saying that there is six hundred times more matter in the solar system than in the paper. We strike a tabletop with our hand and we find something there that is apparently solid and unyielding but it is solid and unyielding only because our hand is tremendously large and our senses appallingly crude.

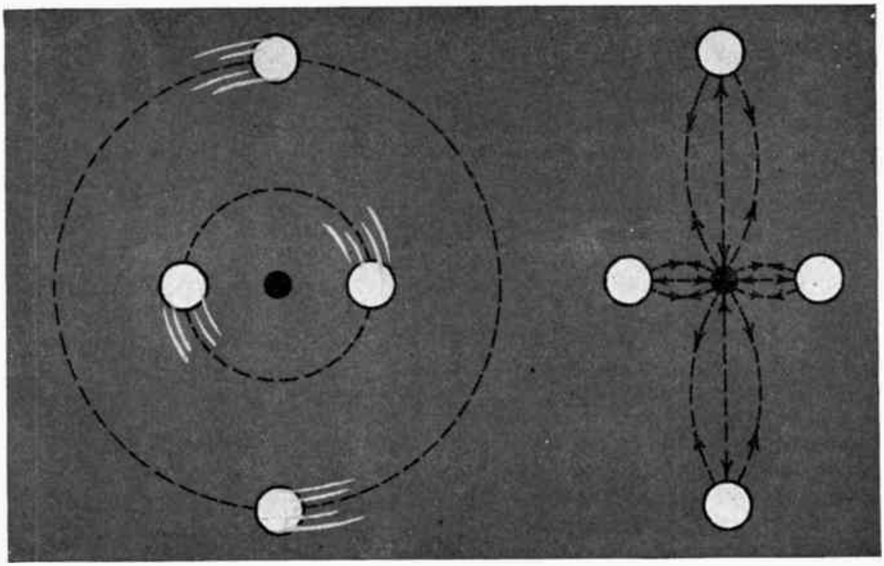
If we could reduce our body to the dimension of an electron we could crawl into that table and wander around for months and months perhaps before we should come to anything that appeared solid or substantial.

If we did happen to see an electron it would be moving with a speed of about 40,000 miles a second and if it should happen to strike us it would have a "wallop" thousands of times greater than anything that could be experienced in the world in which we humans live.

Let us imagine that we have in our hand a piece of copper wire 1/20 of an inch in diameter and 1 inch long. Let us assume also that this wire is magnified until it reaches from New York to San Francisco and that its diameter is proportionately increased. The wire will then be 2550 miles long and 125 miles thick. Under these conditions we would find that the electrons would still be (after having been magnified in the same proportion) 23/1,000,000 of an inch in diameter and that the nucleus would be 1/100,000 of an inch in diameter. The atoms would be separated by many miles of space.

This proton about which we have been talking, although very very small, is very dense, and, considering its size, of tremendous weight. If a large number of them could be crowded into a piece of matter about the size of an apple and packed real close together, that piece of matter would have a weight of many millions of tons and nothing on the earth, not even the earth itself, would be able to support it. It would straightway penetrate the rocks and the soil and travel with a great speed until it reached the center of gravity.

We see that, after all, we are living in sort of a dream world. The things in it are not as supposed for our senses reveal but a small portion of the real truth. The most peculiar part of it is that the theory that we have just been considering (*the electron theory of matter*) has been made to account for everything that happens in the world and radio is no exception. As a matter of fact radio is accounted for very easily by this theory.



THE TWO PREVAILING THEORIES OF THE STRUCTURE OF ATOMS—
SHOWING HOW THE ELECTRONS ARE HELD BY ELECTROSTATIC FORCES.

Illustrated by one of the simplest atoms, that of the element Beryllium. The figure on the left shows the theory of Sir Joseph J. Thomson, as embodied in this Part. The four electrons, represented by white spheres, are held by a balance of attractive and repulsive forces at definite distances from the central nucleus of the atom, represented by the black dot. The other figure (at the right) shows the alternative planetary theory, according to which the electrons are supposed to be revolving around the nucleus much as the earth and the other planets revolve around the sun.

Before we go into the subject of the *ether* and *electromagnetic waves* which account for the phenomenon of radio, let us permit such an eminent authority as Sir Joseph Thompson, F.R.S., to tell us more about the atom and how it is put together.

"I believe that the introduction of the idea of the electron will break down, and indeed has already done so to some extent, the barrier of ignorance which has divided the study of the properties of matter into two distinct sciences, physics and chemistry.

"The properties of matter which are of primary importance to the chemist are those which relate to the power of atoms to unite together to form new combinations, new compounds. Until recently the conception of the atom, formed by the physicist, afforded no clue to the variation in the chemical properties of the atom and gave therefore but little guidance to the chemist in what he rightly regarded as the most important part of his work.

"The chemist wants to know much more about the difference between an atom of hydrogen, and one of oxygen than that 'the atom of hydrogen is a small particle of one kind of matter' and that 'the atom of oxygen is a heavier particle of another kind of matter.'

"The chemist wants to know the

reason why the behavior of an atom of hydrogen is so different from that of an atom of oxygen. This must depend upon the difference in the constitution of the two atoms themselves. Thus to explain the difference between the chemical properties of different atoms we have to go a step further than that considered by the atomic theory. Just as some of the physical properties of matter in bulk had required for their explanation the conception that matter is not continuous but has a structure of finite and measurable fineness, so no progress could be made towards the explanation of their chemical properties until we gave up the idea that the atom was indivisible, continuous and uniform, and assigned to atoms, as well as to solids and liquids, a structure of their own.

"The discovery of the electron in 1897 was the first direct evidence of such a structure. It was shown that these electrons came from all types of atoms, and that whatever the source there was only one kind of electron, which has a mass of only about 1/1700th that of an atom of hydrogen and carries a charge of negative electricity numerically equal to the positive charge associated with an atom of hydrogen in the electrolysis of solutions.

"Thus an invariable electron was proved to be a constituent of all atoms. Means were then devised to measure the number of electrons in the atoms of the different chemical elements. It was found that this number was finite and varied from element to element, and that the number of electrons in the atom of an element was equal to the atomic number of the element—the atomic number of an element being its place in the list when the elements are correctly arranged in the order of their atomic weights.

"Thus, in addition to the structure conferred by the electrons, the positively electrified parts of the atom have themselves a structure. It is the structure conferred by the electrons which is responsible for the chemical properties of the atom, and the structure of the positive core or nucleus is concerned with radioactive transformations.

"Up to the present time nothing has been discovered that cannot be resolved into electrons and positively electrified particles, and so it is natural to frame a theory of the structure of the atom on the supposition that it is built up of these two ingredients. It should be borne in mind, however, that our means for detecting the existence of electrically charged bodies far surpass those for detecting uncharged bodies, and if there were any uncharged constituents of the atoms, they would in any case probably have escaped detection. We know, however, even supposing that such constituents do exist, that their mass must be negligible compared with that of the positively charged parts, for these parts account for well within a fraction of a percent of the whole mass of the atom.

"Confining themselves, then, to the consideration of things the existence of which has been demonstrated, we regard the atom as made up of a massive positively electrified center surrounded by electrons; the number of electrons varying from one, in the atom of hydrogen, to a hundred or more in the heavier elements. The positive charge of the center and the negative charges on the electrons produce a field of electrical force which is determinable when the position of the electrons are specified.

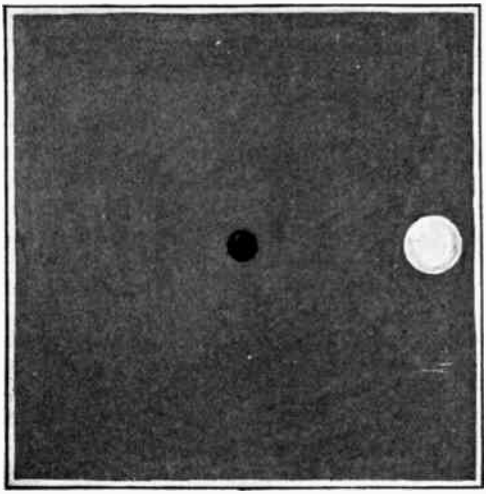
"Thus the force exerted by the atom, and therefore its chemical properties, depend upon the configuration of the electrons and to determine this is one of the most important problems in the electron theory of chemistry.

"This problem is that of determining the way the electrons arrange themselves under the action of their mutual repulsions and under the effect of forces exerted by the positive charge.

"I have adopted the plan of supposing that the law of force between the positive part and the electrons is, at the distances with which we have to deal in the atom, not strictly that of variation with the inverse square of the distance, but a more complex one which changes from attraction to repulsion as the distance between the positive charge and the electron diminishes. This hypothesis leads to a simple mental picture of the structure of the atom and its consequences.

"In this connection it may be observed that the introduction of some new physical law is necessary for any theory of the structure of atoms. We could not form a theory at all if all we knew about the action of electric charges was that they repelled or attracted inversely as the square of the distance, for this would put at our disposal only two quantities—the mass of an electron and its charge, and so we could not furnish the three units of *space*, *mass* and *time* required for any physical theory.

"The discovery of the induction of currents or (what is equivalent) the magnetic effect due to electric charges, introduced another fundamental unit, the *velocity of light;* the unit of length to which this system leads is the radius of the electron, about 10^{-13} cm., a quantity



THE ATOM OF LITHIUM

3 Model of the atom of lithium according to the Thomson theory. The two electrons closest to the nucleus, as shown on page 9, are omitted in this and following models for the sake of clearness. This lithium atom contains only the one electron shown in the shell outside these two inner electrons.

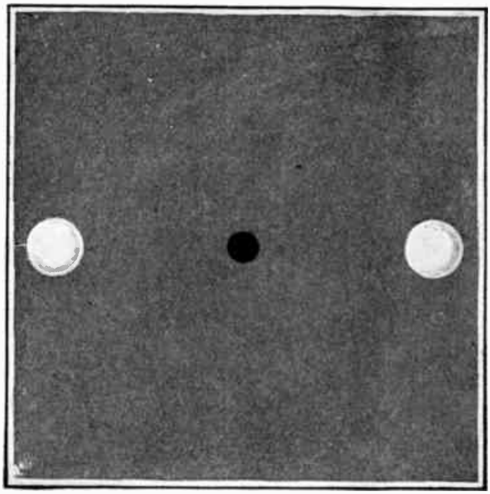
of quite different order from 10^{-8} cm., which corresponds to atomic dimensions. The size of atoms being what it is furnishes proof that there is some law of physics that is not recognized in the older science.

"If the law of force is that just given, then a number of electrons can be in stable equilibrium around a positive charge without necessarily describing orbits around it.

"Thus, for example, if there is one electron in the second shell of the atom (ignoring the two inner electrons that are shown on page 9), this electron will be in stable equilibrium at a certain distance from the positive charge. If there are two electrons they will be in equilibrium with the positive charge midway between them. When there are three electrons, they will be in equilibrium at the corner of an equilateral triangle with the positive charge at the center. The most symmetrical arrangement of four electrons is when they are at the corners of a regular tetrahedron. Six electrons are in equilibrium when at the corners of a regular octahedron. Eight electrons arrange themselves at the corners of a twisted cube, a figure obtained by making two squares, placing them parallel to each other and at right angles to the line joining their centers, and twisting them relatively to each other so that the projection of their corners on a parallel plane forms a regular octagon.

"There must come, however, a stage when it will no longer be possible to have all the electrons at the corners of a regular polyhedron.

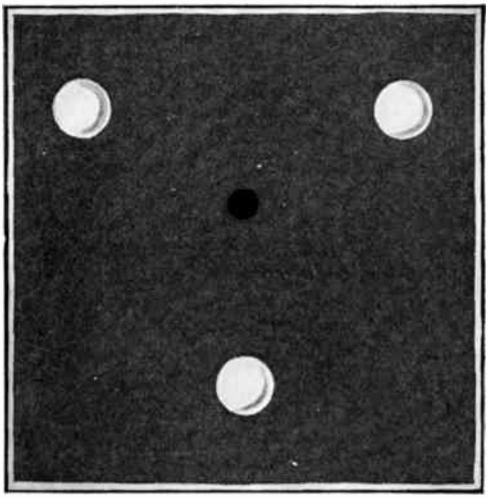
"To keep the electrons in stable



THE ATOM OF BERYLLIUM

4 Model of the atom of beryllium, the same atom shown on page 9. The two inner electrons that are there shown are omitted in this model just as they are omitted in the adjoining model of atom Number 3. The two external electrons are balanced one on each side of the nucleus.

equilibrium in spite of their mutual repulsion requires a finite positive charge and the greater the number of electrons (and, therefore, the smaller the angular distance between an electron and its nearest neighbor) the greater the positive charge must be. When the number of electrons is not greater than eight, the eight this is no longer possible. To keep, say, nine electrons in stable equilibrium would require a positive charge of more than $9e$, where e is the charge of an electron, but in a neutral molecule $9e$ is the maximum positive charge available when there are nine electrons in the atom. Thus the regular



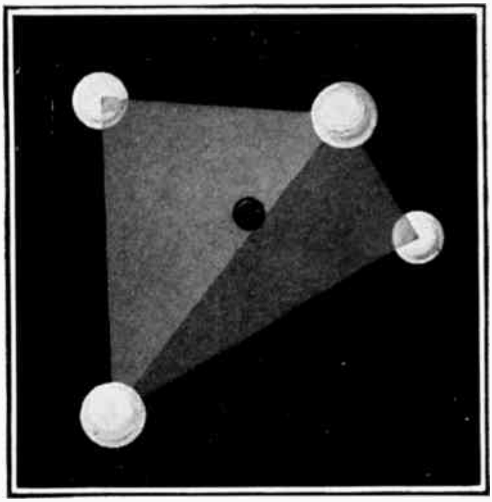
THE ATOM OF BORON

5 Like atoms number 3 and 4 the electrons of this atom (the atom of boron) are arranged in the same plane about the atomic nucleus at equal distances from it and from each other.

electrons can be kept in equilibrium by a positive charge equal to the sum of the negative charges on the electrons, which is the greatest positive charge that can occur in a neutral atom. So that when the number of electrons is not greater than eight, a neutral atom can have these electrons arranged symmetrically at the same distance from the center at the corners of a regular polyhedron.

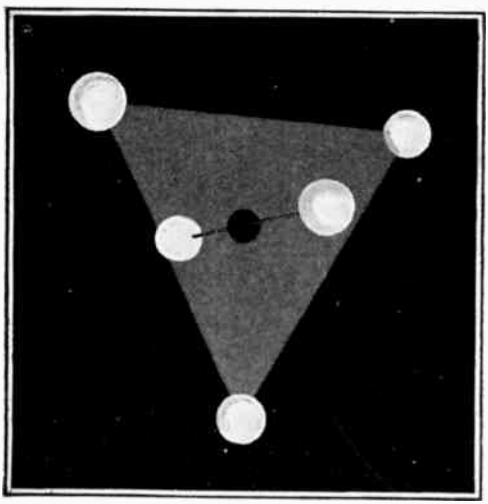
"When, however, the number exceeds progression in the arrangement breaks down when the electrons amount to eight and a new arrangement must come into force.

"Let us suppose that there are nine electrons; then these nine cannot all be arranged at the same distance from the center, for this arrangement would be unstable since a positive charge of nine is insufficient to keep nine electrons in stable equilibrium. The charge $9e$ could, however, keep eight electrons in



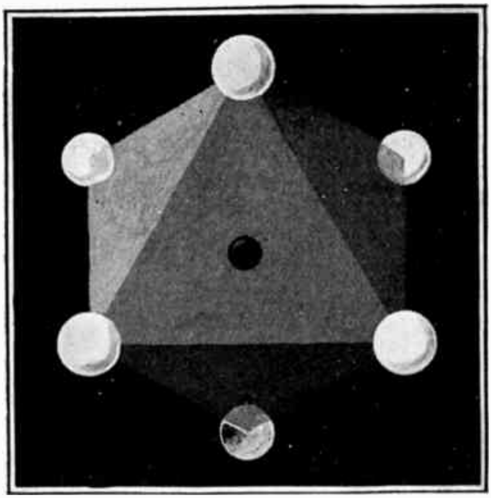
THE ATOM OF CARBON

6 This is the atom of the very common element carbon, the element of coal and of diamonds. Its four external electrons are arranged about the nucleus at the corners of an imaginary tetrahedron. As before, the two internal electrons are not shown.



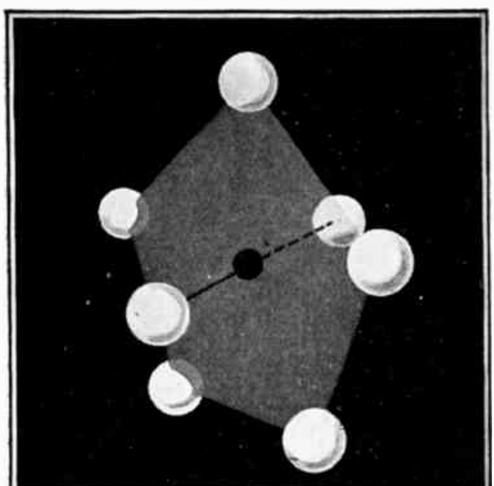
THE ATOM OF NITROGEN

7 The atom of nitrogen—the gas that composes four-fifths of the air. In this there are five external electrons, three of them arranged at the corners of an imaginary triangle, the other two at the ends of a perpendicular line through the center of this triangle.



THE ATOM OF OXYGEN

8 One of the most important of all atoms, the atom of oxygen. This element is the commonest element in the earth's crust and is the element we breathe in air. Its six external electrons are arranged at the corners of an imaginary eight-sided solid or octahedron.



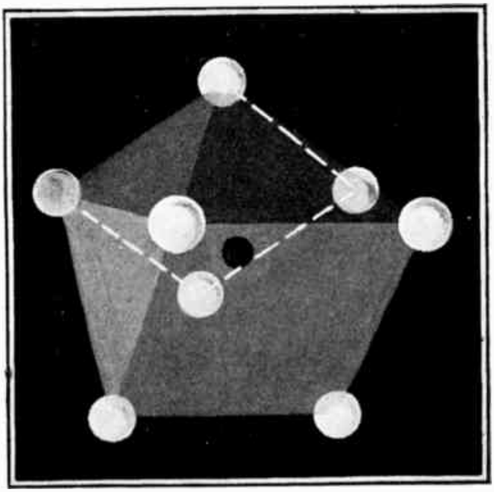
THE ATOM OF FLUORINE

9 The atom of fluorine, containing seven external electrons. Five of these electrons are arranged in one plane through the nucleus, as though at the corners of a regular pentagon; the other two electrons are at the ends of a perpendicular line, as in the case of atom number 7.

stable equilibrium at the same distance from the center, leaving one to go outside, relatively a long way out from the center of the atom.

"If there are ten electrons, these can be arranged so that eight form a layer round the center and two go outside. Eleven electrons can be arranged with an inner layer of eight and an outer one of three, and so on. Sixteen electrons can be arranged with an inner layer of eight and an outer layer of eight.

"We have now got eight electrons on the outer layer and there is not accommodation for any more; as the atom is neutral, the excess of positive over negative electricity in the system consisting of the central charge and the inner layer is equal to the charge on the electrons in the outer layer. We can, however, get a system which will be in stable equilibrium if the electrons proceed to form a third shell; thus, if there are seventeen electrons, we could have an inner shell of eight, then another shell of eight and then an electron a long way outside. If we had eighteen electrons we should get two shells of eight and two electrons outside, and so on, until with twenty-four electrons we shall have filled up the third shell and have to begin again.

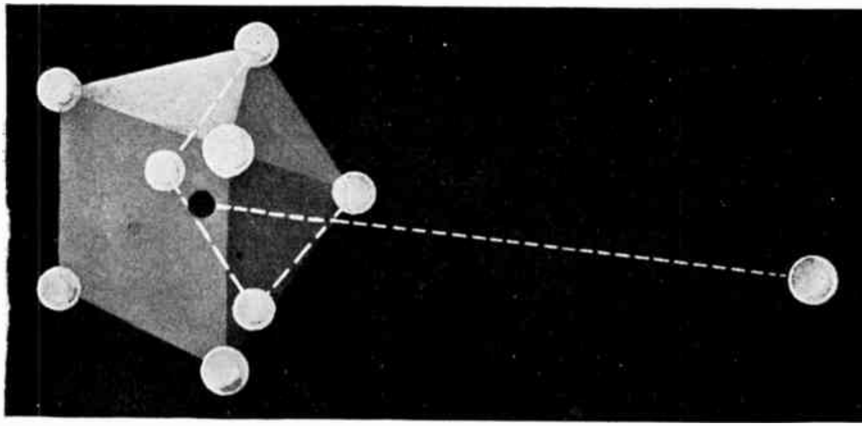


THE ATOM OF NEON

10 The atom of the rare gas neon. This contains eight external electrons, which is the greatest number of electrons, Sir Joseph Thomson believes, that can be held in a single shell all at the same distance from the nucleus.*

"Thus, if we arrange the elements in the order of the number of electrons in the atom, which is the same as the order of the atomic weights, there will be a periodicity in the number of electrons in the outer layer. It will increase from one to eight, then drop again to one; in-

*With the preceding seven models this completes the list of the first ten elements. Element number one (hydrogen) and number two (helium) are not shown in this series as they contain only the two internal electrons shown on page 9; hydrogen having one electron only, helium having both of them.



WHAT HAPPENS WHEN MORE THAN TEN ELECTRONS TRY TO CROWD INTO A SINGLE ATOM

11 The eleventh electron goes into a second shell at a distance from the nucleus 6.7 times as great as the distance of the first shell of eight electrons shown in the preceding models. This eleven-electron atom is that of sodium, one of the elements in common salt.

crease again to eight, drop to one, and so on. Thus, as far as properties depending upon the outer layer are concerned, the elements will show a periodicity in their properties similar to that expressed by Mendeleef's periodic law in chemistry.

"The valency of an element is a property depending on the number of electrons in the outer layer, the electropositive valency being proportional to that number, so that this type of atom would explain the periodic law.

"There are some other interesting results which follow at once from the view we have taken of the constitution of the atom. One is the change in the chemical properties produced by electrifying the atom. Let us take the oxygen atom as an example, it has six electrons in the outer layer, and its valency is determined by the number of electrons in this layer.

"When the oxygen atom is positively electrified it has lost one or more electrons. If it is electrified so that it has lost one electron, the atom will only have five electrons in the outer layer, the same number as there are in a neutral atom of nitrogen. Thus, if the valency depends on the number of electrons in the outer layer, the valency of oxygen carrying a unit charge of electricity ought to be the same as that of a neutral atom of nitrogen, i. e., it ought to form the compound OH_3, a compound having the molecular weight 19.

"This is confirmed by observation with the rays of positive electricity; when hydrogen and oxygen are present in the tube, a line corresponding to this molecular weight is frequently observed.

"If we turn to negatively electrified atoms, a negative electrified chlorine atom would have eight electrons in the outer layer, it would resemble the neutral atom of an inert gas and so would not be able to enter into chemical combination. It might be expected to resemble argon not merely in its chemical properties, but also in the nature of its spectrum. Again, a positively electrified potassium atom has lost an electron and so would contain the same number of electrons as a negatively electrified chlorine atom or a neutral argon one. Thus we should expect the spectrum of positively electrified potassium atoms to show similarities with that of negatively electrified chlorine atoms and with neutral argon atoms.

"Professor Zeeman and Mr. Dik have compared the red spectrum of argon, with the spectrum due to the positively electrified potassium atom and have found some exceedingly interesting points of resemblance.

"Similarly, positively electrified oxygen atoms might be expected to give spectra resembling those of neutral nitrogen atoms and positively electrified nitrogen atoms might show similarities with neutral carbon atoms."

It is interesting to note that the electrons we have been considering are able to accomplish a certain kind of broadcasting and they do this by setting up the same kind of wave disturbance in the ether that is created by a broadcasting transmitter. Instead of broadcasting the long waves of radio, the electrons broadcast the inconceivably short waves of light. It would be best at this point to note what Dr. E. E. Free, Ph.D., a prominent student of the electron theory, has to tell us about how the broadcasting of the electron is accomplished:

"The universe contains, so far as we know, only two things: electricity and ether waves.

"From the center of our earth outward to the most distant of the stars the probing finger of science has discovered nothing else. In every natural phenomenon, from the collision of two vast suns to the life history of an earthworm, everything is explainable as electricity or ether waves or the interactions of the two.

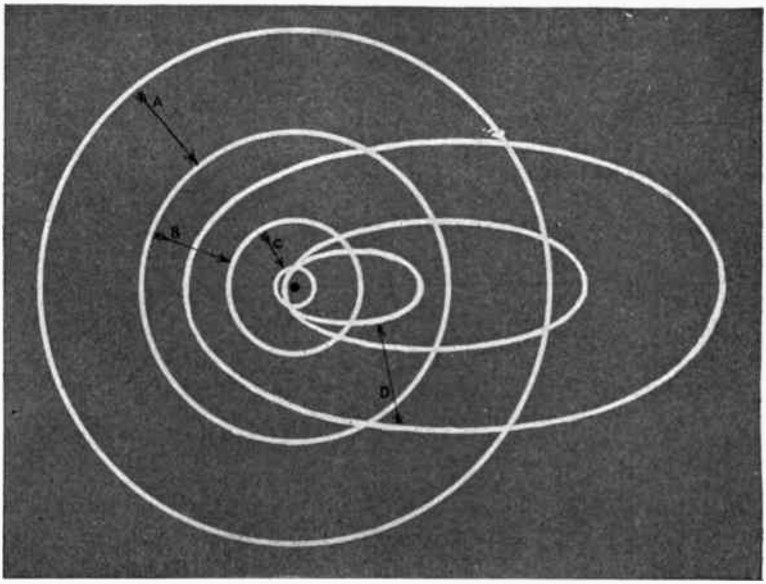
"Light is a form of ether waves. What we call heat is either an ether wave or a form of agitation in matter; and matter, as everybody knows nowadays, is really a form of electricity. Sound, too, is a vibration in matter and is therefore electrical. Magnetism and gravitation remain imperfectly understood, but these also, there is every reason to believe, are caused by some variety of ether waves that we have failed, as yet, to catch and analyze.

"And every material thing; the earth, the bodies of men and women, the eyes we see with and the ears we hear with, the copper wires that we build into our radio sets and the glass that houses our vacuum tubes, the sun and the moon and all the unnumbered millions of the stars; all these are composed of electricity, of the two fundamental kinds of electric particles that scientists call the *proton* and the *electron*. The proton and the electron simply represent two different electrical conditions, the proton, positive and the electron negative.

"The simplest kind of matter, we will remember, is the atom of hydrogen gas. This atom contains only two particles; one electron and one proton. The electron is a particle of negative electricity; the proton is a particle of positive electricity. The electron revolves around the proton as our earth revolves around the sun.

"The other kinds of atoms, making up the list of ninety chemical elements that have been discovered, are composed of these same protons and electrons; varying numbers of them up to nearly five hundred being put together in rapidly moving systems all constructed on essentially the solar system model, a central 'sun' around which revolve a number of tiny 'planets.'

"That is the modern picture of what atoms are like.



WHY THE HYDROGEN FLAME GIVES LIGHT

This diagram shows a few of the many possible electron orbits in an atom of hydrogen gas. There is only one electron in this atom and, accordingly, only one of these orhits is occupied at a time. Whenever the electron jumps from one orbit to another one (as indicated by the arrows A, B, C and D), a pulse of light is sent out. These light-pulses form the "broadcasts from atoms."

"These atomic systems are almost inconceivably tiny. More than 2,000,000,000,000,000 of even the largest atoms could crowd together comfortably enough on the surface of a pinhead.

"The printed letters on this page are composed essentially of atoms of the chemical element, carbon. Each carbon atom contains one central 'sun' and six electrons revolving around this as 'planets.' Yet so tiny is the entire assemblage that the little black dot that indicates a period at the end of this sentence contains more than 30,000 times as many carbon atoms as there are people in the world.

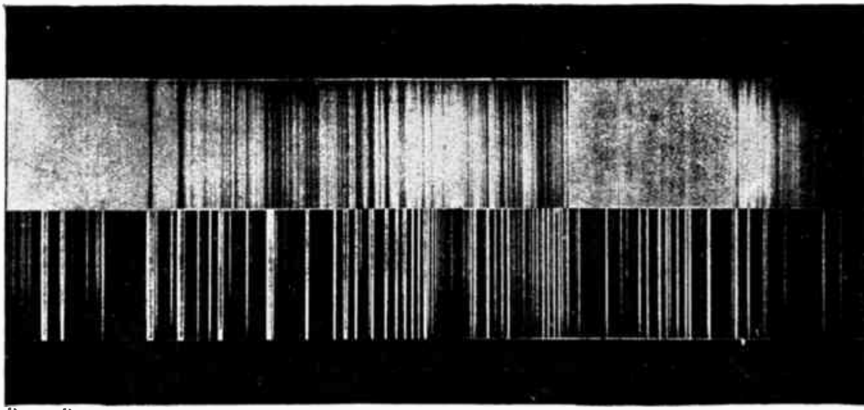
"Of course this is far too small for us to see. The smallest dust speck visible under the most powerful microscope ever devised contains many billions of atoms.

"How, then, can we be sure that the atom really does contain these particles of electricity spinning around a central 'sun' that is also electrical?

"We know by means of ether waves.

"The universe does not consist, remember, of atoms only. It contains, in addition, a great assemblage of ether waves; the waves of light pulsing back and forth between the stars, the waves of heat coming to us from the sun, the waves of electric energy that we are now using so amazingly in radio. The reader should not confuse these intangible waves of the ether with the very tangible waves of sound.

"These ether waves begin and end on atoms. If you light a match what happens is, that the billions of atoms in the flame send out ether waves of light. These ether waves enter your eyes and



Brown Bros.

WHAT A LIGHT SPECTRUM LOOKS LIKE

This picture shows two photographs of spectra, which are the sets of bright lines and bands visible in a spectroscope whenever the light that comes from a group of excited atoms is analyzed by that instrument. Each one of these separate lines corresponds to an electron jump from one definite orbit to another one in each of the atoms that are emitting the light.

strike against the other atoms that compose the organ that you see with, your retina. The act of seeing is a kind of broadcasting. The atoms in the burning match broadcast an ether wave. This wave is picked up by the 'receiver' atoms in your eye.

"The same thing happens when you see a star. Atoms in that star, off many billions of miles in space, are hot or are excited by electricity. They broadcast ether waves in the form of light. These waves travel the vast distance through space and strike, finally, against the receiving instrument of your eye. Starlight is the broadcast news from other worlds.

"The most important thing about all this is the process by which these ether waves are sent out and received. This process represents the *relation* between the two fundamental things in the universe; the atoms (which are electricity) and the ether waves. How do atoms broadcast ether waves? How do other atoms receive them? These are possibly the deepest secrets of the universe and they are secrets which modern science has made substantial progress in deciphering.

"This began with the science of spectroscopy.

"The spectroscope is an instrument that makes an artificial rainbow. Ordinary white light, such as the light of the sun, is passed through an arrangement of glass prisms and lenses. It comes out split up into its seven primary colors just like the colors of the rainbow.

"These colors differ, of course, in the wavelengths of the ether waves that compose them. The shortest light waves are on the blue end of the rainbow strip or spectrum; the longest waves are on the red end of the strip. The atomic broadcasting stations that send out the light waves use a number of separate wavelengths, just as radio broadcasters do.

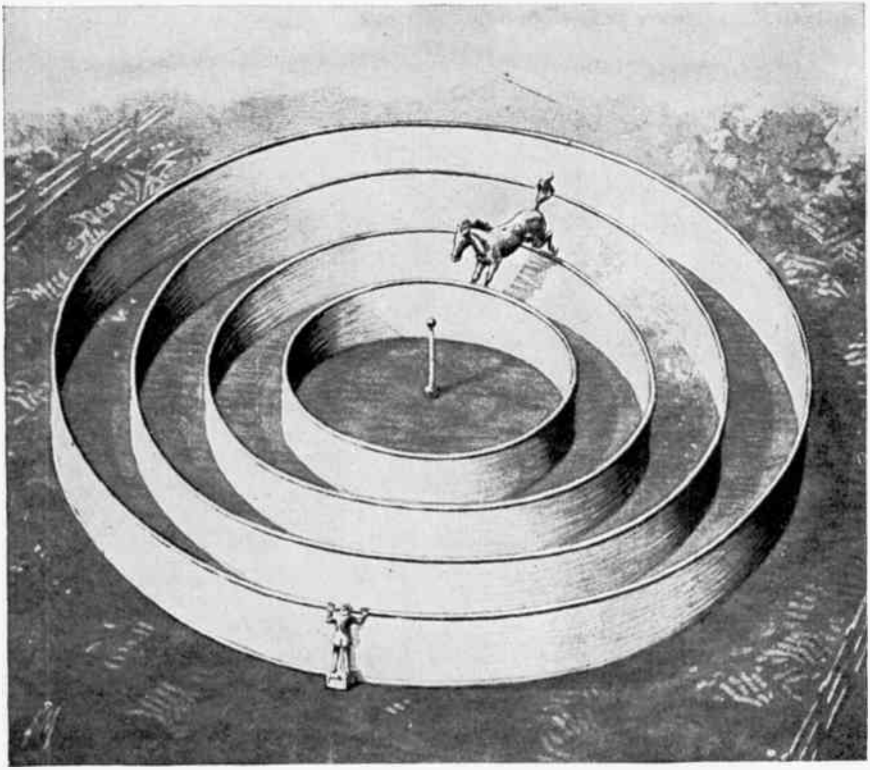
"And curiously enough, it was found that each kind of atom, like each terrestrial broadcasting station, has its fixed wavelength or wavelengths. A white light, such as sunlight, contains practically all the wavelengths, but that is merely because it is coming from a vast number of atoms and assemblages of atoms of many different kinds.

"If the United States contained a billion or two separate radio stations and if they all were sending at the same time, each on its own separate wavelength but if all these wavelengths were separated from each other by very tiny intervals, that would be a fair picture of what is happening when any body like the sun is sending out white light.

"But, if you take one kind of atom by itself and let it send out light, the result is very different. Suppose, for example, that you have a glass tube filled with hydrogen gas and that you send a powerful electric current through this tube so that the hydrogen atoms are disturbed and begin to broadcast. You will not get white light as you do from the glowing sun. On the contrary, the light waves sent out by the hydrogen atoms will comprise only a few distinct wavelengths. In a spectroscope they appear as lines of color at certain fixed positions along the rainbow strip of the spectrum. Other parts of the spectrum are dark.

"This is what scientists call the spectrum of hydrogen. It contains ten very bright lines and a number of fainter ones.

"In broadcasting language this means



HOW WE "SEE" A BROADCASTING ATOM

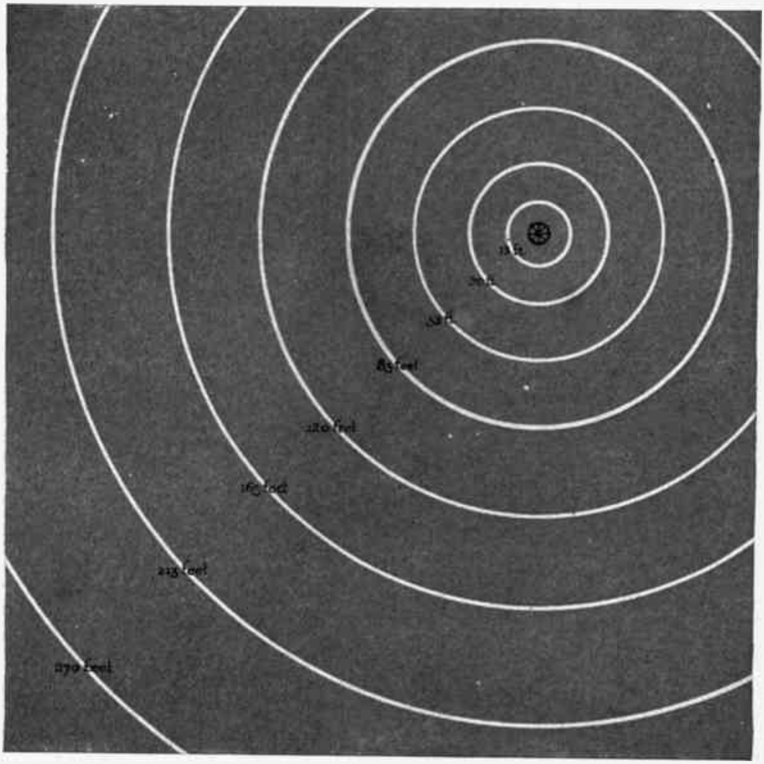
The man at the outer fence can see the horse only when the horse is jumping over a fence. Just so, in a hydrogen atom, we can "see" the electron only when it jumps from one orbit to another.

that the transmitter of the hydrogen atom broadcasts light at ten or more perfectly definite wavelengths; just as WGY, for example, broadcasts its programs nowadays at two separate wavelengths and sometimes at three.

"And these ten (or more) wavelengths of the hydrogen atom are perfectly characteristic of that atom. Every hydrogen atom that sends out ether waves at all sends out one or more of these specific wavelengths. If you find the lines of these wavelengths in an unknown spectrum you know that this spectrum is coming from hydrogen atoms just as surely as when you pick up a station on a radio wave of 492 meters you know that you are hearing from WEAF.

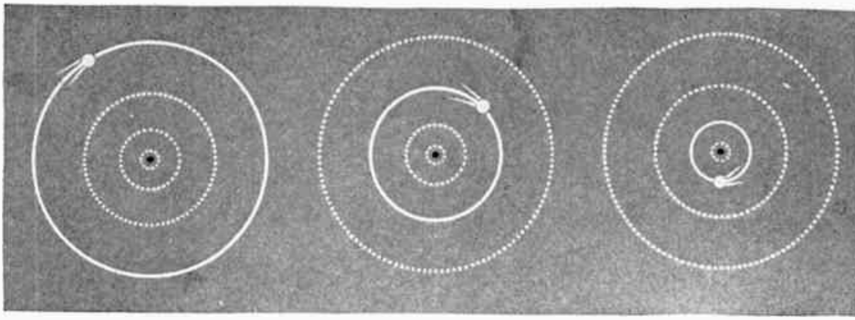
"More surely, in fact, for the different kinds of atoms maintain their wavelengths much more exactly than the man-made broadcasters do and, with a very few exceptions, no two kinds of atoms ever broadcast light on exactly the same wave.

"This gives you the clue to what is called spectrum analysis. The astronomer examines, for example, the light



THE RELATIVE DIAMETERS OF THE ORBITS IN A HYDROGEN ATOM

If the inmost electron orbit of a hydrogen atom is regarded as being the size of the forty-inch wagon wheel at the center of this diagram, then the next eight orbits outside this have the diameters shown here in feet and drawn to scale.



THREE SUCCESSIVE STAGES OF A RETURNING ELECTRON

In the diagram at the left the electron occupies the third orbit from the center. This position is unstable and the electron jumps to the second orbit, as illustrated in the center diagram. This position, too, is transient. The electron jumps finally to the inmost orbit, as illustrated at the right. For each jump a pulse of light is sent out.

rays coming from a distant star. He photographs the spectrum of this light. In it he finds certain definite lines. This means that certain definite wavelengths are present in the light. He compares these with the wavelengths known to be sent out by various kinds of atoms. Thus he determines what atoms exist off there in the star halfway across the universe. This is how we know that the atoms in the stars are the same as the atoms that we find here on earth.

"But this leaves untouched the problem of *why* the atoms broadcast their light messages in this definite way. What kind of oscillators and modulators or other apparatus do the atoms possess that make them able to send out ether waves with such exactness as to wavelength? This is the problem that Professor Niels Bohr has clarified so greatly in the past ten years as a part of his remarkable work on atoms.

"Professor Bohr starts from the idea of atomic structure already explained; the idea that all atoms consist of electron planets revolving around a central particle, also electrical, which acts as the atomic sun. It is convenient to consider the simplest known atom, that of hydrogen. This consists, you remember, of one electron planet revolving around a single positive particle, a proton.

"In the actual hydrogen atom the orbit of the single electron is very small. It measures only about four-billionths of an inch in diameter. We can think better in larger sizes, so let us imagine that we can magnify a hydrogen atom by about ten billions times so that it is forty inches in diameter, about the size of an ordinary wagon wheel.

"On this scale the proton at the center will be still so small that it will be entirely invisible. Even the electron planet, which is nearly two thousand times larger than the proton, will be only about one four-thousandth of an inch in diameter, too small to be visible except with the help of a good microscope.

"These two particles make up the atom. All the rest of it is empty space.

"This represents, furthermore, the normal, inactive atom. It is not sending out any ether waves. So long as the electron stays in this normal orbit, the size of a wagon wheel, it does not broadcast any light. To see how it does broadcast light, according to the theories of

Professor Bohr, we must consider the other possible orbits that it may occupy.

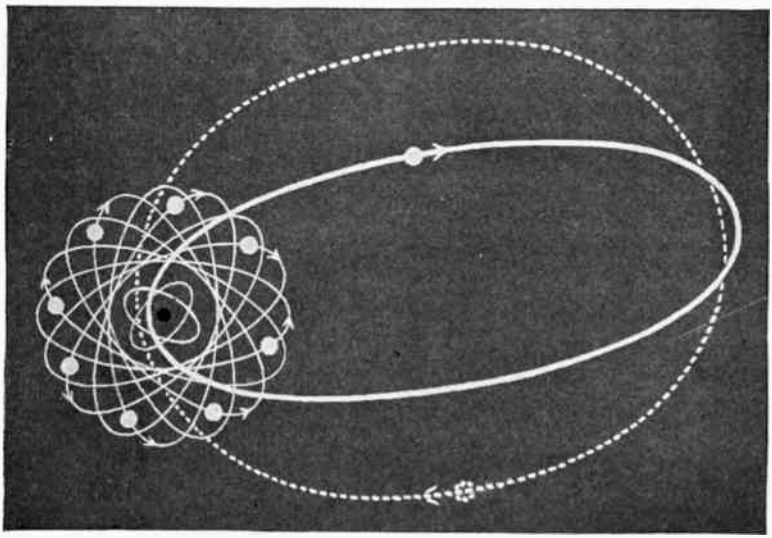
"In the solar system of which our earth and our sun are parts there exist, as everybody knows, eight separate orbits each occupied by a planet. Our earth is the third from the center, both Mercury and Venus being closer to the sun than we are and moving in orbits smaller than the earth's.

"The atom of hydrogen possesses also a number of possible orbits for its electron planet. But there is only one electron in the atom. So what happens is that this same electron may occupy at different times different ones of the possible orbits.

"It is when the electron moves from one of these orbits to another one that there occurs, Professor Bohr believes, the transmission of the ether wave that we call light. It is then that the atom becomes a broadcaster.

"In the wagon-wheel model that we have described the forty-inch orbit is the smallest and inmost one. It is here that the electron stays when the atoms are cold and not otherwise disturbed. But suppose that some outside force, as, for example, another fast-moving electron comes along and knocks the planetary electron out of this inmost orbit?

"If this happens there is another orbit that the electron can occupy at a certain distance outside the smallest orbit. This second orbit would be, on the wagon-wheel scale, 160 inches in diameter, or a little more than thirteen feet. Still outside of this is a third possible orbit thirty feet in diameter; beyond this is a fourth orbit about fifty-three feet in diameter, a fifth orbit about eighty-three feet in



HOW A MORE COMPLICATED ATOM RADIATES LIGHT

This diagram represents an atom of sodium. The electrons that occupy the closely interlaced orbits near the center of the atom do not ordinarily jump about or send out light. But the outer electron, occupying the long orbit shown by the heavy white line, may occupy many other orbits—as, for example, the one shown by the dotted line. When this outer electron jumps about from one of these orbits to another the characteristic light spectrum of sodium is sent out.

diameter, and so on at least as far as an orbit that is 490 feet in diameter and possibly to still larger ones.

"When an electron is knocked out of an atom it must occupy one of these larger orbits or else it must go off altogether. For reasons that we need not discuss here, Professor Bohr believes that the electron cannot occupy any position in the atom except in one or the other of these specified orbits.

"So much for the electron as it goes out. Now let us consider its return.

"The attraction between the electron and the central proton of the atom makes the electron want to come back, just as our earth would be attracted back toward the sun if some force accidentally displaced it from its present orbit.

"And as the electron comes back, it does so by jumps. It occupies, in turn, the succession of orbits that I have described. Suppose that it has reached the fourth orbit, the one that is fifty-three feet in diameter on the wagon-wheel model. Its next move is to cross over by a sudden jump to the next orbit inside, that is, to the one that is thirty feet in diameter. As it does so something very amazing happens. The electron (or *something* in the atom) sends out a pulse of light.

"This is the essential idea of Professor Bohr's theory of atoms and ether waves; the theory that is now accepted by practically all the scientists working in this field. The idea, which is perhaps the greatest piece of thinking since Einstein's relativity theory, may be stated thus:

"*Light is sent out by atoms only when one or more of the atomic electrons move from one possible orbit inside the atom to another orbit closer to the center of the atom.*"

"The wave length of the light that is sent out depends upon which orbit the electron has left and which one it goes to. In the hydrogen atom, for example, a jump from the fourth orbit to the third one sends out a single one of the possible wavelengths. This makes one of the lines in the spectrum of hydrogen. The other lines are made by other jumps; one, for example, by a jump from the third orbit to the second, another by a jump from the fourth to the second (for under certain conditions the electron may skip an orbit), and so on.

"In less simple spectra the conditions may be extremely complicated and difficult to understand. But in all of them that have been studied the general idea here described has been found to hold. All spectral lines—all the ether wave broadcasts that atoms send out—are believed to be due to sudden jumps of this kind made by electrons or groups of electrons inside the atomic structure.

"It is by taking the observed lines of spectra as measured in the laboratory and working backward from them to the atomic orbits and electron jumps that might have caused them that Professor Bohr and his associates have been able to establish most of the conclusions about atoms that we have already described.

"The atomic transmitter, then, is the electron. The thing that determines the wavelength transmitted is the particular jump that the electron makes. Only when the electron jumps is there any radiation of light. So long as it stays in a single orbit it radiates nothing.

"Let us quote an analogy that has been used elsewhere to make this clear.*

"Imagine a series of race tracks one inside the other like the concentric

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*"Bohr's Model of the Atom," by E. E. Free. *Industrial and Engineering Chemistry*, vol. 16, pages 192-193 (February, 1924).

grooves of that once familiar game called 'Pigs in Clover.' Imagine these tracks separated by high board fences. Now put a race horse in the outermost track and instruct him to run around it until, when he happens to feel like it, he is to jump the inside fence into the next track, run around it for a while and then jump the next fence, and so on until he reaches the innermost track of all.

"If, then, you watch this procedure from the field outside the outermost fence, you will not see the horse at all so long as he is running in a single track. The fences hide him. But whenever he jumps a fence from one track into the next you will see him for an instant as he goes over.

"So with the hydrogen atom. You see the electron only as it jumps from one orbit to another one, for it is only then that the electron radiates light.

"The next step that atomic science must take is the discovery of what really happens when one of these electron jumps occurs. We know nothing about this at all. We do not even know that the electron 'jumps' in the ordinary sense of that word. What happens, so far as we can judge, is that an electron disappears from one orbit and simultaneously an electron appears in another orbit.

"Perhaps it is not the same electron at all. Perhaps an electron is destroyed in the first orbit and a second electron created out of ether or ether waves or something in the second orbit. We do not know what electrons are. It is entirely conceivable that they may be merely a form of ether waves or that both they and ether waves may be different forms of the same thing. These things are still mysterious.

"And they lie close, we may be sure, to that greatest of all scientific problems, the problem of what constitutes that ultimate reality of Nature which appears to us now as matter, again as electricity, another time as waves in the ether and perhaps—who knows?—as what we are accustomed to describe as mind.

"Like the fable of the blind men who attempted to describe the elephant, although each had felt a different part of him, all these apparent facts of nature may be equally imperfect descriptions each of one aspect of the whole.

"Doubtless, science will attain, some day, a more complete description of these things. And nothing is likely to contribute more largely to this end than the investigation of those much longer ether waves that originate, we do not yet know how, from masses of moving electrons in wires, and that we call *the waves of radio*."

The radio waves or the electromagnetic waves that are used in radio transmission have the same fundamental nature as the waves Dr. Free mentions in his treatment of the subject. They travel with the same speed, i. e. 186,000 miles a second and they have the same properties. They may be reflected, refracted and polarized. While our light waves may be measured in the millionths of an inch, our radio waves are measured in meters and they may be as small as 1/1000 of a meter (1/1000 of 39.37 inches) or as large as 25,000 meters. They move forward from the point of disturbance in exactly the same way as the waves in a pond move forward when a stone disturbs the water. We picture them going forward at the great speed of 186,000 miles a second in all directions at the same instant of time. They pass through solid matter, or at least this solid matter of our imagination, as easily as air passes through an open window.

For all practical purposes we can consider these ether waves in the light of the above paragraphs but it is interesting to note at the same time how certain great scientists feel about the wave theory. The trend of these private theories should not confuse us. On the contrary they should help us to gain a more general view of the science.

There is one theory in particular that is important to our understanding of radio in that it tries to account for the way in which radio waves are held to the surface of the earth. We must not forget that ether is an all-pervading substance and that when superficially considered there is no reason why these waves should not go romping off into space instead of following the curvature of the earth as they must in travelling from one point to another.

To account for this following of the surface of the earth, radio scientists have evolved what is called *the Heaviside layer theory*. This tries to account for the phenomenon by assuming that there is in the upper reaches of our atmosphere an ionized or charged layer which tends to reflect the waves back to the earth causing them to flow in a channel between the earth proper and this theoretical layer. It will be remembered that we said previously that long ether waves could be reflected just as we reflect light waves from a mirror.

Dr. Elihu Thomson, Ph.D., Sc.D., has something vitally interesting to say about his theories of the Heaviside layer, which he airs in the following paragraphs:

"When Marconi brought out his system of wireless telegraphy about 1896, it was at first thought by most scientists or physicists of the time that it was a plain case of the sending out of waves of the Hertzian type, which Dr. Heinrich Hertz had so ably investigated ten years before. If such were the case, the transmission was necessarily in straight lines from the oscillator; necessarily, also, such waves could not follow the curvature of the earth's surface, but they must leave the earth as if they were light beams—another case of electromagnetic waves moving in a straight course.

"There were some of us, however, who, taking into account the grounding at the base of the antenna, recognized the fact that the Marconi transmission was not made by real Hertzian waves, but on account of the grounding, by half-Hertzian waves only, and that the Marconi oscillator or antenna system was a half-oscillator only. From this it followed that the waves were in reality attached to and guided by the earth's surface, and particularly by the sea surface, more conductive than the land.

"It followed that there would be electric currents in the sea and earth-surface accompanying these half-Hertzian waves, and magnetic fields overlying the currents in the space above the earth's surface.

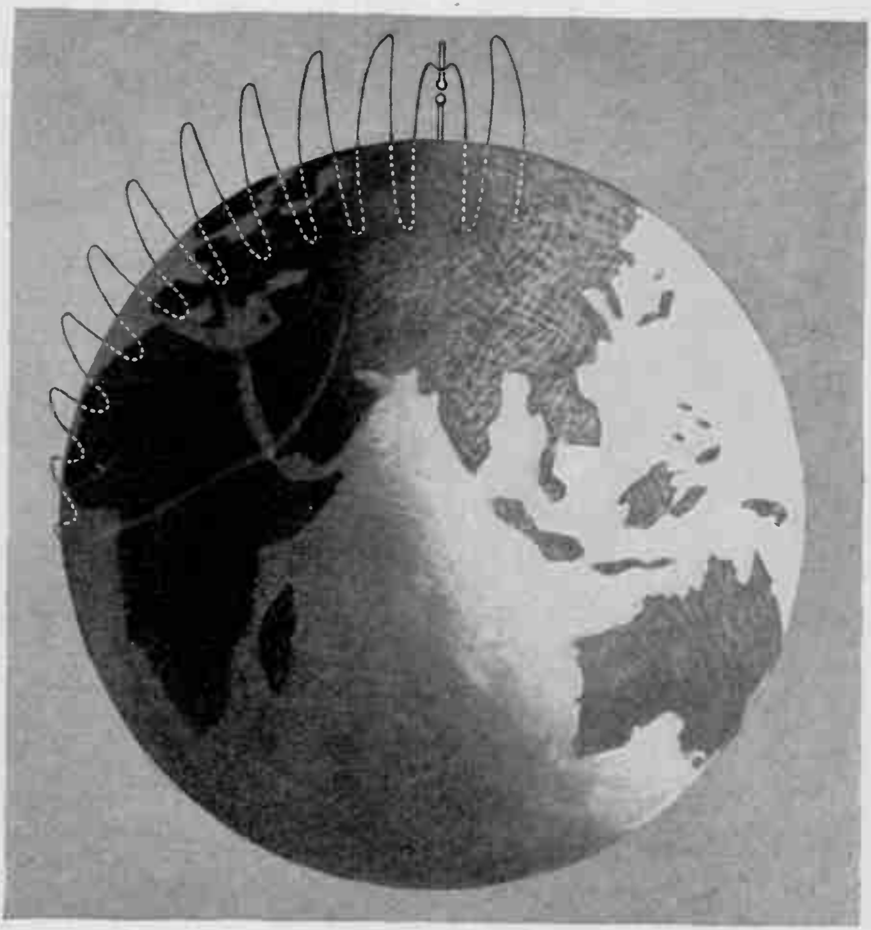
"When it was announced by Marconi a few years later that he had received signals across the Atlantic ocean by flying a kite, the cord of which constituted an antenna with the usual ground, many regarded him as something of a faker. At least, they believed that he was mistaken in his observations. Among these doubters were not a few of the leading scientific men and engineers of the day. It followed that if the waves were of true Hertzian type and were propagated in straight lines, they could not by any possibility curve around and over a mountain of water nearly two hundred miles high, as they would have had to do if they crossed the Atlantic close enough to the earth's surface to be detected.

"As it was soon demonstrated that

Marconi was right and that the signals did come around the curve of the earth's surface, those scientists who failed to recognize (and some of them even yet seem so to fail) that there was a fundamental difference between the waves in their propagation and in their generation as regards true Hertzian waves, had been mistaken—and not Marconi.

"Then a singular thing happened.

"When confronted with the facts, this assumption pure and simple was made, which unfortunately lives and has character even today: that there was an electric mirror of ionized gas, or conducting gas, say fifty or sixty miles up in our



THE "GLIDING WAVE" THEORY—WHICH DR. THOMSON ACCEPTS

"The radio waves are in reality attached to and guided by the earth's surface, and particularly by the sea surface which is more conductive than the land," states the American scientist. According to this theory, the half-Hertzian waves propagated from a grounded system would follow the curvature of the earth and would be accompanied by electric currents in the earth and sea surface, and by magnetic and electrostatic fields in the space above the earth's surface.

atmosphere, the under surface of which was so definite as to reflect the waves without diffusing or mixing them up, and so send them around the earth by successive reflections from above.

"I think that anyone who reflects for a moment on the requirements in such a case must predict that such an assumption is not only unnecessary, but that it strains the imagination too far, and plainly will not work. In order to work, it would have to be something like a metal surface, confined to a certain smooth regularity and of such a nature that the wave fronts could not penetrate it to any considerable depth without being turned back. It must be without swellings or wavy contour, and it must reflect the waves in such a way as not to interfere with those that are more directly transmitted, and so keep the waves in phase. It would have to be, as it were, Nature's gigantic whispering gallery for electric waves. The assumption itself (if it could be shown to be probably true, with the required limitations) might have justified the extended and complicated mathematical treatment it has received at the hands of some able men. But an assumption, if not needed or not true, is not helped by such treatment. The mathematics may be valid enough, but they do not make the assumption itself valid. Reasoning on false premises, whether mathematically or otherwise, does not make the conclusions valid.

"According to what has for many years been known as the 'gliding wave' theory, there never was and never could have been any doubt of the waves used by Marconi (the half-Hertzian) following the rotundity of the earth's surface.

"Experience shows that transmission over the sea is far better than over the land. Direction finding discloses that the direction of transmission favors the sea.

"Experience shows that when the land surface between two stations has been wetted by rains, great improvement in the transmission follows, to be again lost when the land surface is once more dried by evaporation. A good ground for the transmitting system or an ample condenser counterpoise is shown to favor greatly the launching of the waves. That the waves above the earth's surface tend to follow closely that surface, or may even be said to cling thereto, accords with the results obtained from aerial antennae, ground antennae, and loops or coils used as antennae.

"There never has been any occasion for the existence of the assumption of an upper conducting layer of such a nature as to reflect the waves without confusing them or diffusing them, and it is regrettable that such an assumption, having once received the sanction of great names, thereby continues to have a support and recognition which should never have been given and was never needed.

"The views presented by me in 1913 have been more and more confirmed by practice in the years since elapsed. They represented the views of the group, by whom the assumption of an upper reflecting layer was recognized from the start as a fallacy."

Reginald A. Fessenden, Ph.D., one of the most accomplished pioneers in the science of radio communication and a man who has laid down many of the basic facts of radio as we know it today, reflects scientifically on the manner in which electromagnetic waves move. He calls this new line of reasoning the "gliding wave theory" and he describes it as follows:

"The sliding wave theory appears to have been somewhat misunderstood both by its advocates and its opponents. The nature of this misunderstanding and how it arose will be better appreciated if we consider the general state of the art at the time the sliding wave theory first appeared, in the Proceedings of the American Institute of Electrical Engineers, November 22, 1899.[1].

"Joseph Henry, who was the founder of wireless telegraphy, had discovered electromagnetic induction and invented the induction coil[2]. He had also made the fundamental discovery that the discharge of a condenser was under certain conditions oscillatory, or, as he puts it, consists 'of a principal discharge in one direction and then several reflex actions backward and forward, each more feeble than the preceding until equilibrium is attained.' Henry was not only the first to produce high-frequency electric oscillations, he was the first to detect them at a distance, using what was later known as the magnetic detector. The high-frequency oscillations were generated in the upper floor of a building and transmitted to the cellar, where they were received by a receiving coil and utilized to shake out the magnetism from a magnetized needle[3].

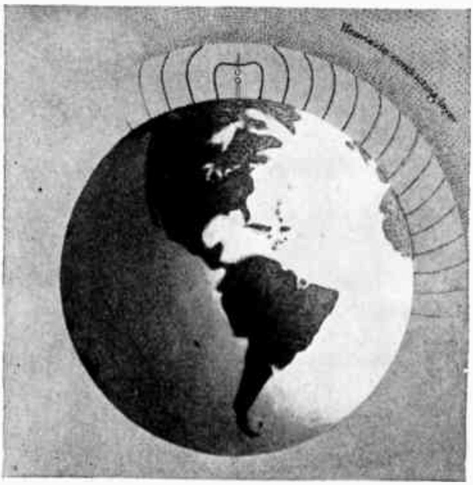


DIAGRAM OF THE HEAVISIDE LAYER THEORY

According to most scientists, radio waves are reflected from [and transmitted around the earth by] a layer of ionized gas that is suspended high in the atmosphere of the earth. Sir Oliver Lodge is the foremost exponent of this theory.

"Edison, Elihu Thomson and Houston made many experiments on these transmitted waves, and reports of their experiments will be found in Edison's papers in the technical journals of that period and in the paper by Houston and Thomson in *The Journal of the Franklin Institute* for April, 1876[4]. Between 1870

[1]Reginald A. Fessenden, "The Possibilities of Wireless Telegraphy." (A discussion.) Trans. *Amer. Inst. Elec. Engs.*, volume 16, mail edition pages 635-642, regular edition pages 607-614 (1899).

[2]Joseph Henry, "On the Production of Currents and Sparks of Electricity from Magnetism." *Amer. Jour. Science*, volume 22 (appendix), pages 403-408 (1832).

[3]"The Scientific Writings of Joseph Henry," 1832-1848. The Smithsonian Institution, Washington, D. C. Henry's important papers on electromagnetic induction are reprinted in "The Discovery of Induced Electric Currents," edited by J. S. Ames, volume 1, 107 pages, The American Book Company, New York, 1900.

[4]Edwin J. Houston and Elihu Thomson, "The Alleged Etheric Force. Text Experiments as to its

and 1888 von Bezold, Fitzgerald and Hertz had cleared up to a very considerable extent the nature of the phenomena observed, and Hertz's work had shown that the experimenters were dealing with true electrical waves.

"Dolbear[5] and Edison had been using vertical grounded antennas for telegraphing wirelessly, though the effects they obtained appear to be mainly electrostatic and only partially true wave transmission.

"Crookes in the *Fortnightly Review* for February, 1892, proposed that resonant tuned circuits should be used to select out messages from different stations. Lodge[6] and Popoff[7] had used these waves for signalling, and Popoff, who had used a vertical grounded antenna, coherer and tapper back, pointed out that the apparatus might 'be adapted to the transmission of signals to a distance.'

"Tesla[8], who had been doing a great

Identity with Induced Electricity." *Jour. Franklin Inst.*, volume 101, pages 270-274 (April, 1876).

[5]U. S. Patent No. 350,299, issued October 5, 1886.

[6]Sir Oliver Lodge, "The Work of Hertz." *Proc. Royal Institution* (London), volume 14, page 321, June 1, 1894.

[7]Popoff, *Jour. Russian Phys. Chem. Soc.*, April 25, 1895.

[8]Nikola Tesla, "Experiments with Alternate Cur-

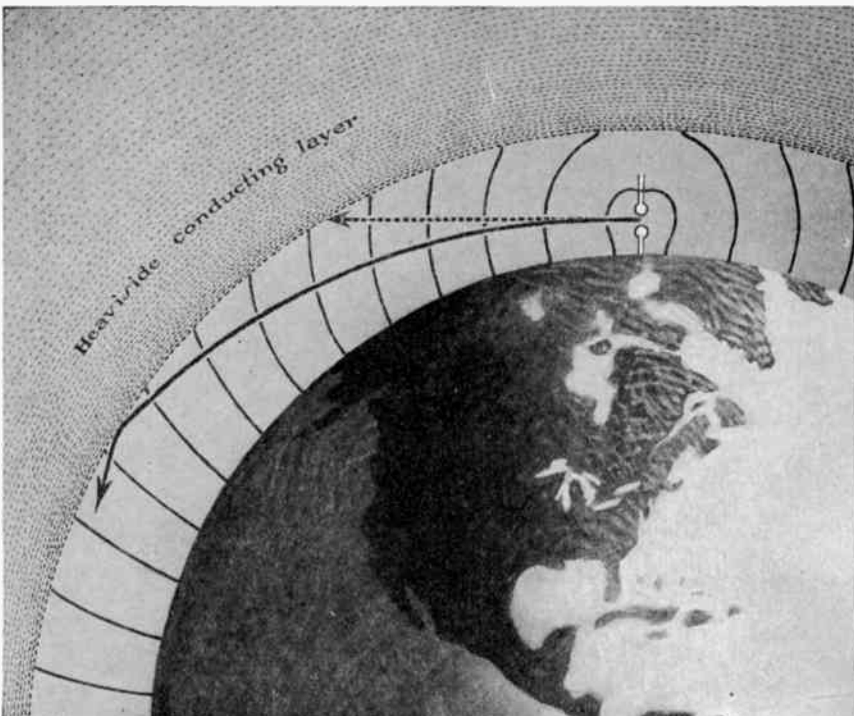


DIAGRAM OF DR. FESSENDEN'S THEORY

Instead of moving in straight lines outward from the source, as shown by the dotted line, the waves really move in a curve like that shown by the solid line. But this curve tends to bend away from the earth's surface and reflection from the Heaviside Layer is necessary to bring it back again.

deal of work in high-frequency oscillations, in 1892 proposed a system for transmitting signals wirelessly using the vertical antennas of Dolbear and tuned transformer circuits at the sending and receiving ends.

"Edison, in 1884, discovered and invented the hot-cathode vacuum tube[9], and used it for rectifying high-frequency currents. De Forest's great invention, which consisted of the introduction of a third electrode between the other two, was made about 1907.

"Marconi, who had worked under Righi's instructions, had, with the keen eye for commercial opportunity possessed by his race, realized that there was a market for such a telegraphic system, even if working over only short distances, and in July, 1896, gave a demonstration to the English Post Office at Salisbury Plain and succeeded in increasing the range from its previous figure of a half mile obtained by other experimenters to a distance of two miles, using parabolic reflectors and the coherer. In the same year Captain Jackson (now Admiral) of the British Navy found that considerably greater distance could be obtained by using the Dolbear-Edison-Tesla arrangement of vertical antennas and tuned sending and receiving transformers at both transmitting and receiving ends.

"Such was the state of the art in 1899. Henry had discovered the method of producing high-frequency oscillations and of detecting them at a distance, utilizing his other inventions, the induc-

DIAGRAM OF THE GLIDING WAVE THEORY

On the other hand, a number of eminent scientists (of which Dr. Elihu Thomson is one) maintain that radio waves are attached to and glide over the earth, following its contour in much the same way as do the radio waves in line radio.

rents of High Potential and Frequency." *Jour. Institution Elec. Engs.* (London), volume 21, pages 51-163 (1892).

[9] U. S. Patent No. 307,031, issued October 21, 1884. See also Edwin J. Houston, "Notes on Phenomena in Incandescent Lamps," *Trans. Amer. Inst. Elec. Engs.*, volume 1, first paper, 8 pages, October, 1884.

tion coil and the magnetic detector, for this purpose. Dolbear had invented the vertical antenna. Edison had invented the hot-cathode vacuum tube detector. Tesla had invented the tuned sending transformer and tuned receiving transformer, connecting to the vertical antennas. Marconi, Samuels and Isaacs had undertaken the commercial exploitation of the field. De Forest was about to begin the work which resulted in his invention of the audion.

"But even then the nature of the phenomena involved were not clearly understood. Possibly influenced to some extent by patent reasons there was a strong effort made to show that there was something radically new and strange in the systems which were being commercially exploited. It was stated by a number of authorities that the phenomena were *not* due to high-frequency alternating currents, but that some peculiar 'whip-crack' was necessary in the ether. A few quotations will illustrate this point[10].

"Professor Cross stated that 'alternating currents in the vertical wire will not produce Hertzian waves in the ether, as such waves are produced only by the disruptive discharge. Probably a crude mechanical illustration would be the case of a whip-lash—motions of some kind would be produced, but they would be of a quite different character.' Fleming stated that 'although in the third claim the patent speaks of employing rapidly recurring or alternating electric impulses, unless some form of a condenser is discharged to cross the spark gap there cannot be any production of Hertzian waves—the disruptive discharge is the one essential condition for the production of Hertzian waves.'

"Marconi stated that 'the difference between Hertzian oscillations and ordinary alternating currents is most certainly *not one of degree*. An analogy may be found in the case of a sound wave in air. The swinging of a bell in a church steeple to and fro will produce no wave, and further, no sound, but if the rim of the bell is struck soundly with a hammer, it effects the air with sufficient suddenness. Hence it appears absolutely clear to me that there is no Hertzian wave telegraphy without the essential feature for producing Hertzian waves, which is the Hertzian spark.'

"The writer had been lecturing and experimenting on the production and detection of Hertzian waves for a number of years[11], and was convinced that there was no essential distinction between the Henry high-frequency oscillations and Hertzian waves. With the object of demonstrating this a considerable number of experiments were made in 1899, with the assistance of one of the writer's former students, Dr. Kintner, and the results published in the American Institute paper above referred to, that is of November 22, 1899, in which the sliding wave theory referred to by Professor Elihu Thomson[12] was fully explained and illustrated.

"It will be seen that this paper on the sliding wave theory was written for a specific purpose, i. e., to show that there was no mysterious 'whip-crack of the ether' involved in wireless telegraphy, but merely the well-known high-frequency currents, and though it led to important developments, for instance. the wave chute, the use of the magnetic component of the wave, the loop an-

[10]Court reports in Marconi *vs.* De Forest, Southern District of New York. Proceedings Electrical Congress at St. Louis; Discussions *Inst. of Elect. Eng.* (England) and "Principles of Electric Wave Telegraphy."

[11]Purdue University catalogue for 1892-93. Thesis, Bennet and Bradshaw, Western University of Pennsylvania, 1895.

[12]POPULAR RADIO, volume 2, pages 231-235, (December, 1922). See also Elihu Thomson, "A Short Story in Wireless," *The Electrician* (London), volume 89, page 148 (August 11, 1922).

tenna, the pelorus or wireless compass, continuous wave generation, the wireless telephone and the heterodyne, it was never intended as a presentation of the complete theory.

"This has resulted in the theory being misunderstood to some extent. Professor Thomson has supposed, it would appear from his article, that the waves are *entirely* guided by the surface of the conductor and follow the earth around. Eckersley[13], on the other hand, states that the transmission of the half waves is not influenced *at all* by the conductor but 'the energy is propagated in straight lines.'

"The correct theory lies between these two opinions. The original mathematical investigation made by the writer in 1900 shows that the sliding waves are guided by the earth's surface to a quite considerable extent near the origin, but that the effect rapidly falls off. The amount of the bending is expressed by a series formula, the first term of which is an angle equal to half the angle between a tangent to the source and a straight line joining the surface of the conductor at a distance of a quarter wavelength from the source, and the source. The effect of this series falls off very rapidly with the distance. For transatlantic distances it is negligible, but for the distances dealt with in my original paper it is quite appreciable.

"The reception of waves across the Atlantic cannot, therefore, be due to guiding of the sliding waves by the conductor and must be due to some conducting layer in the upper portion of the earth's atmosphere.

"Writers on the subject of the Heaviside Layer seem to assume that this layer is more or less hypothetical and are apparently not aware that it was investigated fully prior to 1907.

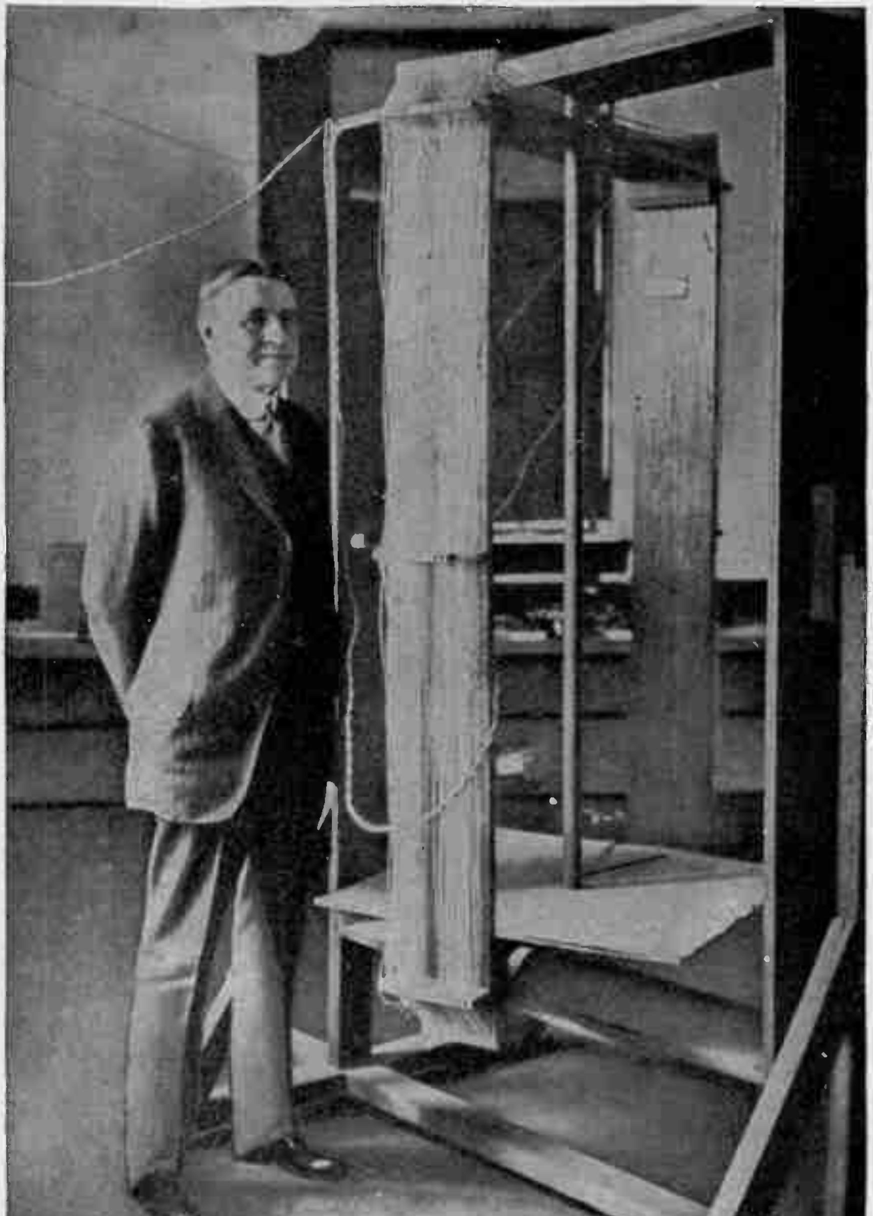
"The investigation was begun by the writer in 1900 at Cobb Point, Maryland[14], where two masts were erected one mile apart and by means of hot wire barreters and ring receivers, the exact method of transmission of the waves was experimentally determined[15]. By means of ladders placed at varying distances from the antennas the course of the waves in the air was fully mapped out up to distances of several hundred yards from and to the antennas, and by burying the receivers at different depths in the ground and immersing them to different depths in the sea water, the rate of decay below the surface and the strength of the currents flowing in the surface were accurately determined. The results appeared in papers published by the writer some twenty years ago, where, for example, the figure is given that with a certain amount of salt in the sea water and with a certain wavelength the strength of the high-frequency currents falls off to the fraction 1/e of its former value at a depth of 18 inches. Figures are also given of change intensity in going up and down sloping ground. Later, in 1906, while operating across the Atlantic between Brant Park in Massachusetts and Machrihanish in Scotland extensive measurements were made on the efficiency of transmission of different wavelengths at different hours during the day and night. A curve showing the results was published in 1906[16] and again in 1908[14].

[13] T. H. Eckersley, "A Short Story in Wireless" (letter to the editor). *The Electrician* (London), volume 89, pages 242-243 (September 1, 1922).

[14] Where speech was first transmitted wirelessly, December, 1900. See Reginald A. Fessenden, "Wireless Telephony." *Trans. Amer. Inst. Elec. Engs.*, volume 27, pages 553-629 (1909).

[15] A. Frederick Collins, "Fessenden's Work in Wireless Telegraphy." *Electrical World*, volume 42, pages 474-476 (September 19, 1903).

[16] Reginald A. Fessenden, "Wireless Telegraphy," *Electrical Review* (London), volume 58, pages 744-746 (May 11, 1906) and 788-789 (May 18, 1906).



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A FAMOUS AMERICAN RADIO INVESTIGATOR

Dr. L. W. Austin of the Bureau of Standards, with the apparatus used for investigating the effects of the ionized clouds described by Dr. Fessenden.

"The first point determined, as will be seen from these articles, was that the failure in transmission during daylight was not, as Dr. Fleming had stated and attempted to show mathematically[17], due to absorption in the neighborhood of the sending station. This was determined by measuring accurately and simultaneously the difference in intensity between the daytime and nighttime reception of signals at six different stations at distances of 200 yards, 30 miles, 170 miles, 270 miles, 400 miles and 3,000 miles from the sending station. It was found that there was no difference in the daytime and nighttime transmission for nearby stations, and that the difference increased rapidly with the distance.

"A second point determined was the efficiency of different wavelengths for transmission during daytime and nighttime. From the curves given in the papers referred to it will be seen that the absorption increased slightly as the wavelength increased, up to a frequency of 70,000 and then fell off with extreme rapidity. It was for this reason that long wavelength was adopted by the writer for transatlantic working in January, 1906. Up to this time short waves had been used in the attempts to work across the Atlantic, under the impression that they gave a sharper 'whip-crack,' but as the result of these experiments and the publication of these curves it became generally known that long waves should be used for successful operation.

"The third result was the determination of the height of the conducting layer. This is given in section 10 of the article of May 18, 1906[16], as follows:

"'The height above the earth at which marked absorption begins to take place may be roughly estimated as about 300 miles at nighttime and 100 miles during daytime.'

"It will be noticed that the height of this reflecting layer as determined in 1906 from the transatlantic wireless experiments agrees almost exactly with the height at which aurora are formed, as determined ten years later by trigonometrical photographic measurements.

"The fourth point determined was that the Heavyside Layer was not a smooth surface but was broken up into clouds of ionized air, '*ionephs,*' as the writer has termed them. To quote from the paper referred to, 'these masses of ionized air are not continuous but somewhat resemble clouds.'

"The fifth point determined was the size of these clouds, which is given in the article referred to as varying in diameter from 150 feet to two miles and more.

"The sixth result was the discovery of aeolotropic absorption or the variation in intensity in different directions on different nights.

"The seventh point referred to in the paper is the discovery of diffraction effects.

"The eighth result was the discovery of a relation between the efficiency of transatlantic transmission on different nights and the curves of variation in the earth's magnetism. The two sets of curves were found to be substantially identical in character.

"The ninth point was the discovery of what were called 'echo signals.' To quote from the article: 'On certain nights there appeared to be indications at the Boston station that a double set of impulses were being received, one about a fifth of a second later than the other. It is too early yet to make any definite statement in regard to the matter, but there is some reason for think-

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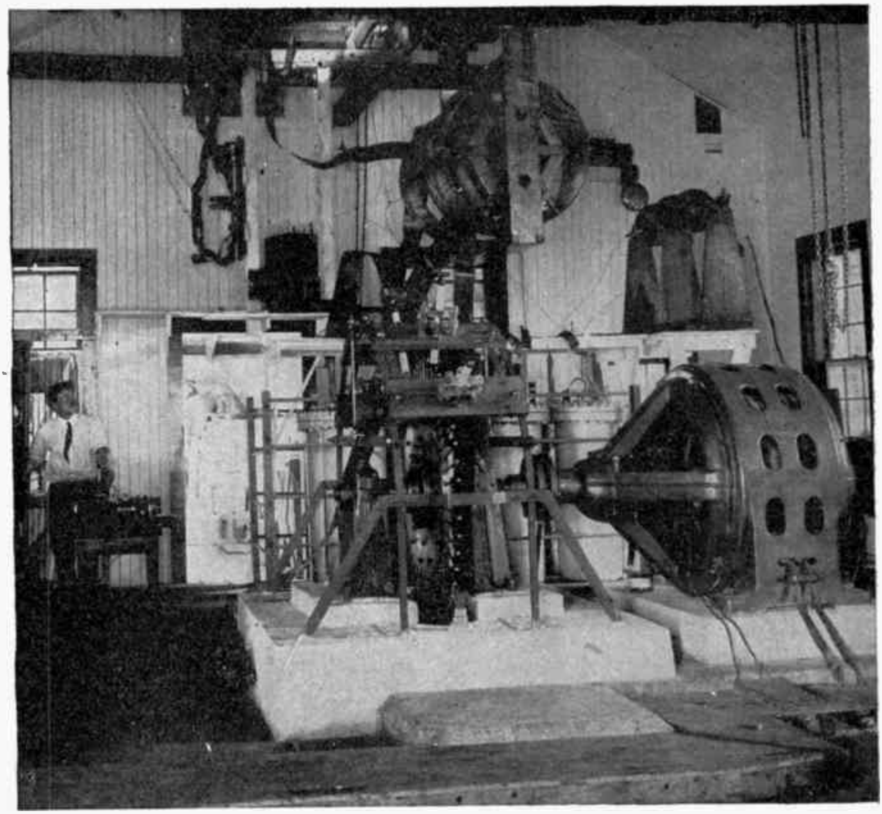
[17] J. A. Fleming, "Principles of Electric Wave Telegraphy," pages 617 and 618.

ing that the second set of signals arrived at the station after going the longer way round. To take an actual numerical example, the strength of signals received at Boston from Machrihanish on the night of January 30 was 480 times that of audibility. If the second set of signals went around the other way, their intensities, according to the square law, would be as 1 is to 70. Hence signals that had gone the other way round would have an intensity of 480 divided by 70, or 7 times audibility. As a matter of fact, the second set of signals, which we may call the echo signals, were really nearly twice as strong. This, of course, might be taken as an argument against their having come that way, but I am not disposed to consider it as a conclusive one. If, however, they did come round the other way, it is evident that the rate of absorption must become uniform after a certain distance.'



MEASURING THE HEIGHT OF THE HEAVISIDE LAYER

By means of this elaborate transmitter Dr. Fessenden carried on experiments in 1906. The operator, Guy Hill, has since become known to radio fans everywhere as Captain Hill, for several years associated with Major General George O. Squier.

"Though the statement was severely commented upon at the time (May 18, 1906), the existence of these echo signals has since been confirmed. In the January, 1922, issue of the 'Monthly Notices of the Royal Astronomical Society,' from the Greenwich, Poulka, Uccle and Edinburgh Observatories, Professor Sampson gives curves of 'the error in wireless time signals which demonstrate the curious fact that each observatory is liable to be in error by 0.2 second, and that the error frequently persists for some weeks in the same direction. The cause is obscure; lateral refraction due to dissymmetry in the distribution of atmospheric pressure is examined, but is insufficient to explain the whole anomaly.'

"It will be seen that a quite considerable amount of experimental work had been done on the Heavyside Layer as far back as May, 1906, and it is hoped that someone else may take up work along the lines indicated. Some additional information will be found in a paper on the pelorus published in 1919[18].

"Dr. Elihu Thomson and Sir Oliver Lodge have referred to the 'skepticism' concerning Marconi's first attempt to transmit wireless signals across the ocean to Newfoundland. This is really a commercial and not a scientific matter.

"The reference is, of course, to the disclosures of fact which appeared in The *London Electrician* for November 22, 1907; to the fact that three dots were used as a signal letter; the fact that the receiver used (a carbon-mercury coherer) can be made to give a succession of three dots followed by a period of silence by adjusting the electrodes to the right distance; the fact that no one was allowed to listen in to the signals except Marconi and a single assistant who had no knowledge of electric circuits; the fact that the experiments were abruptly discontinued in spite of the very generous offer of the cable companies to waive their monopoly so far as experimental work was concerned and not only to permit but to assist Mr. Marconi in making any further tests; the fact that we now know that with the short wavelength used and with the single, kite-supported wire at the receiving end, the small amount of power and no amplification, no signals could possibly have been received over that distance with that apparatus; the fact that even with the much more highly powered stations subsequently built at Cape Cod it was found necessary to first send the Roosevelt message by cable from the Holland House, New York, and then, after it had been sent out from the Cape Cod station wirelessly, to send a second cable message by the Duxbury cable directing the release of the message cabled from the Holland House; the circumstances connected with the Glace Bay tests as discussed in The *London Electrician* of the date referred to, and the fact that a considerable amount of cable stock had been sold shortly prior to the announcement of the Newfoundland tests. These facts have undoubtedly influenced public opinion to skepticism. But this is a matter on which everyone must form his own opinion, and those who may be inclined to pass harsh judgment should remember that the standard of commercial ethics is not quite the same as that of abstract science.

"To conclude, I think that perhaps the most striking evidence of the reality of the Heavyside Layer is the close agreement of the results of the tests

[18]Reginald A. Fessenden, "The Fessenden Pelorus (Wireless Compass); a Caution as to Its Use." *The Electrician* (London), volume 83, pages 719-721 (December 19, 1919).

[19]Reginald A. Fessenden, "A Regular Wireless Telegraph Service Between America and Europe." *The Electrician* (London), volume 60, pages 200-203 (November 22, 1907).

made to determine the height of this layer (as given in the paper in *The Electrical Review* for May 18, 1906, cited above) with the determinations of the height of the aurora borealis made in 1920. The fact that these two heights agree almost exactly is pretty conclusive evidence of the existence of such a layer. At first sight the aeolotropic transmission referred to in the paper of May 11, 1906, cited above, might be considered as equally conclusive evidence, but it will be seen from the paper of 1919 in *The Electrician* (also cited) that such a deviation would still exist even though there were no Heavyside Layer."

In the last paragraphs we talked a great deal about ether waves. When Hertz found that electromagnetic waves existed, scientists immediately thought that it was necessary that these waves should have some kind of a medium upon which to travel. The ether was invented partly as a matter of convenience. No one has ever heard, seen, felt or smelled the ether and there is not a single scientific instrument that can vouch for its existence. It is simply one of those inventions of the scientific mind created to temporarily account for certain observed phenomena. As far as we are concerned with the practical understanding of radio we do not care whether there is an ether or not. All we need to know is that waves are created and that these waves move with a certain speed and have a certain definite length. It is most interesting, however, to gather in the thoughts of our great scientists on this subject and the ideas expressed by the late Charles Steinmetz, "There Are No Ether Waves," may form a fascinating chapter in our present discussion. Steinmetz, basing his assumptions on the newer findings of the Einstein Theory of Relativity, goes on to say:

"The greatest contribution to science of the last ten or fifteen years, in my opinion, is the theory of relativity as worked out by Einstein and his collaborators. It is of vital importance because it revolutionizes our whole conception of nature and space. The theory of relativity concludes that there exists no absolute position or motion, but that these elements are relative.

"In other words, if we had only one single body in the universe we could never know whether that body is moving or standing still. If we had two bodies we could never find out whether body A moves and body B stands still, or whether body B moves and body A stands still. Nor could we determine whether they both move. There is no real absolute motion and we can speak of motion as relative only. If we had only one body in other words there would be no reason in speaking of that body as either moving or standing still. The conception of motion comes in only when there is more than one body.

"This conclusion is incompatible with the hypothesis of the ether as carrier of light.

"If ether fills all space, then there must be absolute position and absolute motion. A body is at rest or is moving relative to the ether, and this would be an absolute motion and would enable us to find out whether the body is standing still in regard to the ether or whether it is moving in regard to the ether, even if no other body existed.

"If the theory of relativity is right, therefore, then there can be so such thing as the ether and the ether hypothesis is untenable. It becomes necessary, then, to look into this ether hypothesis to determine how it was evolved and what it means.

"The first theory of light which demanded attention was promulgated by

Newton. He explained light as a bombardment of minute particles projected at extremely high velocities. If this corpuscular theory of Newton's is right, then two equal beams of light when superimposed, must always combine to a beam of twice the intensity. Experience shows, however, that two equal beams of light, when superimposed, may give a beam of double intensity or they may extinguish each other and give darkness, or they may give anything between these two extremes. This can be explained only by assuming light to be a wave, like an alternating current. Depending on their phase relation the combination of two waves, as two beams of light or two alternating currents, may be anything between the sum and the difference of the two intensities. Thus two alternating currents which are in phase add; if they are out of phase they subtract.

"If light is wave motion, there must be something to move, and this hypothetical carrier of the light wave has been called the ether. At this point our troubles begin.

"The phenomenon of polarization shows that light is a transverse wave; that is, the ether atoms, or whatever it is that moves in the ether, move at right angles to the light beam, and not in the direction of the beam as is the case with sound waves. In such transverse motion, a vibrating ether atom neither approaches nor recedes from the next ether atom, and the only way in which the

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DO WAVEMETERS REALLY MEASURE "ETHER WAVES"?

If, as Dr. Steinmetz maintains, there is no such thing as ether there are obviously no such things as ether waves. Accordingly this machine, instead of recording lengths of ether waves, must be recording some other forms of resonant phenomena which do not rest upon the ether hypothesis.

vibratory motion of each ether atom can be transmitted to the next one is by forces that act between the ether atoms so as to hold them together in their relative positions. That is, transverse waves can exist only in solid bodies. As the velocity of light is extremely high (180,000 miles a second) the forces between the ether atoms, which transmit the vibrations, must be very great.

"In other words, the hypothetical ether is a solid with a very high rigidity —infinitely more rigid than the hardest steel.

"At the same time the ether must be of extremely great tenuity, since all the cosmic bodies move through it at high velocities without meeting any friction. In the revolution of the earth around the sun either the ether stands still and the earth moves through the ether at twenty miles a second, or the earth carries a mass of ether with it. In the first case, there should be friction between the mass of the earth and the ether; in the latter case, there would be friction between the ether that is carried along with the earth, and the stationary ether. But in either case, the frictional energy would come from the earth and show astronomically as an increase of the length of the year and increase of the solar distance. And no such evidence of ether friction is observed.

"The conception of the ether is one of those hypotheses, which have been made in the attempt to explain some difficulty, but the more it is studied, the more unreasonable and untenable it becomes. It is merely conservatism or lack of courage which has kept science from openly abandoning the ether hypothesis. Belief in an ether is in contradiction to the relativity theory, since this theory shows that there is no absolute position nor motion, but that all positions and motions are relative and equivalent.

"Thus the hypothesis of the ether has been finally disproven and abandoned.

"*There is no such thing as the ether. And light and wireless waves are not wave motions of the ether.*

"What, then, is the fallacy in the wave theory of light, which has led to the erroneous conception of the ether?

"The fact that beams of light can cancel out each other, and can interfere, proves that light is a wave, a periodic phenomenon, just like an alternating current. Thus the wave theory of light and other radiations stands today just as unshaken as ever. However, when this theory was established the only waves with which people were familiar were the waves in water and sound. Both are wave motions. Waves involving movement of matter. As the only known waves were wave motions, it was natural that the light wave was also considered as a wave motion. This led to the question; what moves in the light wave? And this question led to the hypothesis of the ether, with all its contradictory and illogical attributes. But there is no more reason to assume the light wave to be a wave motion of matter than there is to assume the alternating current wave to be a motion of matter. We know that nothing material is moving in the alternating current, and if the wave theory of light had been propounded after the world had become familiar with electric waves of alternating currents, that is the waves of periodic phenomena (which are not wave motions of matter), the error of considering the light wave as a wave motion would never have been made and the ether theory would never have been propounded.

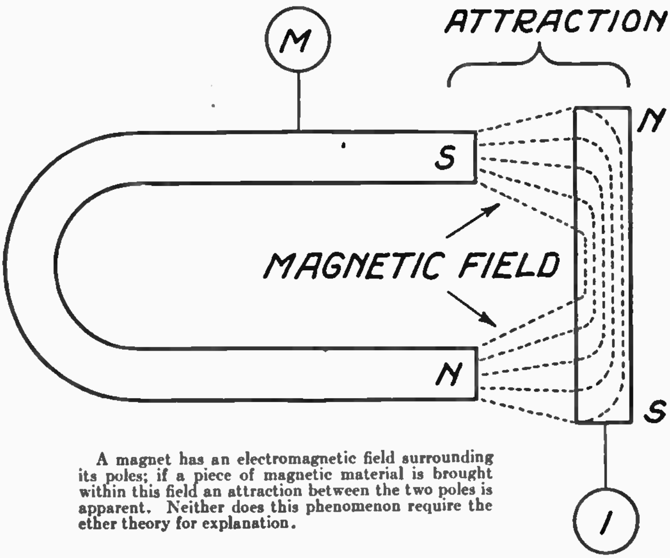
"Hence, the logical error, which led to the ether theory, is the assumption that a wave must necessarily be a wave motion. Electrical engineering has dealt with alternating currents and voltage waves; it has calculated their phenomena and applied them industrially, but it has never considered that anything material moves in the alternating current wave and has never felt the need of an ether as the hypothetical carrier of the electric wave. When Maxwell and Hertz proved the identify of the electromagnetic wave and the light wave, the natural conclusion was that the ether is unnecessary also in optics. But curiously enough, we then began to talk about electric waves in the ether and about ether telegraphy. In other words, we dragged the conception of the ether into electrical engineering, where it never had been found necessary before.

"But, if the conception of the ether is unnecessary what are we to think of as the mechanism of the light wave and the electromagnetic wave?

"Suppose we have a magnet. We say that this magnet surrounds itself by a magnetic field. Faraday has given us a picture representative of the lines of magnetic force. Suppose we bring a piece of iron near this magnet. The iron is attracted or moved. A force is exerted on it. We say that the space surrounding the magnet is a magnetic field. A field, or field of force, we define as 'a condition in space, exerting a force on a body susceptible to this field.' Thus a piece of iron being magnetizable—that is, susceptible to a magnetic field—will be acted upon. A field is completely defined and characterized at any point by its intensity and its direction.

"To produce a field of force requires energy, and this energy is stored in the space we call the field. Thus we can go further and define the field as 'a condition of energy storage in space, exerting a force on a body susceptible to this energy.'

"The space surrounding a magnet is a magnetic field. There are other kinds of fields of force. For instance, if we electrify a piece of sealing wax by rubbing



A magnet has an electromagnetic field surrounding its poles; if a piece of magnetic material is brought within this field an attraction between the two poles is apparent. Neither does this phenomenon require the ether theory for explanation.

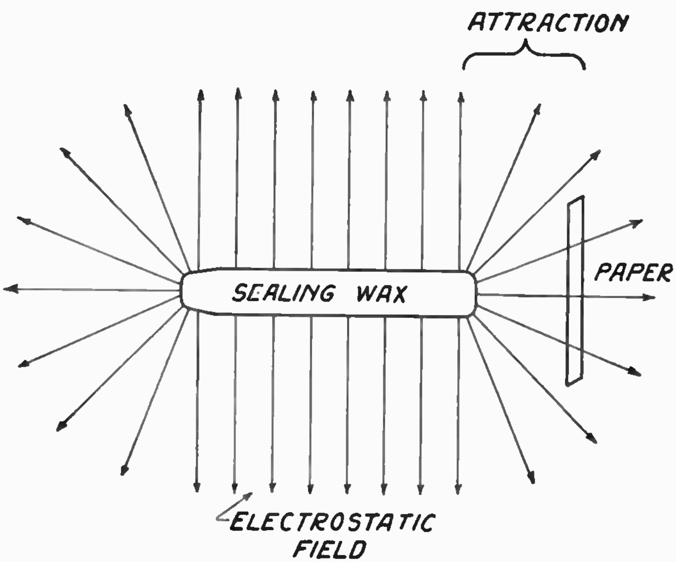
it, it surrounds itself by a dielectric or electrostatic field, and bodies susceptible to electrostatic forces—as light pieces of paper—are attracted.

"So the earth is surrounded by a gravitational field. If a stone falls to the earth, it is due to the stone being in the gravitational field of the earth, and being acted upon by it.

"Now suppose that, instead of our permanent magnet with its magnetic field of force, we have a bundle of soft iron wires, surrounded by a coil of insulated copper wire, and that we send a constant direct current through this coil. We then have an electromagnet, and the space surrounding the magnet is a magnetic field. If now we increase the electric current, the magnetic field increases; if we decrease the current, the field decreases; if we reverse the current, the field reverses. If we send an alternating current through the coil the magnetic field alternates, that is, the field becomes a periodic phenomenon or a wave: an alternating magnetic field wave.

"Similarly, by connecting an insulated conductor to a source of voltage we produce around it an electrostatic or dielectric field; a constant field, if the voltage is constant, an alternating dielectric field, (that is, a periodic or wave phenomenon), if we use an alternating voltage.

"Magnetic and electrostatic fields are usually combined, since where there is a current producing a magnetic field there is also a voltage producing an electrostatic field. Thus the space surrounding a wire that carries an electric current is an electromagnetic field, that is, a combination of a magnetic field and an electrostatic field. If the current and volt-



This diagram illustrates an electrostatic field that is set up around a piece of sealing wax by rubbing it with a bit of cloth, thus attracting such objects as pieces of paper, for example. This phenomenon does not rely upon the ether theory for explanation, states Dr. Steinmetz; it is explained on sounder scientific grounds.

age are constant, the electro magnetic field is constant. If the current and voltage alternate, the electromagnetic field alternates; that is, it is a periodic field or an electromagnetic wave.

"Maxwell deduced mathematically, and Hertz demonstrated experimentally that the alternating electromagnetic field (the electromagnetic wave), has the same speed of propagation as a light wave. It has been shown that the electromagnetic wave and the polarized light wave are identical in all their properties. Hence light is an electromagnetic wave.

"Electrophysics has been successfully developed to its present high state, has dealt with alternating currents, voltages and electromagnetic fields, without ever requiring a medium such as the ether.

"The conception of the field of force, or, as we should say more correctly, the field of energy, thus takes the place of the conception of the ether. The beam of light, the wireless wave, any electromagnetic wave is a periodic alternation of the electromagnetic energy field in space. Differences between light and other waves are merely those due to differences of frequency. Thus the electromagnetic field of the 60-cycle transmission line has a wavelength of

$$\frac{3 \text{ x } 10^{10}}{60} \text{ cm} = 5000$$

kilometers. The field is limited to the space between the conductors and their immediate surroundings. This is extremely small compared with the wavelength. Under these conditions, the part of the electromagnetic energy which is radiated into space is extremely small —so small that it can be neglected. In radio communication we use wavelengths of 15,000 to 200 meters and less; that is, frequencies of 20,000 to 1½ million cycles and more. The circuit is arranged to give the electromagnetic field the greatest possible extent, as it is the field which carries the message. Then a large part, even a major part, of the energy of the electromagnetic field is radiated. The frequency of the light wave is much greater still, 600 millions of millions of cycles. The wavelength, 50 microcentimetres, is a very tiny part of the extent of the field. Therefore practically all of the energy of the field is radiated; none is returned to the radiator.

"Our lack of familiarity with the conception of an energy field in space, and our familiarity with the conception of matter as the carrier of energy, may lead to the questions: What is the carrier of the energy of the field of space? Would not the ether be needed as a carrier of the field energy, just as on the older theory it was needed as a carrier of the hypothetical wave motion of matter?

"These questions are due to a mental error. Familiarity reverses the relation between primary and secondary conceptions.

"All that we know of the world is derived from our senses. They are the only real facts; everything else is conclusioned from them. All sense perceptions are due to energy; they are exclusively energy effects. In other words, energy is the only real existing entity. It is the primary conception, a conception which exists for us only because our senses respond to it. All other conceptions are secondary conclusions, derived from the energy perceptions of our senses. Thus space and time and motion and matter are secondary conceptions with which our mind clothes the events of nature."

END OF SECTION I

SECTION II

The Electricity of Radio

These elusive little electrons that we have been considering are able to pass through organized matter with ease and an electric current is composed entirely of such particles bumping along from atom to atom or molecule to molecule. A very good idea of what happens will be gained from the illustration (page 46) where we see a crudely enlarged portion of a copper wire and the electron particles passing through it. In reality the copper atoms shown are much farther apart; so far indeed that if the proportionate distance were shown, the size of the paper upon which this course is printed would be hopelessly inadequate. However, for all practical purposes we can visualize the process as illustrated. Of course we must keep in mind, too, that these electronic current builders are anything but lethargic for they move through conductors with a speed so great that we cannot even imagine how fast they really travel. A racing automobile traveling 140 miles per hour is moving with an almost imperceptible speed—barely crawling in fact—when its rate of motion is compared with that of an electron rushing through a circuit at a rate of 35,000 miles per second.

These electrons are no different from the electrons that go to make up the atoms of matter. They are simply wandering electrons; electrons that have been torn loose from atoms to form a vast, roving population in the world of matter. Sometimes they become dissociated through perfectly natural causes, but more often through the use of the devices which we have invented to pull them away from organized matter that heavy electrical currents may be set up and used. All of our generating devices are merely employed to set these electrons in motion through wires.

Let us for the moment return to our crude picture of the electrons crowding through the copper wire. They do not move with the same speed through all matter. For instance, in passing through a piece of iron wire they are not found so frisky because the atoms of the iron, for some reason not yet thoroughly understood, interfere with their passage. On the other hand a wire made up of silver would permit them to pass more freely than one made of copper. All of the metals could be arranged in a scale to show their relative resistance to the passage of electric currents. Some, like iron, lead and the trade wire, Nichrome, offer very great resistance while other materials like copper, silver and gold place very little resistance in the path of electronic current.

Substances that permit the free passage of electric currents which are nothing more or less than the passage of free electrons, are called conductors. A substance like water, although it is a relatively poor conductor when compared with copper, is, nevertheless, considered one of the conductors because it allows the passage of current in large quantities. There is no substance in the world that will not permit the passage of a certain amount of electric current

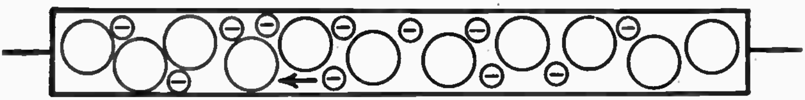


Fig. A: HOW ELECTRONS DRIFT THROUGH A CONDUCTING WIRE

Figure A: The small spheres represent the electrons; the large spheres represent the atoms of copper. The arrow shows the direction of drift of the electrons under the electromotive force applied by the battery. The electrons are really much smaller, in proportion to the atoms, than they are shown here. Collision of the electrons with the atoms is one cause of resistance.

but there are a few substances that pass so little that for practical purposes they are called non-conductors or insulators. Glass, for instance, puts up such an effective opposition to the passage of anything but a most insignificant number of electrons that scientists have learned to respect its resistance and they have placed it in the classification of the better non-conductors.

As a matter of fact, it is very fortunate for us that certain substances will not pass electricity freely for if this were not so we would find it impossible to carry electricity from one place to another over metallic channels. If we did not have insulators upon our telegraph poles the messages and power passing over them would, instead of going to a destination, leak off into the earth.

In many ways we may compare the flow of electricity through a metallic circuit with the flow of water through pipes. In the case of water, we find that it always has a certain pressure and that this pressure is usually measured in pounds per square inch. A water pipe may also deliver a certain amount or volume of water in a given time. If we stop to figure it out, we will find a direct relation between the size of the pipe (that is its internal diameter) the pressure of the water and the amount of water delivered per minute. We should find that by increasing the pressure the amount being delivered per second will be increased. We should also find that if we doubled the size of the pipe but left the pressure the same, that the amount of water delivered would be greater.

Although we deal with different terms in the case of electricity flowing through a wire, we have practically an analogous condition. Even though electrons are more intangible than water it is evident that we must have some sort of a pressure to cause them to be moved through a wire, for any particle even though it be an electron, cannot be urged to move on without some physical incentive. A ball will roll down a hill unaided, but force must be applied if it is to be moved on a level surface. In the case of water, we always find it moving from a higher to a lower pressure. Electrons obey the same impulse but it is said that instead of flowing from a higher to a lower pressure they flow from a higher to a lower potential. The higher potential is called positive and the lower one is called negative.

Coming back to our water analogy, it will be remembered that the pressure of the water was figured in pounds. The measurement of the pressure of electrons is made in voltage. One volt would be considered a very low pressure while 100,000 volts would be considered exceptionally high. The "volume" or flow of electrons, in place of being figured in gallons per minute as in the case of water, is calculated in units called amperes.

When water flows through a pipe there is a drop in pressure between the pump and the destination of the water at the end of the pipe line. This drop in pressure is due to the resistance offered by the pipe to the flow of the water; a certain amount of energy originally imparted to the water has to be used in overcoming the resistance in the line. This resistance will depend upon the diameter of the pipe and the conditions of the walls.

Our analogy between the passage of water through a pipe and electricity through a wire may be carried further by likening the falling of the pressure in a water pipe to the falling of pressure in an electric wire. In the latter case, this falling of pressure or voltage in a wire (as in the case of water) depends entirely upon the nature of the conductor; that is, whether it is brass, copper or iron and upon the size of the wire. If a very small wire is used, the current will meet a tremendous opposition and very little of it will flow. Such a wire would be said to have a high resistance. If the voltage should be pushed high enough, this little wire would finally burn up just as a water pipe with a pressure too high might burst. The substitution of a larger wire would permit the current to flow more freely and by reducing the pressure (voltage) the same amount of current could be made to pass.

Just as the pressure of electric current is measured in units called volts and the flow in units called amperes, so is the resistance measured in units called ohms. This term is used in honor of Dr. Ohm, the German physicist who constructed the classic law of resistance which we are about to consider. In the case of measuring the resistance of very poor conductors the unit the megohm is used more conveniently, for the megohm is equivalent to 1,000,000 ohms. Very poor conductors may have a resistance as high as 500 megohms per cubic centimeter. When very minute resistances are employed (a large volume of pure silver for instance) the more convenient unit the michrom is used. The michrom is 1/1,000,000 of an ohm.

In reviewing these facts about the flow of electricity through a wire, the relationship between voltage, amperage and resistance must have been evident for we found that an increase in voltage caused an increased current to flow and that a decrease in resistance caused exactly the same thing to happen. We find that the flow of current can be controlled either by an (1) increase or decrease of resistance, and (2) by increasing or decreasing the voltage. Dr. Ohm found that these relationships took on a definite mathematical form and he expressed this form in Ohm's Law. Summed up it simply states that for a constant resistance, the current flowing in an electric circuit is directly proportional to the voltage and that for a constant voltage the current is inversely proportional to the resistance. Giving voltage the symbol "E" (meaning electro-motive force), resistance "R" and current "I." the following formulae make up Ohm's Law.

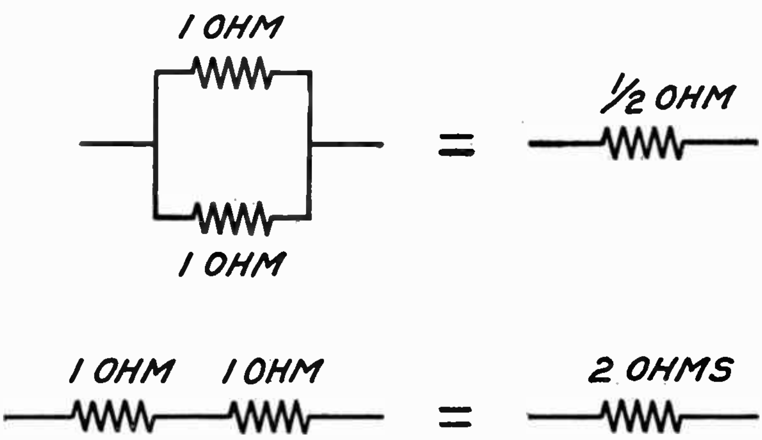
$$I = \frac{E}{R} \quad \text{or} \quad E = I \times R \quad \text{or} \quad R = \frac{E}{I}$$

As an example, let us assume that we have a circuit having a voltage of 12 as measured with an instrument known as a voltmeter. The amount of current flowing as shown with an ammeter is found to be 2 amperes. According to Ohm's Law R = E divided by I, and on this assumption 2 is divided into 12 which gives an answer of 6 ohms. Since Ohm's Law is of great importance in radio work, it will be wise to keep the forerunning facts in mind.

In Fig. B we notice how resistance may be added or divided depending upon the way in which it is connected in the circuit. In many cases engineers do this to properly control the flow of current. Instead of relying upon the natural resistance of copper wire forming the circuit, a wire having a very large resistance is wound onto a form and inserted. Such action, of course, always causes a drop in the amount of current flowing by reducing the pressure. At the top of the sketch we see the effect of two ohms of resistance in parallel or multiple. In this case the resistance will be the reciprocal or the equivalent resistance or I/R. Instead of the resistance being two ohms, as might be supposed, it is ½ ohm. By connecting the same resistance in series as shown in the lower portion of the sketch, the resistances are added and 2 ohms result.

Ohm's Law applies not only to portions of the circuit but to the circuit as a whole. If we had a generator and a circuit containing a number of electric lamps in series we should find it necessary to determine the resistance of each individual length of the wire and the internal resistance of the generator itself before we could add the factors together to determine the resistance of the complete circuit.

There will always be a drop of voltage when a current passes through wire offering resistance. The greater the resistance the greater the drop in voltage. If the terminals of a voltmeter are connected directly to the terminals of a resistance coil carrying a current the degree of drop in voltage may be determined by reading the meter. This is usually referred to as the drop in voltage or "potential drop."



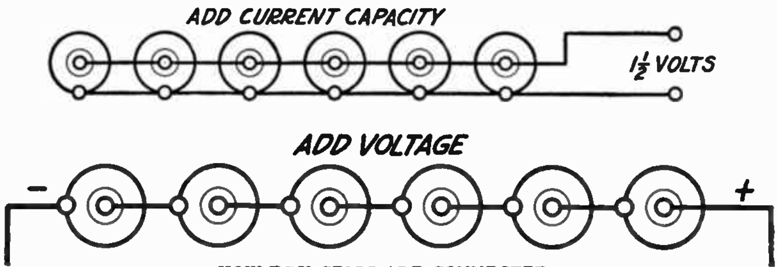
HOW RESISTANCES MAY BE ADDED OR DIVIDED

Figure B: The upper figure shows two resistances in parallel; the joint resistance is half that of either one. In the lower figure the same two resistances are connected in series; the joint resistance is then twice that of a single one.

It has been said that a flow of electric current is established only when a difference of potential or a pressure is created. There are a number of different ways of creating such a pressure. There is a chemical way of doing it which is carried on by the aid of devices called batteries. If a rod of zinc and carbon are inserted in a vessel containing a fairly strong solution of sal ammoniac there will exist between the copper and the zinc a difference of electrical potential. It will be found that the carbon will have the higher pressure and it is consequently marked positive. The zinc having the lower pressure will be marked negative. If a voltmeter is connected between this negative and positive pole the degree of the electrical potential existing between these elements may be determined. It will be found to be in the neighborhood of 1.5 volts.

If a current consuming device like a small electric toy motor should be connected to this simple cell, a rather energetic chemical reaction would be set up between the sal ammoniac and the zinc plate as long as the circuit was closed. If this action should be continued long enough the zinc would gradually be consumed and would finally almost completely disappear. We find that we have here a sort of a chemical furnace which, instead of consuming coal for its supply of energy, consumes zinc. This energy represented by the consumed zinc presents itself in the form of electronic flow in the circuit containing the cell and the motor.

If we had a number of such chemical cells on hand and connected them in series we should find that the voltages of the various units would be added together but their current capacity would be the capacity of one cell. If ten cells were arranged in series or tandem there would be available an electrical potential of 15 volts. This series connection is shown in the sketch. By arranging the batteries differently and placing them in what is known as parallel relationship the current capacity could be increased at the terminals. This parallel method of connecting the cells is also illustrated.



HOW DRY CELLS ARE CONNECTED

Figure C: At the top the cells are connected in parallel so that the voltage of the complete battery will be that of one dry cell. At the bottom the cells are connected in series so that the voltage of each cell is added. In the case shown there would be available 9 volts which is 6 x 1.5.

In the previous paragraphs we considered the flow of electricity as established by a chemical producer of potential differences. In applying the voltmeter to the chemical cell mentioned we would find that it would be necessary to connect the meter in a very definite way to have the needle or pointer register correctly. Reversing the meter would reverse the needle and no intelligent calculation of the voltage could be formed. This proves that the current in this very simple producer of electricity is flowing in one direction only, just as water flows through a pipe. Such a current is called a direct current in electrical parlance and it is produced by batteries and sometimes by mechanical generators.

If we should wind a few turns of insulated wire around a nail and connect the terminals of this crude coil to an ordinary dry cell a most interesting thing would happen. We would find that the nail would have the property of attracting to it articles made of iron or steel. In short it would behave in exactly the same manner as a permanent steel magnet.

The magnetism of the nail could easily be accounted for by placing an ordinary compass close to a wire carrying current. It is known that a compass functions by reason of the magnetic poles of the earth and that it is extremely sensitive to magnetic disturbances. Any wire carrying a current will have about it a magnetic field and the compass will faithfully detect such a field if it is brought close enough to the wire so as to be within the range of its influence.

If we experiment with this compass and circuit a number of very interesting points may be brought out. By placing the compass at various distances from the wire and by varying the strength and voltage of the current we would soon find that the strength of the magnetic field, and, consequently its range of action, would depend upon the amount of current flowing. If the wire was large and a great quantity of current could be forced through it, the magnetic field in the vicinity of the wire would be strong and it would be found to influence the compass over a great distance.

When wire is formed into coils this magnetic field about it is concentrated and the amount of concentration depends upon the number of turns, the size of the wire, the amount of current flowing through it, the nature of the coil, etc. By using heavy enough current and enough wire, magnetic fields so powerful that they can attract several tons of iron may be produced.

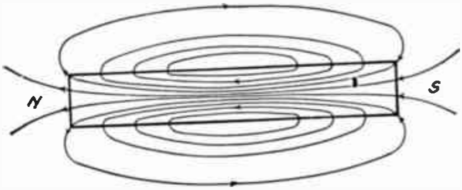
If the little compass that we are describing should be brought into proximity with a heavy coil of wire carrying a current, it would be found that it could detect the magnetic field over a considerable distance. A real sensitive compass will sometimes indicate the passing of a street car several blocks away.

It has been found that magnetism will penetrate all solid substances. We could prove this by placing a piece of cardboard before the nail magnet. If this was done, the nail would still be able to attract to it small bits of iron and steel. However, careful calculation and experimentation has shown that all substances do not permit the passage of magnetism with the same degree of freedom. Air seems to offer considerable opposition while soft iron will greedily absorb magnetism. In fact, iron is the best conductor of magnetism that has been found and it is for this reason that it is used as a core in all magnets of the current consuming type. Such magnets, that is magnets that depend for their action upon the passage of current through a wire, are called electromagnets to distinguish them from permanent steel magnets that have no wire. It must be remembered, too, that electromagnets develop magnetic fields only so long as the current flowing through them exists. If the current is suddenly stopped the field collapses instantly and if the current is reduced in any way through the interposition of resistance, the intensity of the field about the core will also be reduced.

A few iron filings, a piece of pasteboard and a permanent magnet of the horseshoe type are the only materials necessary to show that magnetism is not the topsy turvy action that we might have expected, but an orderly systematic disturbance that follows well established laws. If some of the iron filings are carefully scattered over the cardboard (Fig. G) it will be found that they try to assume different positions when the magnet is brought under them. It would seem that these tiny particles of iron struggle to align themselves in a definite pattern. When they do this, they follow what is known to electricians as magnetic lines of force. These magnetic lines of force are used merely as a matter of convenience in calculating the strength of magnets. These lines of force do not only exist around wires and coils but at the ends of all permanent steel magnets.

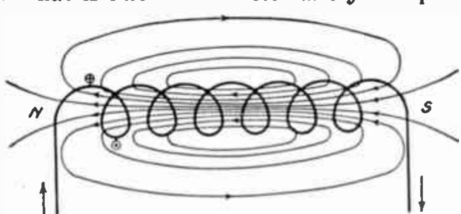
In the electromagnets that we have been treating we have two different poles, a north pole and a south pole. Furthermore, there is a law in magnetism that states that like poles repel each other and dislike poles attract each other. This statement can be very easily verified by bringing together the poles of two horseshoe magnets. If no action results it will be found that the like poles are in contact. If action does exist, it will be known that a north and a south, and a south and a north pole are connected.

It is surprising how a few simple materials will permit of an almost endless variety of experiments with electromagnetism. The winding of another coil of wire upon a nail and the addition of a sensitive current indicating device (called a galvanometer) to the experimenter's kit, makes possible demonstrations involving the elementary princi-



PERMANENT MAGNETIC FIELD

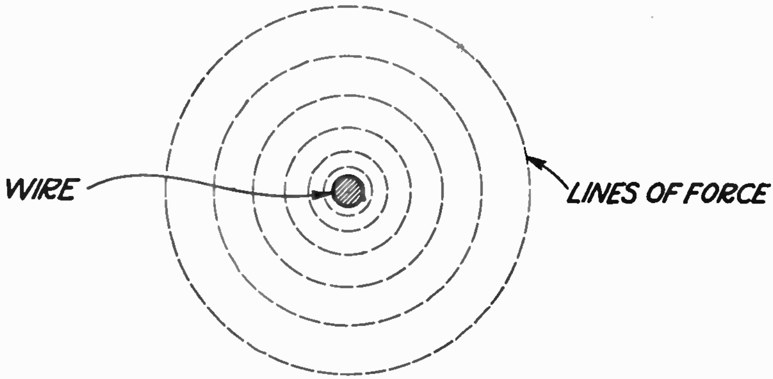
Figure D: The curved lines show how the magnetic field about a permanent magnet would appear if they were visible to the human eye. The shape taken by the field depends somewhat upon the shape of the magnet.



MAGNETIC FIELD ABOUT A COIL

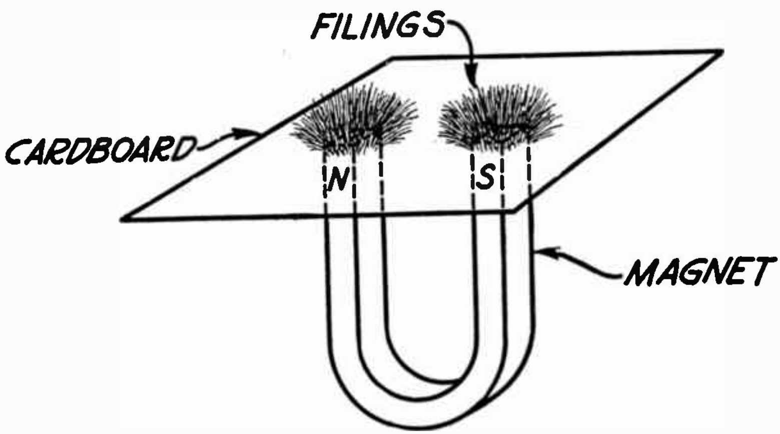
Figure E: This diagram shows the similarity between a field produced by a permanent magnet and a coil of wire carrying an electric current.

ples of electromagnetic induction. The galvanometer is connected to the terminals of the second coil and this coil is brought into the neighborhood of the original coil connected to the cell. If the battery is alternately connected



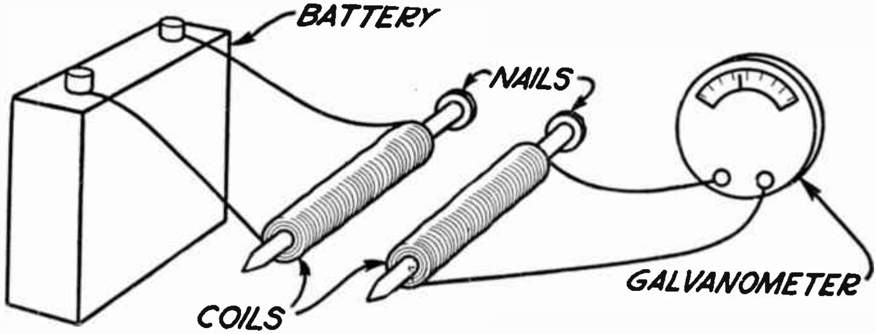
MAGNETIC LINES OF FORCE

Figure F: If the magnetic lines of force about a current carrying wire were visible and one of the wires in the coil at Fig. E should be cut the lines of force about it would appear as above. The strength of these lines depends not so much upon the voltage carried by the wire but the current strength. If a very heavy current was travelling through the circuit the lines of force would be proportionately great. Even with a very high voltage the lines of force would be small if the current was small. The student will also note that the lines of force become weaker in the outside circle which is indicated by the growing distance between the concentric lines. The field will be at maximum intensity close to the wire.



MAGNETISM OF HORSESHOE MAGNETS

Figure G: It was said in connection with Fig. D that the shape of the magnetic field produced by a permanent magnet which is a magnetized piece of steel depends upon the shape of the magnet. Here we really have a bar magnet bent into a horseshoe shape. This brings the magnetic fields which are strongest at the ends of the magnets into close relationship and hence a greater force is exerted. By placing a small piece of cardboard over the poles of a horseshoe magnet and sprinkling it with iron filings a very good idea of the course taken by the magnetic lines of force may be had. The tiny pieces of iron will tend to align themselves with the invisible magnetic force and will appear somewhat as shown in the sketch.



ELECTRIC ENERGY TRANSFER

Figure H: Here the student will see how it is possible for an electric current to jump across space from one circuit to another. The battery connected to the coil about the first nail generates a magnetic field which is picked up by the coil about the second nail, reconverted back into an electric current and registered on the sensitive galvanometer. The distance over which this energy transfer will take place depends upon the strength of the battery, the size of the coils, etc.

and disconnected, the indicating needle of the measuring instrument will jerk back and forth in response. This indicates that an electric current has been set up in the second coil although it is in no way connected to the first coil except through these invisible lines of force.

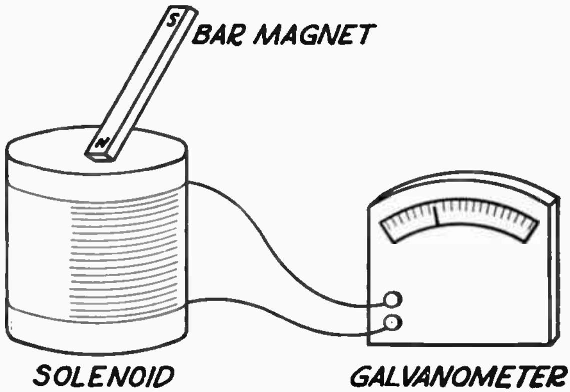
This simple experiment proves that a very definite relationship exists between electricity and magnetism for we have set up a magnetic field by the aid of an electric current and reconverted it back into its original state. Not only this, but we have succeeded in transmitting electric energy across space, which is, of course, wireless. While we do not care to go into the matter of radio at this moment, it may be said that very similar phenomena are involved.

Transmitting energy from one coil to another in this fashion is called electromagnetic induction and it finds great application in the workaday world, not only in radio but in telegraphy, telephony, power generation, etc. It is the most valuable property of electric current.

Let us come back again to the experiment with the coils. It was noticed that the indicating needle of the measuring instrument was jerked into motion only upon the instant of connecting the battery. Even though the battery was left in connection, the needle dropped back to zero. This simply means that no current can be transmitted across space unless the magnetic lines of force are in motion, or unless the coil picking up the magnetic lines of force is *caused to constantly cut through the lines of force.*

This simple law of electromagnetic induction may be demonstrated in another fashion. A coil of wire is wound upon a cardboard mailing tube and the terminals of the coil are connected to a current indicating instrument. A permanent steel magnet is then inserted in the coil. As long as the magnet is moved within the coil the indicating needle of the instrument will show the presence of a current. However, if the magnet is permitted to remain stationary no current will flow. If the magnet remains stationary and the coil is moved, the current will flow again. In either case the wire turns of the coil were made to cut through the invisible lines of force. In other words, work must be done before electromagnetic energy can be transformed into usable electric current. If the mere presence of a steel magnet inside a coil of wire would generate an electric current we would not need to burn coal or harness waterfalls to generate power. It would only be necessary to construct large power it is necessary to connect the steam engine to an electric generator and if one horsepower of electric current is to be produced the power of the steam engine must be at least one-and-one-quarter horsepower for there is always a loss when power is transformed from one kind to another.

So far we have been dealing with direct current (D.C.). By this we mean



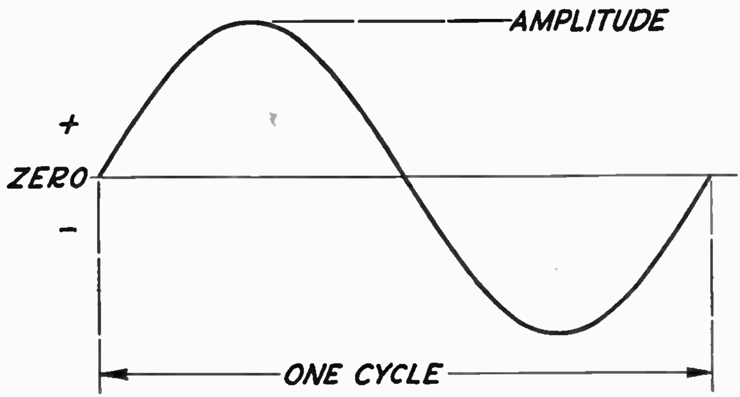
SIMPLE CURRENT GENERATOR

Figure I: Here is another experiment that further illustrates the mysterious connection between electric current and magnetism. As long as the bar magnet is moved inside the solenoid shown there will be a deflection of the galvanometer needle which indicates the generation of a current. It is upon this simple principle that all electric generating machinery is based.

coils and place magnets within them. The law of the conservation of energy says that this cannot be done and the little experiments which we have just conducted prove that it cannot be done.

From the last experiment we receive the idea of the method used in the generation of electric power. An electric dynamo or generator is nothing more than a coil of wire revolving upon a shaft through a magnetic field. The magnetic field is set up by what is known as the "field windings" of the generator. If we wish to transform kinetic energy (energy of motion) produced by a steam engine into electric a unidirectional current; a current flowing between positive and negative in one direction only. Such a current may be supplied by a battery or by what is known as a D.C. generator.

We are now ready to take up a widely applied form of current called alternating current (A.C.). Alternating current is quite different from direct current in that it does not hold to a uniform direction of travel. Rather it insists on going first in one direction and then in the opposite direction. An automobile or any moving object cannot move and stop and reverse itself unless the energy that is moving it in the original direction is



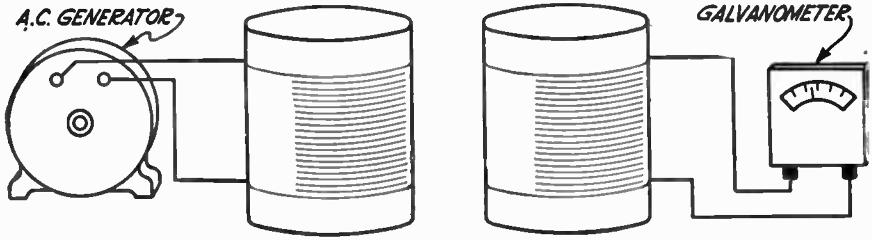
PICTURE OF AN ALTERNATING CURRENT

Figure J: This shows how an alternating current starts out at zero voltage, rises to maximum amplitude, drops back to zero and turns about doing the very same thing in the opposite direction. The number of times it does this in one second is referred to as its frequency which is always expressed in cycles. 60 cycles would mean that it was making 120 reversals per second.

brought down to absolute zero. You cannot set an automobile going twenty-five miles an hour and reverse its direction from forward to backward instantly without first bringing the energy expended down to zero. The same holds true of electric current. When it changes its direction of motion its voltage and amperage first drop to zero and for the barest instant of time there is absolutely no current flowing in the circuit.

This interesting action of alternating current can best be explained by the aid of a diagram. In the diagram we have a line which represents zero current and zero voltage. One side of the line represents one direction and the other line the opposite direction. The current starts out at zero and gradually increases until the voltage and amperage reach a maximum. The current then prepares itself for reversal and gradually drops back to zero. Then it starts out in the opposite direction and does exactly the same thing again. The number of these reversals that occur in a second of time determines the frequency of the current. We often hear it said that such and such a circuit has a sixty-cycle current travelling in it. This simply means that the current is reversing itself one hundred twenty times a second and that each complete reversal from zero to zero and back to zero is a cycle. We have both high and low-frequency alternating current and although one hundred twenty reversals in the space of a single second may seem to be a very great speed to the dull human mind, it is mere loafing for an electric current with its extremely mobile electrons. Electric currents do not reach the high-frequency class until they are reversing at least 500,000 times a second in their circuits. This frequency may be carried to five million with very little difficulty.

Let us see what would happen if a coil carrying an alternating current was brought into the proximity of a second coil connected to a current indicating instrument capable of registering alternating currents. It would be found that a current, almost the exact replica of the



A. C. ENERGY TRANSFER

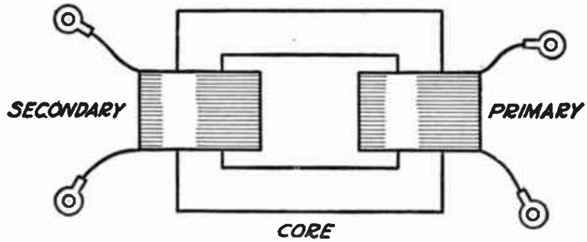
Figure K: This shows how an alternating current, due to its constantly fluctuating quality. may be transferred from one circuit to another by electromagnetic induction.

original current, would be developed or *induced* in the second coil. This is intriguing because we remember that in the case of direct current a current existed in the second coil only while the first coil was being moved through the magnetic lines of force. In the case under discussion, however, we must remember that we have a current that is constantly going up and down from zero to maximum and that this is equivalent to interrupting the current as we did in the dry cell. This constant interruption causes the magnetic field to build up and collapse and it is this movement of the field that causes it to constantly cut through the turns of wire in the second coil thereby building up an electrical potential that faithfully follows the action of the current in the first coil. Since we deal largely with this particular principle of electromagnetic induction in the science of radio, it will be well for the serious student to convince himself that he thoroughly understands the foregoing before passing on to a further consideration of the subject.

Since we discovered that iron is a much better conductor of magnetic lines of force than the surrounding air, it follows that a maximum transference of electrical energy between coils can be brought about only by providing an iron magnetic path between the coils. This proves to be true in practice. If it is decided to transmit current from one coil to another the coils are wound upon hollow forms and these forms slipped over a soft iron frame.

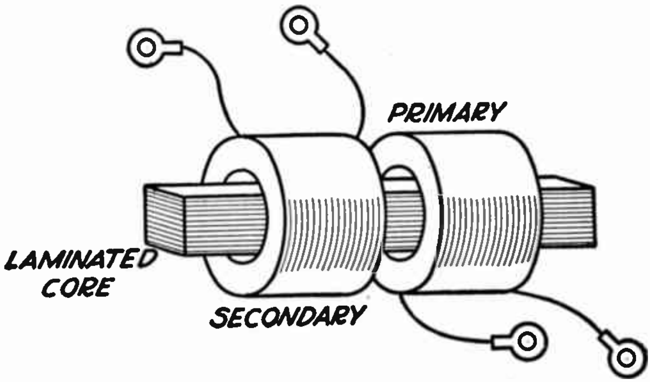
It is natural for the student to ask, "What possible object could we have in merely transferring current in this fashion? Why not simply leave the coils out and complete the circuit without them?" If we desired to use the current in its original form this system of coils (which is usually called a transformer) would be quite unnecessary. In fact it would be highly impractical because it is at its best an inefficient instrument. It is only when electricians wish to *raise or lower the voltage* of a current that transformers are used. Whether the voltage of a current will be raised or lowered depends entirely upon the way the transformer is designed and principally upon the number of turns or the ratio between the number of turns in the first coil and the second coil. Incidentally it might be well to mention at this point that the first coil or the coil in which the current enters the instrument from its source is called the primary and the second or output coil is called the secondary.

Let us take into hand the simple problem of increasing the voltage of a sixty-cycle current. It will be assumed that a voltage of two hundred and twenty is desired instead of one hundred



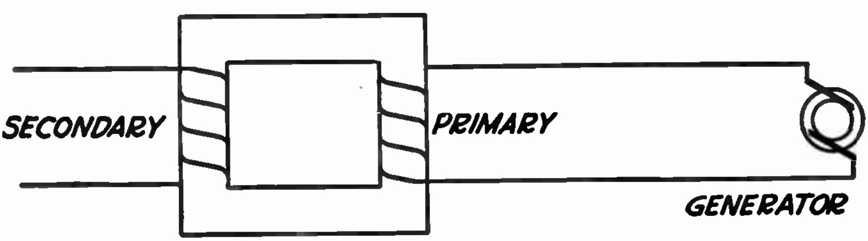
CLOSED CORE TRANSFORMER CONSTRUCTION

Figure M: The transformer illustrated above is called a closed core transformer because its core encompasses a certain area. The portion of the core upon which the secondary and primary are wound is referred to as the legs. For instance, there is the primary leg and the secondary leg. The coils of transformers are carefully insulated from the core to prevent short circuits and in the case of high voltage transformers the various layers of wire have to be insulated from each other so that the voltage will not be able to break down the insulation on the wire.



OPEN CORE TRANSFORMER

Figure N: When both primary and secondary coils of a transformer are wound on a rectangular core as illustrated the device is referred to as an open core transformer. They are less efficient than the closed core types because a continuous magnetic path for the field developed by the primary coil is not available. The cores in these transformers may be either round or square in cross section.



CLOSED CORE TRANSFORMER

Figure L: By providing an iron path between the coils shown in Fig. K the efficiency of the energy transferring system could be greatly improved because of the ease with which iron transmits magnetic lines of force. The side of the transformer connected to the generator is called the primary while the output coil of the transformer is called the secondary.

and ten. In other words, we wish to multiply our voltage by two. This simply means that there will have to be twice as many turns in the secondary as in the primary or a ratio of two to one. If we desired to triple the voltage, the ratio would have to be three to one, etc. We could keep on increasing this ratio between the windings until an electrical pressure of one million volts would be induced in the secondary coil.

It is evident that we cannot increase both the current and the voltage for here again we would be interfering with the law of the conservation of energy. We must not forget that as we increase the voltage and the current we increase the power for voltage times amperage equals watts (there are 746 watts in one horsepower). If we increase the voltage we must reduce the amperage and if we increase the amperage we must reduce the voltage. In other words we cannot get something for nothing.

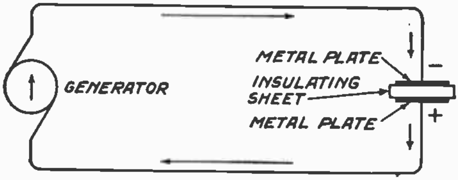
Transformers are used for many purposes in both radio and electricity in general. Perhaps their most important function in the workaday world of electricity is that of boosting voltage for long-distance transmission lines. By using a high pressure, that is a pressure from thirty to one hundred and fifty thousand volts, the line losses are reduced and it is possible to use smaller conductors.

The electric lighting companies all use power transformers for home lighting is distributed to neighborhoods at a rather high pressure. It is then tapped off through the secondary of the transformers and delivered to the consumers.

We also find transformers that reduce the voltage to a very low point by increasing the current far beyond the values used for ordinary purposes. Such transformers are usually called *low pressure transformers* and they are used mostly for welding purposes. Perhaps a secondary output would be in the neighborhood of ten volts but a current of several hundred amperes may be made to flow even with this small pressure if the wire used in the secondary leg of the transformer is very large and but a few turns are employed.

It is well to keep in mind the fact that all transformers are not of precisely the same type. Some of them have open cores and others closed cores. The difference between these two types is illustrated on page 57. In either case the core material must be of suitable iron laminations. A material called silicon steel is used extensively for this purpose.

When we come to the study of alternating current we really come to the parting of the ways for the study of alternating current brings with it numerous phenomena that are not associated with direct current. One of these phenomena is the ability of an alternating current to pass through a solid dielectric material used in electrostatic condensers. To assist our understanding of this peculiar property let us refer to Fig. O, where we see a D.C. generator connected to two metal plates separated by an insulating sheet. In the case of D.C. we may look upon this as an open circuit for there is an insulator interposed between the two terminals of the generator. These two metal plates separated by a sheet of insulation (which may be mica, hard rubber, glass or paraffine paper) constitute an electrostatic condenser and we find that the current of the generator is used for the small fraction of a second in storing electricity in this condenser. However, when D.C. is used the condenser, like a water reservoir, simply becomes filled up and the current from the generator stops flowing, or, in other words, the load is taken off the generator.



CONDENSER AND GENERATOR

Figure O: A direct current generator connected to a condenser will store up a charge on the condenser plates, one side positive and one side negative. The condenser may be discharged by connecting the plates together.

The time required for the generator to charge the condenser depends roughly upon two factors, the size of the condenser and the voltage of the generator.

The simple experiment above may be very beautifully and convincingly demonstrated by the use of a current indicating instrument. Such an instrument placed in the circuit would indicate the flow of a current while the condenser was under charge, but the needle would fall back to zero after its momentary deflection.

If this condenser were placed in an alternating current circuit it would be found that the current would pass through it rather freely, depending upon the design of the condenser and the voltage and frequency of the current. In general it would be found that the lower the frequency the larger the condenser must be for the condenser would be called upon to discharge automatically at the voltage peak of every current reversal. In the case of very, very low voltage and extremely high frequency such as found in radio circuits, the condenser would needs be extremely small so that it could respond rapidly.

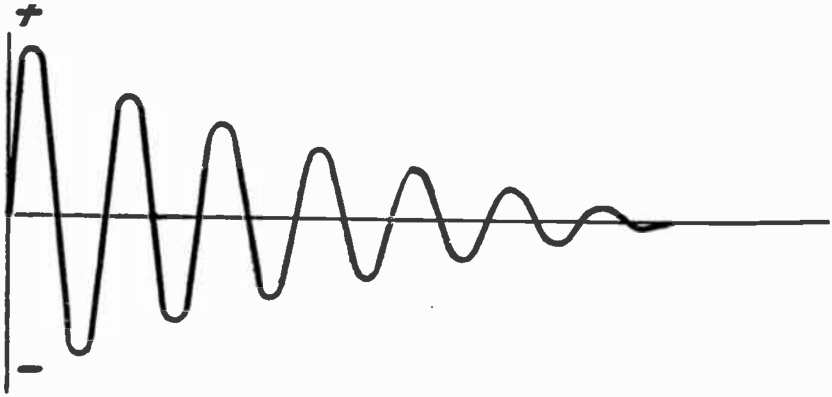
The capacity of condensers to hold electric currents depends largely upon the nature of the dielectric substance (the insulator) and upon the distance the plates are apart. At this point it is well to note, too, that all condensers are not made up of two plates. As a matter of fact, very few condensers are made up of two plates. Most of them have many sets of metal and dielectric plates pressed together in a unit. A condenser having maximum capacity for any given current will be a condenser having a high dielectric material with very small separation between the metal plates. The closer these plates are the greater will be the capacity providing a highly efficient dielectric substance is used. If too thin a dielectric is used, the voltage that charges the condenser may puncture it and render the entire device inoperative.

Air is found to be an exceptionally efficient dielectric material and in figuring the dielectric constants of other materials air is taken as 1. Glass, depending upon its nature and manufacture, ranges from 4 to 10, mica from 4 to 8, hard rubber from 2 to 4, paraffine from 2 to 3 and porcelain from 3 to 4.

We may say in general that there is always an electrostatic capacity between bodies of different electrical potential. In radio we often hear it said that an antenna has a capacity. This is because the antenna is at one potential and the earth at another while the dielectric air is the medium in between. However, for direct current this capacity effect, as it has often been called, can usually be overlooked for it is so rarely met that it does not interfere with operation of any sort.

If a condenser of suitable size were connected to an alternating current generator in the manner in which the condenser was connected to the D.C. generator an indicating instrument in the circuit would betray the presence of a current constantly flowing. The condenser would be charging and discharging in step with the current (providing it was large enough) and the generator would be practically short circuited.

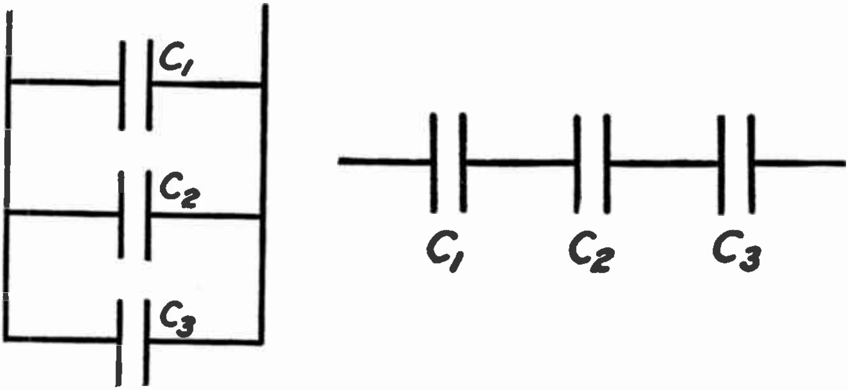
By another very simple experiment it is possible to charge a condenser and to watch it discharge. This may be done with a spark coil or what is known as a Wimhurst machine; a device that is capable of generating high voltage currents by friction. If a Leyden jar (a Leyden jar is a glass bottle covered inside and outside with tinfoil), which is a crude sort of a condenser, is properly connected to either a Wimhurst machine or a spark coil in operation, it will accumulate a very heavy charge of electricity—one side of the glass in the bottle will be at an extremely high potential while the other will be at a low potential. If the experimenter should put one hand in contact with the outer coating of tinfoil and the other hand in contact with the inner coating so that both the coatings would be connected through the body, a terrifying shock would be experienced. If a bent piece of wire attached to a hard rubber handle is brought into contact with two such surfaces, a heavy crashing spark will result as the condenser discharges.



LEYDEN JAR DISCHARGE

Figure P: This is a picture of how the current produced by a discharging Leyden Jar or condenser would look if it could be charted. It starts out with great gusto but rapidly spends its force and tapers off to zero value.

Although this discharging of the Leyden jar was accomplished in the small fraction of a second, many very interesting things happened. There was not simply one mad rush of the current from one surface to the other to level the electrical potential. The original rush of the current was so great as to bring the opposite side of the condenser to a higher voltage than the originally charged surface. This causes a reversal of the current and the process is repeated a number of times before the condenser is really discharged. The action of a discharging Leyden jar is depicted in Fig. P. We see that the current is



CONDENSER CONNECTIONS

Figure Q: Here we see the two principal methods of connecting condensers so that they may be made useful for various purposes. These connections hold true for all types of condensers, Leyden Jars included.

alternating or oscillatory in nature. First the current reaches a high value and then through a long series of reversals it gradually dies out just as one might strike the free end of a spring when the opposite end is held in a vise. The spring would vibrate with gradually decreasing amplitude until it finally came to rest.

This business of condensers may confuse the reader who remembers how emphatic we were in our statement regarding insulators. It was very definitely claimed that insulators would only permit comparatively small amounts of current to pass. We may still regard this as true for direct current but we must make reservations for alternating current, and especially alternating currents of high frequency. This does not mean that alternating current cannot be insulated. It can be but there is always a little loss through this "condenser effect" unless the conductors are widely separated.

As to the actual mechanics of this transfer of energy through insulating materials we can say little. The present theories of dielectric absorption and the like could be included but the introduction of these subjects would probably confuse the lay student who, after all, is more anxious to know the practical side of radio than the purely theoretical side.

It is very important that the student should know the effect of connecting condensers in series and in parallel. It might be thought at first hand that should a number of condensers be connected in series their capacities would be added. This is not the case, however, for three condensers connected in series as illustrated at the right of the sketch on this page would give a total capacity smaller than the capacity of any single member of the group. If it is desired to connect condensers so that their capacity may be added they must be connected in parallel as shown in the Fig. Q. Here total capacity $= C1 + C2 + C3$.

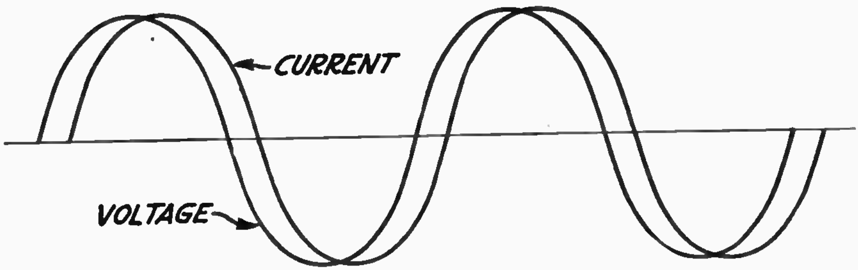
We have been talking about the capacity of condensers without considering the unit used in the measurement of these capacities. Since it was Michael Farraday who conducted most of the first practical research in connection with condensers the unit of capacity was chosen in his honor. It is called the farad. Now a condenser with one farad capacity would be so tremendous as to be quite beyond practical consideration. In other words condensers do not need to be made that large. For that reason a smaller unit is used. This unit is called the microfarad and a condenser of one microfarad capacity has a capacity of 1/1,000,000th that of a condenser with one farad capacity. In other words the microfarad is 1/1,000,000th of a farad. In extreme cases, where infinitesimal capacities are to be calculated, the still smaller unit, the micro-microfarad, is used.

An alternating current passing through a condenser does a very funny thing. Before reaching the condenser the voltage and amperage are travelling hand in hand so to speak. The introduction of a capacity in an alternating current circuit causes the current to lead the voltage. This is illustrated graphically in the sketch where we see the line representing the current leading the line representing the voltage. Exactly the opposite effect would be produced if the condenser were taken from the circuit and replaced with an inductive resistance, or in other words a coil of wire. Alternating currents do not pass through coils of wire in the same way as direct currents. Here the current lags behind the voltage. In either case the lag may be as great as ninety degrees; that is the voltage may be caused to lag behind the current 90 degrees or the current behind the voltage 90 degrees.

Before leaving this subject of condensers, let us keep in mind the fact that condensers have an actual ohmic resistance and that this ohmic resistance is not as high as might be expected simply because the current is called upon to pass through a dielectric material. If a condenser is properly designed with the correct materials used in its construction it may have an ohmic resistance of a fraction of an ohm.

While on the subject of resistance it is well to point out that Ohm's Law cannot be applied to alternating current calculations as it is applied to direct current. Changes in the formula are necessary to account for inductive, capacitative and reactance effects.

We are now ready to take up the subject of electrical measurement through the medium of instruments. While it



ALTERNATING CURRENT LAG

Figure R: When an alternating current is made to pass through a condenser the current is caused to jump ahead of the voltage and the degree of this jump will depend upon the capacity and nature of the condenser. The theoretical limit of this lead is 90 degrees. However, this point has never been reached.

would be possible in many cases to determine the flow of potential through the application of Ohm's Law it is much more practical and convenient to apply a calibrated instrument so that the result may be had without calculation.

The two most used instruments in electrical measurement are the voltmeter and the ammeter. The voltmeter is a device which measures volts and the ammeter is a device which measures amperes and fractions of amperes. It will be seen at the outset that an instrument designed to give readings in connection with direct current circuits could not be so employed in alternating current circuits. We must not forget that in the case of alternating current we have a rapidly fluctuating current rising to amplitude and falling to zero many times during the course of a second. If a direct current instrument were placed in such a circuit the needle would simply vibrate and no indication of the potential or current value would be given. It is necessary to employ a special type of meter on alternating current circuits and therefore we have alternating current and direct current meters.

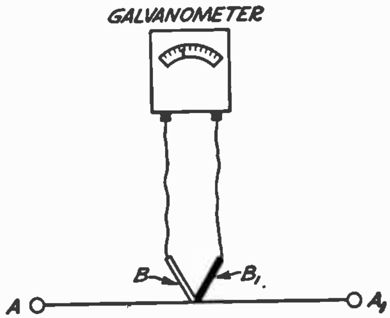
In radio, where we deal with especially small currents, it is necessary to use instruments of a very delicate nature and to measure in very small units. For instance, in radio circuits current is usually measured in millivolts and milliamperes. The prefix "milli" meaning 1/1000th of an ampere or 1/1000th of a volt. In some cases the microvolt or micro-ampere is used as a unit of measurement. This is equal to 1/1,000,000th part of either of the units mentioned.

Early in the nineteenth century it was found that when two dissimilar metals were brought together and heated that a current of electricity was generated. The two metals forming the union make up a unit called a thermo-electric battery or thermo-electric generator. This very principle is used a great deal in measuring radio currents. In Fig. S we see the method used. An extremely small wire is connected between points A and A1. Two dissimilar metals, B and B1, are brought into junction with the fine wire and the metals are connected to the terminals of a very sensitive galvanometer. The wire between the points A and A1 is so fine that a very weak electrical current will cause it to heat and while this heat may not be perceptible it nevertheless raises the temperature of the thermo-electrical juncture and develops a current in the circuit containing the galvanometer. The current in this circuit will be in exact proportion to the amount of heat developed in the wire, which, on the other hand, depends entirely upon the amount of current.

The most superficial layman would understand that either a direct current or an alternating current may be used with an instrument operating on the thermoelectric principle. In either case heat will be developed through the passage of the current. The heat due to a given number of amperes of alternating current is the same as that of an equal number of amperes of direct current.

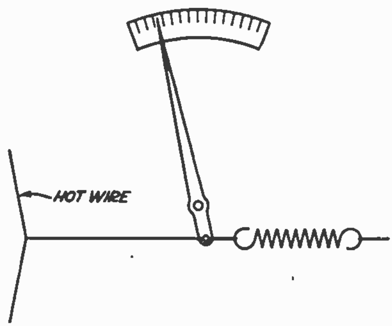
There still is another method of measuring currents of any frequency by the application of the heated wire. A very fine wire is stretched between two points and connected to a pointer of very delicate construction. The passage of the current through the wire causes more or less heating which is indicated in current strength upon the hand calibrated scale (See Fig. T).

While instruments like the above are used a great deal in measuring currents of radio frequency, magnetically con-



THERMO-GALVANOMETER

Figure S: Here we see a thermo-couple made up by the metals B and B1 connected to a galvanometer. The current passing from A to A heats the couple and causes a second current to be generated.



HOT-WIRE AMMETER CONNECTION

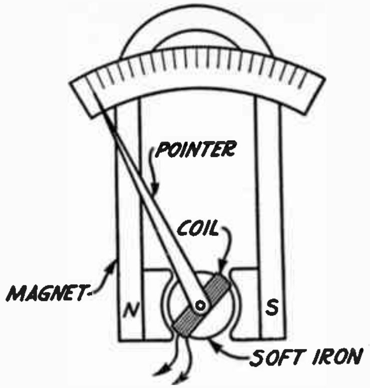
Figure T: When a current passes through the hot wire the wire expands causing the spring to move the needle over the scale of the instrument. The amount of expansion depends upon the strength of the current.

trolled instruments are still widely used and if we refer to Fig. U we will be able to readily determine the principle used in what is known as d'Arsonval meters. A tiny coil of wire is delicately pivoted between the poles of a powerful steel magnet. The needle (which is connected to the coil) and the coil are held in a normal zero or no current position by the action of a small hair spring similar to that found in watches. Very flexible lead wires are brought from the tiny coil and connected to the terminal poles of the instrument. When the instrument is brought into contact with a source of current through its terminals, part of this current will flow through the tiny coil and naturally will set up a magnetic field about it. This field will cause the coil to have a tendency to align itself with the field already existing between the north and south pole of the permanent magnet. The degree to which it succeeds in this depends upon the voltage of the circuit.

The circular piece of iron placed in the center of the moving coil and between the north and south pole of the permanent magnet is used to form a low resistance path for the magnetic lines of force. The interposition of this greatly increases the efficiency of instruments of this type.

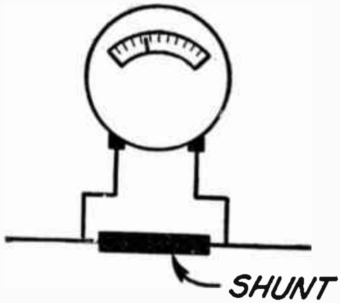
It will be understood that the moving coil for d'Arsonval instruments may be made for practically any sensitivity providing the active parts are sufficiently delicate. Instrument makers have developed amazing ingenuity in the application of this absorbing principle and instruments capable of registering in microvolts and microamperes are not at all uncommon. The moving parts have been refined to such an extent that fifty microamperes are sufficient to cause the indicator to move over a rather large scale. Even a single ampere is a relatively small amount of current and when we divide it into a million parts we have left but an unimaginable whiff of energy.

We said that our last instrument had a moving coil made up of a fairly large number of turns of very small wire. Such an instrument is used to measure voltage and is very properly called a voltmeter. While the same type of instrument is used in constructing ammeters the resistance of the coil must be low. It is evident that to keep the re-



D'ARSONVAL INSTRUMENT

Figure U: Here is shown the principle of all D'Arsonval instruments, which consists of a current carrying coil balanced in a strong magnetic field. The coil is mounted upon delicate bearings and tends to rotate when a current passes through it. D'Arsonval instruments are widely employed.



HEAVY CURRENT MEASUREMENT

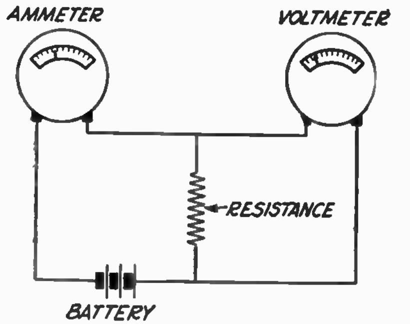
Figure V: By providing a specially calibrated ammeter with a heavy shunt thousands of amperes can be measured with safety to the instrument. Only a small fraction of the current is allowed to pass through but this is in proportion to the amount of current passing through the shunt.

sistance of this coil low will ultimately result in making the moving parts heavy and unwieldy. Low resistance means large wire and large wire means greater weight. Hence the smaller ammeters are made only for the measurement of small currents. When large currents are to be measured, ammeters are provided with what is known as a shunt which is illustrated. This shunt is usually made of a number of strips of special alloy large enough to safely carry the current. Upon reaching this point, the current divides most of it going through the shunt while a small portion of it flows through the meter. Since the resistance of the shunt is known. the amount of current flowing through the ammeter can be used as a basis for calculating the current flowing in the main circuit. Therefore, the scale of the ammeter can be used to register the actual number of amperes flowing through the circuit containing the shunt.

Many radio experimenters during their most inquisitive days have had the sad experience of attempting to learn the condition of their storage battery with an ammeter of the pocket type. To their surprise the ammeter was probably burned out for when such an instrument is placed across the terminals of a storage battery the battery is practically short circuited. The resistance of an ammeter is very low and probably as many as 40 or 50 amperes might flow through it from the battery heating and destroying the device to a point beyond repair.

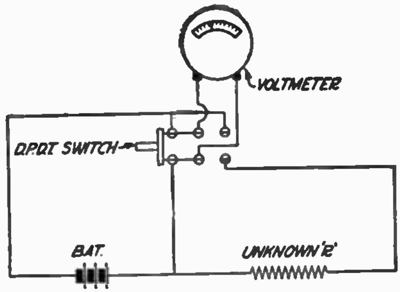
A voltmeter may be connected across the terminals of a storage battery with absolute safety for here we have an instrument with a high resistance capable of choking off a damaging supply of current.

In Fig. W we find that voltmeters and ammeters are connected to circuits in different ways. One is usually in series and the other in multiple. By connecting two instruments up in this fashion the current and voltage of a



CURRENT AND VOLTAGE MEASUREMENT

Figure W: This shows how a voltmeter and ammeter would be connected to measure the current and voltage of a simple battery circuit. It will be noticed that the instruments are connected differently.



RESISTANCE MEASUREMENT

Figure X: Here is shown a method of measuring the resistance by the drop method. By determining the degree of voltage drop across R and knowing the other factors it is possible to calculate the resistance of R.

circuit may be registered simultaneously.

We must not think that the types of instrument described represent the whole range of current indicating devices. There are innumerable different types and designs, but those which we picked for description are used almost entirely for radio calculations.

By the proper use of a simple voltmeter and ammeter fairly accurate calculations in resistance can be made. In the sketch we see the connections necessary for what is known as the drop method of calculating resistance. Only a voltmeter is necessary for this test. This is connected to a two-way switch which permits the meter to first be thrown across a known resistance. This permits the voltage drop across the known resistance to be measured. The meter is then connected across the unknown resistance and the voltage drop is again measured. We then have:

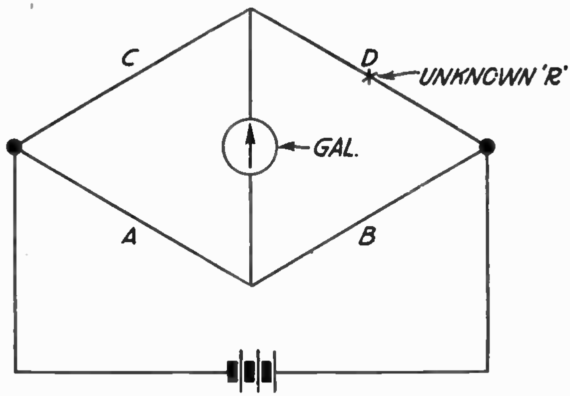
$$\frac{\text{drop across known resistance}}{\text{drop across unknown resistance}} = \frac{\text{known resistance}}{\text{unknown resistance}}$$

from which we obtain unknown resistance =

$$\frac{\text{known resistance} \times \text{drop across unknown}}{\text{drop across known resistance}}$$

There is a more accurate method of measuring resistance by the aid of a device called a Wheatstone bridge. If Fig. Y is studied it will expose the underlying principle involved. There are four arms to the bridge, A, B, C and D. Current flows through all four from a battery and the voltage of this battery is immaterial so long as it is capable of forcing a current through the arms. Arms C, A and B are made up of variable resistances carefully calculated so that the resistance of these parts of the bridge is known at all times. The unknown or X resistance is connected to the arm D. When this is done the resistance in arms A, C and B are adjusted until zero current flows through the galvanometer. The galvanometer will then come to a normal position of rest. If it is found that A and C have 20 ohms and 200 ohms respectively B will be 30 ohms and D will be 30 × 200 ÷ 20 = 300 ohms.

Before leaving this subject of pure



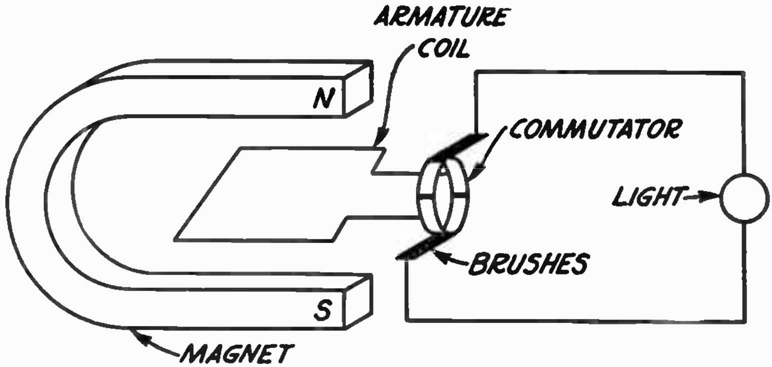
CONNECTIONS OF THE WHEATSTONE BRIDGE

Figure Y: Although many important electrical calculations can be made with a Wheatstone Bridge the connections of the device itself are comparatively simple. The "arms" A, B and C are made of variable resistances. They are shown as mere straight lines here as a matter of convenience.

electricity it will be well to gather in a few simple facts concerning the electro-dynamic generation of current. Reference to Fig. Z will aid greatly in understanding the simple principles involved in the production of direct current. Here we have a permanent magnet which, as we already know, is capable of developing a magnetic field about its poles. From the simple experiments described previously it was also shown that the movement of a coil of wire through a magnetic field so that the coil cuts the lines of force resulted in the setting up of a current. If a coil of wire is wound upon a shaft and revolved between the poles of a magnet as shown, there will be generated in the coil a current of electricity. This current is led off for use by a device known as a commutator. This is really a rotating connector making contact with stationary parts called brushes. The brushes are the real terminals of the generator and they are connected to the outer circuit.

The revolving coil in a generator of this type is referred to as an armature. The magnet in this case would be called the field magnet since it is depended upon to produce the magnetic field through which the armature rotates.

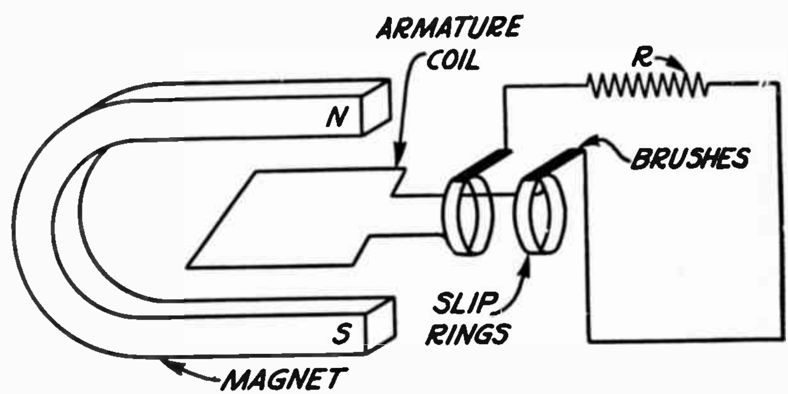
A little thought will make it evident that the voltage and amperage of this little generator that we have sketched depends upon (1) the strength or density of the magnetic field between the poles, (2) size and number of turns of wire of the armature, and (3) speed with which the armature revolves. If the armature is wound with extremely fine wire and revolved at high speed so that it cuts through a large number of lines of force in a second there will be available at the terminals of the generator a very high pressure or voltage. If, instead of a large number of turns of fine wire, there is placed upon the armature a small number of turns of very coarse wire we will have instead of a high voltage a high amperage and a low voltage. Thus it is seen that the output of the generators may be controlled to a nicety by the application of these well investigated rules of design.



D. C. DYNAMO PRINCIPLE

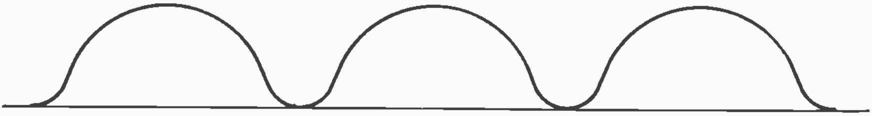
Figure Z: It will be seen that a D. C. dynamo is nothing more or less than a coil of wire moving in a magnetic field with means provided for leading the current away from the moving coil with sliding contacts.

The generator that we have shown is of the simplest type imaginable. The application of the bare permanent magnet is made practically only in the case of magnetos used on ignition systems of automobiles. Larger and more efficient current generators are always provided with what is known as a field winding. Generators with field windings do not have permanent magnets. In place of permanent magnets, soft iron is used and the field windings are placed over this iron mass. It is the function of the field winding to take a small portion of the current from the terminals of the generator to build up the magnetic field. While it is true that iron loses practically all of its magnetism when the exciting source is withdrawn there is always enough residual magnetism



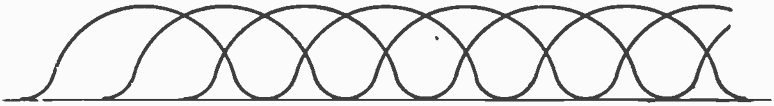
A. C. GENERATOR PRINCIPLE

Figure AA: The principle involved here is the same as that in the dynamo in Fig. Z save that the commutator arrangement is different. By employing two rings as shown the current produced by the moving coil is caused to zigzag back and forth in its circuit.



PICTURE OF A DIRECT CURRENT

Figure BB: This shows how a direct current would look with a single coil and a simple two piece armature.



A DIFFERENT DIRECT CURRENT

Figure CC: This shows how the current would look when produced by a three-coil D. C. armature.

left in the iron field to permit the generator to build up when power is applied to its armature.

We must not make the mistake of taking the above as an accurate description of all of the direct current generators used. There are several different types and a profusion of different designs. For instance, commutators of all but the simplest types are made up of a number of copper segments in place of the two shown in our sketch and instead of one independent coil there is a number of coils connected to the segments.

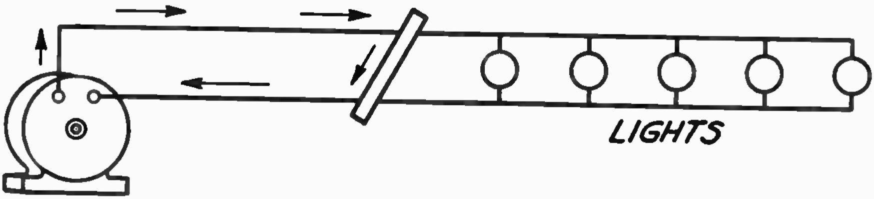
We have just completed a discussion concerning direct current generators, that is, generators that are capable of producing direct current. However, they do not produce direct current in the sense of a dry battery. That is, the current produced, although it is in the same general direction, is not of uniform value. It will be seen that every time the brushes come to a break between the segments there will be an interruption. In the case of a simple two-pole generator the current produced at the poles if charted would appear as shown in Fig. BB. The current does not change its polarity but it falls back to zero in each revolution. By increasing the number of coils in the armature and the number of segments and by providing the field with a pole to match each coil we produce a current or a series of currents that take the form shown in Fig. CC. The tendency of each generator is to build a fairly uniform current. The little variations are known as ripples and for all ordinary purposes the current may be looked upon as uniform.

If we wished to change our first simple direct current generator into an alternating current generator it would only be necessary to alter one part. That would be the commutator. In place of a two segment commutator we would use two independent metal rings each one attached to one terminal of the armature coil. The brushes would make contact with these rings. Under such conditions there would be two complete reversals of the current at every revolution of the armature. We see, then, that the frequency of such a generator would depend not alone upon the speed of the armature but upon the number of coils in the armature and upon the number of poles in the field of the generator. By providing the generator with two field coils and four poles the frequency would be doubled at the same speed.

Aside from the facts just mentioned,

alternating current generators operate on the same principle as direct current generators; currents are produced with armature coils that cut through magnetic fields.

The amount of current generated by either a direct current or alternating current producer depends to a certain extent upon the load in the external circuit. If the external circuit is opened was thrown across it. This will permit an exceptionally heavy current to be built up in the generator and a tremendous load will be thrown on the whole system. If no provision has been made for such an emergency either the wire comprising the external circuit will melt through at the excessive passage of current or the windings in the armature of the generator will be burned out.



WHAT A SHORT CIRCUIT MEANS

Figure DD: When the path of an electric current is shortened as it would be in the sketch, the current always increases because of the shortened path and what is known as a short circuit is developed.

and there is no current flowing in it there will be no load on the generator and, save for mechanical friction, no resistance will need to be overcome in turning the armature. With such conditions prevailing the generator would be said to be running idle. When the external circuit is closed current is immediately induced in the armature and there is set up in it a magnetic field opposing the original magnetic field developed by the field coils. The amount of opposition will be determined by the amount of current flowing in the armature coils and this in turn depends upon the size of the wire and the amount of current that is required by the devices in the external circuit. Let us imagine that a heavy conductor is thrown across the external circuit of the generator as illustrated. Since nature has decreed that electricity will always follow the path of least resistance, it is evident that the current flowing will avoid the part of the circuit beyond the point where the conductor

To prevent such dangerous accidents, which, in the case of large power houses, might run into as much as $100,000, circuit breakers or fuses are used as a protection to the circuits and generators and also as a protection against fires, for a heavy current on the rampage is a prolific producer of fire. In the case of circuits carrying only a few hundred volts fuses are employed. A fuse is nothing more or less than a strip of metal made up of a low melting alloy. Lead is the basis of it. This little strip of metal is designed to have a definite current carrying capacity. When this capacity is overstepped through a short circuit or through the action of a device requiring too much current for the safety of the circuit, the excessive current heats up the alloy instantly and causes it to melt or "blow." The melting of the alloy, of course, interrupts the circuit and it is left "open" until a fresh fuse is inserted.

The circuit breaker, which is used for heavy currents where fuses would be impractical, operates upon an electromagnetic principle. A movable contact element is placed before the poles of two heavy electromagnets. These magnets carry the current that is passing through the circuit. The moving part of the breaker is provided with contacts that are normally closed. However, when the current becomes too strong the magnets exert a greater force upon the movable element and it is eventually drawn down opening the circuit as it moves.

We have, in this portion of the course, gained a fairly comprehensive idea of the romantic side of electricity. The laws and effects that we have studied and assiduously absorbed are extremely pertinent to the subject of radio for after all radio is a mere subdivision of electricity. All of the laws of electricity hold true in radio and for this reason it is always necessary for the student to gain at least a superficial knowledge of practical electricity before he ventures further into the still more fascinating realm of radio.

The ambitious student must be warned against passing on to what follows without first having assured himself that he is familiar with the electrical principles outlined.

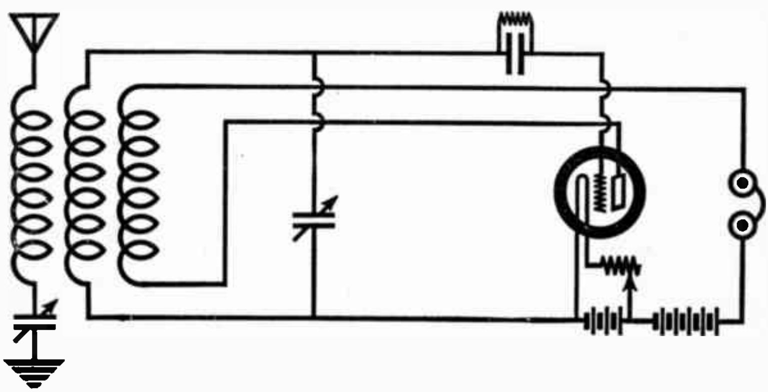
END OF SECTION II

SECTION III

Diagrams—The Shorthand of Radio

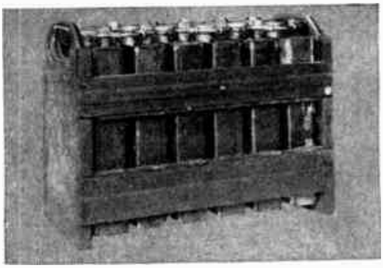
As in chemistry, the radio man has a shorthand method of expression which he uses in sketching out circuit connections. In place of depicting the constructional details of transformers, sockets, coils and the like, symbolic characters that have been agreed upon by the profession are used. The reader will not only find that an understanding of the symbols used will be of great convenience to him in practical work, but that few articles pertaining to radio can be intelligently assimilated without a mastery of radio shorthand. Since the editors of the present instruction believed that the student should be led into the practical phases of the study as soon as possible, it was decided to insert this matter here. This will permit the use of standard diagrams throughout the remainder of the course.

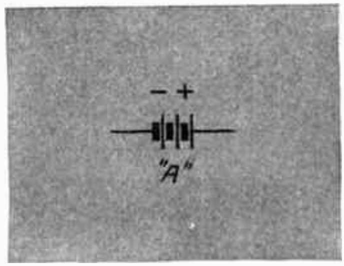
After a little practice the student will find the symbol method of diagram printing a most convenient help in his work of radio experimentation or in keeping abreast with radio progress by constant perusal of the current publications. As time goes on he will find himself capable of absorbing the electrical details of any circuit presented in this fashion by a mere glance at the instruments shown and their position. It will also be found very easy to use these symbols in preparing notes on the subject of radio. Radio diagram symbols are practically standard.



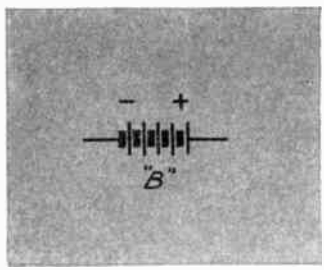
DO YOU KNOW WHAT THE ABOVE SYMBOLS MEAN?

Unless you do, you cannot understand the practical and useful hook-up drawings that constitute such a valuable part of this course.

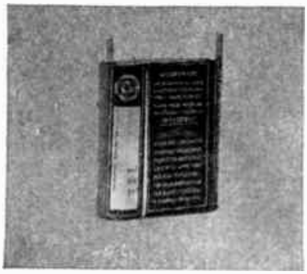


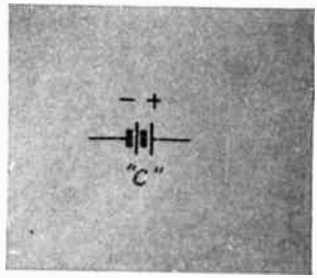


"A" Battery—Until recently the "A" or filament-lighting battery was almost universally of the storage type. It may be well to note here that the UV-201-a tube is primarily a storage-battery tube, and that it is not economical to operate more than one of these tubes on dry cells. However, the use of tubes, such as the UV-199 and WD-11, which operate on an "A" battery made up of dry cells, has increased materially in the last year or two. Although made up of several cells, the "A" battery has two main terminals which connect to the filament of the tube; one of these is positive and the other negative. Make sure that the voltage at these terminals is correct for the tubes you are using, and also that the "A" battery is capable of furnishing current for the number of tubes which you intend to use. Three WD-11 tubes should have three dry cells connected in parallel, for instance. One dry cell would have the same voltage but it could not furnish current for three tubes economically. By using three cells in parallel the current is divided between the three.

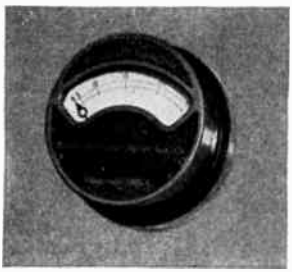


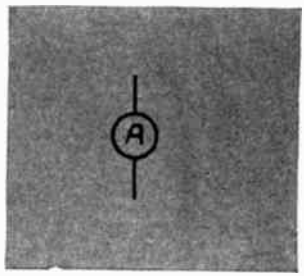
"B" Battery—The "B" battery is made up of a number of "flashlight" cells connected in series and sealed together in a convenient container, there being fifteen of the cells in the 22½-volt size and a correspondingly larger number in the higher-voltage batteries. The large-type "B" battery will prove more economical for a permanent set, while the smaller sizes have their points of advantage for portable sets. The detector battery is usually a 22½-volt, tapped type which gives any voltage in steps of 1½ volts from 16½ to 22½ volts for soft detector tubes which are critical to plate voltage. The amplifier "B" battery can be conveniently made up of 22½ or 45-volt blocks connected up in series to give the required voltage. The battery made up in this manner will have two outside or unconnected terminals, one positive and one negative, and these will form the connections to the set.





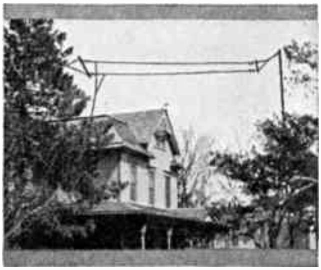
"C" BATTERY—With more than 67½ volts on the plate of the average tube it is advisable to connect a "C" battery in the grid circuit to bring the potential of the grid to the correct negative point with respect to the filament. Small flashlight cells of 3 to 4½ volts make good "C" batteries and are easy to obtain. To connect a "C" battery in an amplifying circuit, break the grid lead between the amplifying transformer and the filament, and connect the ends to the two terminals of the "C" battery, the negative side of the latter should be toward the transformer and grid. Another advantage of the "C" battery is that it cuts down the average plate current greatly and makes the "B" battery last much longer. There is very little current drain on the battery.

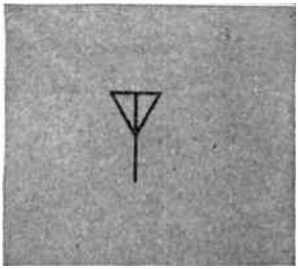




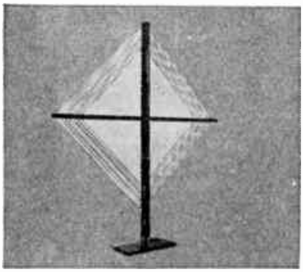
AMMETER—The ammeter is a device for measuring the current flowing in some particular circuit; for instance, it could be placed in the filament circuit of a vacuum tube to see how many amperes were being drawn from the storage battery. An instrument for smaller current values (the milliammeter) could be connected in the plate circuit of the vacuum tube to see how many thousandths of an ampere were being drawn from the "B" battery. An ammeter never measures how many amperes there are in the battery, but it does measure the number of amperes that some other instrument is drawing from the battery or whatever source of power we may have. The ammeter has two terminals and is always connected in series in the circuit; that is, one of the wires of the circuit is broken and the two resultant ends are connected to the two terminals of the ammeter.

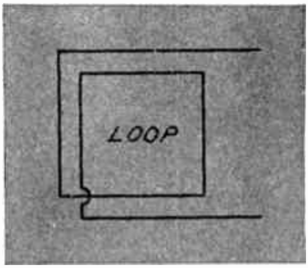
It is not unusual to see ammeters sketched in diagrams with shunts across their terminals. Shunts are used when exceptionally heavy currents are to be measured and they are usually depicted by an oblong which represents a solid piece of copper.





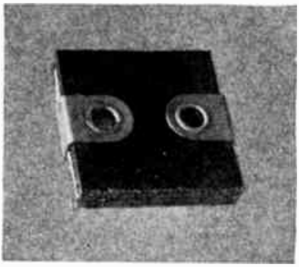
ANTENNA—The most common type of antenna (and one that gives universal satisfaction for receiving) is the single-wire "L" type, approximately 100 feet long. It is insulated at each end, preferably with a glazed porcelain antenna insulator, and the lead-in to the receiving set is taken off at one end. Number 14 seven-strand bare copper wire is most suitable for antenna wire because of its larger surface and greater strength than the solid wire of the same gauge. For transmitting, four parallel wires are often used to give greater radiating area; a wire joined to each of these is in turn connected to the single lead-in. As the multiple lead-ins always are joined to one common wire we may regard the antenna as having a single connection and thus it is shown in the diagrams.

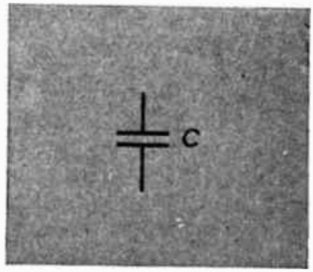




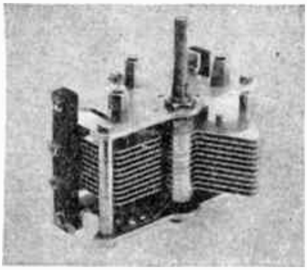
LOOP ANTENNA—The regulation outdoor antenna always gives reception over greater distances and also louder signals than the loop on the same receiving set. However, circumstances may make the use of a loop necessary; in this case the amplification will have to be increased considerably over what would be necessary with the outdoor antenna. Two or three stages of radio-frequency amplification will be required in addition to the customary detector and two stages of audio-frequency amplification. Do not attempt to use a loop on the ordinary three-bulb regenerative set. For broadcast reception the loop antenna may consist of twelve turns of No. 18 wire wound in a square, two feet on a side, the turns being separated one-half inch. The loop antenna has two connections, although one of these may be arranged so that it can be cut in on different turns.

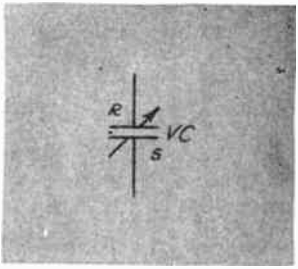
Although numerous methods showing loops are employed by technicians, the form taken will usually approximate the one shown. The number of turns may vary, some engineers using but a single turn of wire, but there will always be a representative feature that will enable the reader to recognize the instrument.





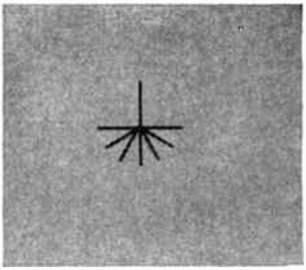
Fixed Condenser—The most satisfactory type of fixed condenser for receiving sets, and one that is comparatively inexpensive, is the small mica condenser of reliable make. As the amount of energy handled is extremely small, it is not advisable to use home-made condensers of doubtful quality. One of these small condensers of .00025 or .0005 mfd. capacity can often be connected in series with the antenna to cut down the wavelength if necessary. In places where some loss does not matter and where the cost of a mica condenser of such large size would be prohibitive, such as the filter condensers for transmitting sets, paper condensers are often used. The fixed condenser has fundamentally two metal surfaces which are separated by an insulating sheet, although the metal surfaces may be made up of a large number of sheets. There are two connections, one to each of the metal surfaces.



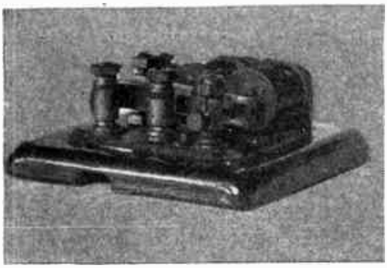


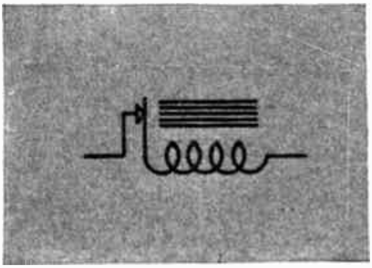
Variable Condenser—The variable air condenser has become fairly well standardized in form; it consists of a number of stationary plates, closely spaced and connected together, and approximately the same number of rotary plates which are also connected together and which mesh between but do not touch the stationary plates. The condenser has two connections, one to the stationary plates and one to the rotary plates. Always connect the rotary plates to the part of the circuit which is nearest the ground potential to avoid "body-capacity" effects. The condenser should be well made *mechanically* and *electrically;* the bearings should fit well and preferably be of metal; and the stator and rotor should be separated by a good insulating material to avoid excessive dielectric loss.

This method of showing a variable condenser is practically standard. Sometimes one of the lines that is shown parallel here is curved slightly to represent the movable plates. This, however, should not confuse the reader who knows the general symbol.



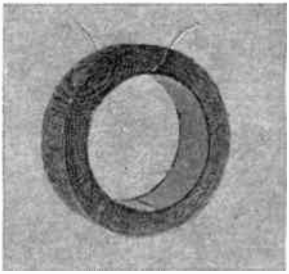
Counterpoise—When a ground connection is impossible or when a natural ground gives too high a wavelength on our transmitting set, we fall back on the counterpoise; this is placed below the antenna and far enough above ground to clear obstructions. The counterpoise may take the form of the antenna or it may be spread out fan shape. At any rate it should be well insulated just the same as an antenna; otherwise, if it should be grounded (even poorly) at some point, we defeat the purpose of the counterpoise which is to give a uniform electric stress over its entire area much the same as the stress between condenser plates. The wires of the counterpoise should be all connected and soldered together to form a single lead-in to the transmitting or receiving set. The form and size taken by any counterpoise will depend somewhat upon the space available for it. In any case, it is always indicated as illustrated,

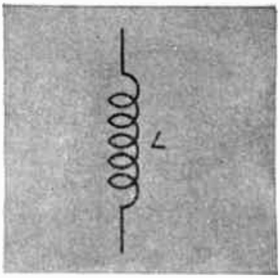




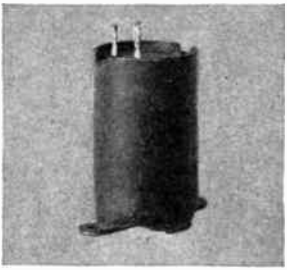
Buzzer—The chief uses of the buzzer in radio are for code practice and for testing out crystal detectors to find a sensitive spot. The buzzer for either of these purposes should (preferably) be one of the special high-frequency type. The note of an ordinary call buzzer is much too low. For code practice a buzzer, battery (dry cell) and a key are simply connected in series. For testing crystal-detector adjustment, a buzzer, battery, and a key or push button are connected as above. and in addition a wire is connected. from the binding post nearest the buzzer interrupter, to the ground lead of the receiving set.

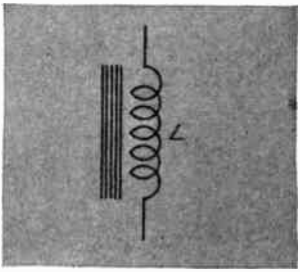
Sometimes buzzers are shown with one electromagnet and sometimes with two. However, this is not technically important for a buzzer with one electromagnet functions in exactly the same way as a buzzer with two magnets. It will be noticed that the wiring diagram of the buzzer itself is shown. This may be done because of the simplicity of the circuit used in such instruments.





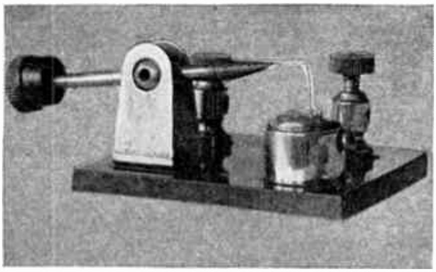
RADIO-FREQUENCY CHOKE COIL—The uses of the radio-frequency choke coil are very similar to the audio-frequency choke coil except that it is constructed to operate at much higher frequencies and is therefore generally made with an air core. The coil shown in the illustration is an ordinary honeycomb coil, which type is usually satisfactory for radio-frequency choke-coil purposes. The radio-frequency choke consists of a single winding and has one connection at each end. Such a coil may bo used in a low-power vacuum-tube transmitting set as a radio-frequency choke in the grid-leak circuit or in the plate circuit to keep the high-frequency energy from getting back into the power supply. These coils find many uses,

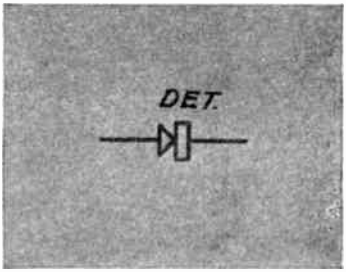




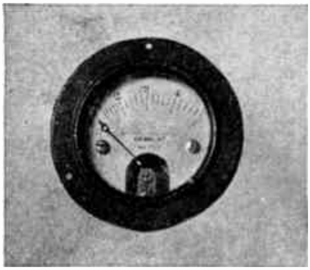
AUDIO-FREQUENCY CHOKE COIL—The audio-frequency choke coil consists of an iron core with a continuous winding, and has two connections, one to each end of the winding. The choke coil has a tendency to smooth out variations in current as its magnetic field opposes all changes in the current. An example of this use is to steady the plate current of a transmitting tube by connecting one or more choke coils in series with the rectified supply. There is always a drop in voltage across a choke coil and this is used in choke-coil-coupled amplifiers. The choke coil is connected in the plate circuit of one tube and the drop across it used to operate the succeeding tube in the next stage of amplification.

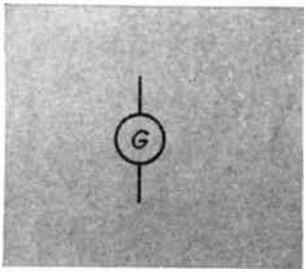
Sometimes audio-frequency choke coils are constructed so as to be variable by taps. When they are arranged in this manner diagrams usually give some indication of the variable feature. When the coil is shown without taps it is usually taken to mean that the inductance is of fixed value. Such coils are also used as A. C. chokes.





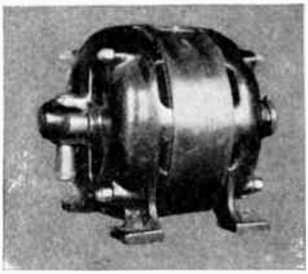
CRYSTAL DETECTOR—The crystal detector generally takes the form of a fine wire or "cat-whisker" pressing lightly on some kind of mineral crystal; the common minerals are galena, silicon, pyrites, carborundum or one of the synthetic crystals. Within 15 to 25 miles of the large broadcasting stations the crystal set will give good, clear reception on the telephones; a loudspeaker cannot be used with a crystal set. In selecting a crystal detector see that it is so constructed mechanically that the entire surface of the crystal can be easily explored with the "catwhisker." There are two connections to the crystal detector, one to the "catwhisker" and one to the cup which holds the mineral.

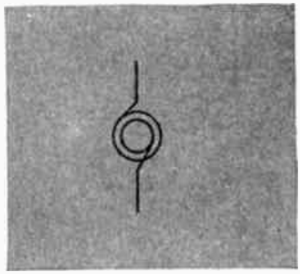




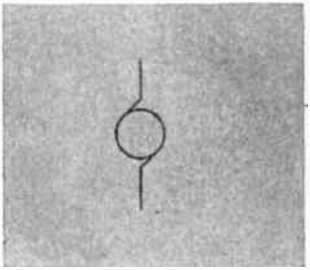
GALVANOMETER—The galvanometer is a delicate instrument for indicating a small electric current, but is not used for measuring current. That is, it may be used to show when the current is minimum or maximum, but not the exact value of it. The galvanometer is useful in bridge-measurement work where it is necessary to compare unknown values of resistance, inductance or capacity with standards of the same. It can also be used for wavemeter work in radio. The galvanometer has two connecting terminals and there will always be shown two wires running to it in any circuit diagram.

In the case of the galvanometer we will also find that other writers prefer to show it diagramatically in different styles and while it will be standardized throughout this course we cannot always expect to find it illustrated in this fashion outside this work. However, galvanometers are frequently identified by the letter "G" which is usually placed inside the circle.



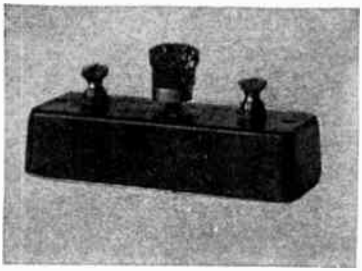


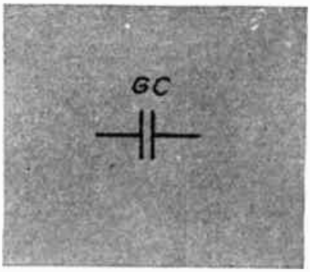
A.C. Generator or Motor—The A.C. generator finds little use in radio work except in spark transmitters but the motor is often used as a source of power for motor-generator sets when the local electric supply is alternating current. The A.C. generator or motor frequently has three terminals in the larger sizes as three-phase distribution of power is more satisfactory than single phase. The single phase motor is not inherently a self-starting device, and must have some sort of starting mechanism incorporated within it; on the other hand the three-phase motor *is* self-starting and is much more rugged. The single-phase motor has two terminals brought out to binding posts. Alternating and direct current motors are never employed in receiving sets. It is only in the diagrams of transmitters that we find the symbols used.



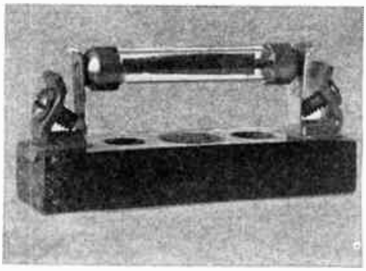
D.C. Generator or Motor—The D.C. generator is used in radio work to produce the high-voltage plate supply for the better class of transmitters. It also finds a use in stepping the voltage down for battery charging. The D.C. motor is used for power in the motor-generator set, for driving spark gaps, etc., when the local electric supply is direct current. There will usually be two connections for the generator and also two connections for the motor unless the latter is so powerful that it requires some sort of starting mechanism. The local electric company will have its own regulations about the sizes of motors requiring starters. The motor itself will have two external connections or terminals.

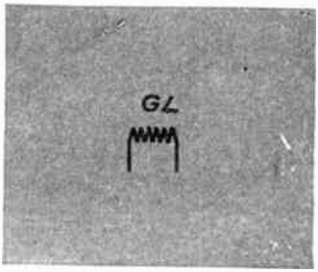
Since every direct current motor functions as a generator if it is turned mechanically by a gas engine or another electric motor there is no distinguishing mark between direct current motors and direct current generators in diagrams. Sometimes when a generator is shown it is so marked but when the motor is pictured no indication is made.





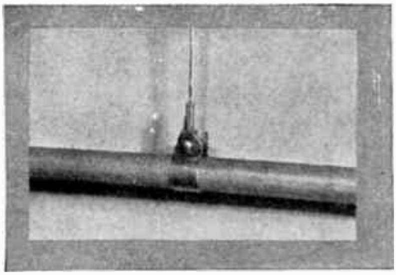
Grid Condenser—For the purpose of detection we must operate the tube at the knee of the "characteristic curve" by the use of a "C" battery or resort to the grid condenser, which isolates the grid and allows the negative charge on it to build up through several cycles instead of changing to positive at each half cycle as it would normally do. The grid-condenser method of detection is used in most receiving sets and the common value of the grid condenser is .00025 mfd. One of the small mica fixed condensers is just as good as something more expensive. However, do not try to economize by using a paper condenser at this point. The grid condenser has two leads.

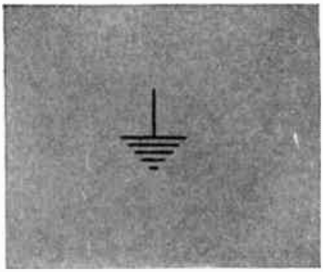




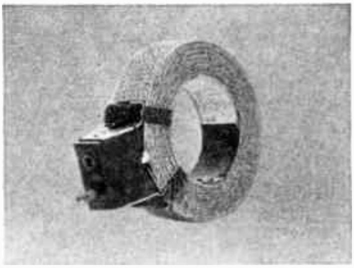
Grid Leak—With the grid-condenser method of detection some means must be provided to allow the negative charge on the grid of the tube to *leak off gradually;* otherwise the charge would build up until the tube was paralyzed. For this purpose a high-resistance path called the grid leak is connected between the grid and the filament; the value of the grid leak runs into the millions of ohms, 2 megohms (2,000,000 ohms) being a common value. While there may be some advantage in a variable grid leak, it is so difficult to find a good one, that the tubular type is perhaps the safest one to use. There are two connections to the grid leak, one to each end of the resistance unit.

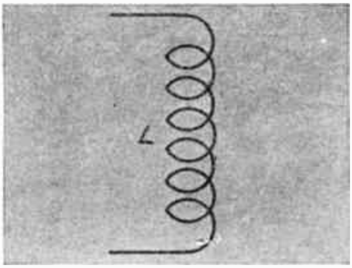
While there are many different types of variable grid leaks on the market, as yet technicians have not decided to indicate this variable feature in a diagramatic way. This is probably because the grid leak once adjusted for any particular tube does not need to be touched again for some time. Adjustments are so few and far between that it is practical to show all grid leaks as being fixed in both electrical and mechanical form.





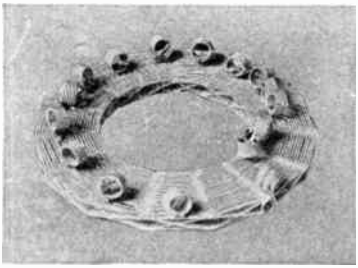
GROUND—Fortunately a good ground *is* available to most of us; the solution of this important problem is the ordinary water-piping system of the house. The ground wire may be soldered to a brass fitting, or one of the faucets, or it may be connected directly to the pipe itself by means of a ground clamp. The pipe should be brightened up with a file before connecting the ground clamp. If a ready-made ground is not at hand, a galvanized pipe driven in moist earth or a buried copper sheet is the best substitute. There is a single lead to the ground connection and the size of this should not be smaller than No. 14 copper wire. A low-resistance wire must be used. Ground wires should also be heavily insutated when used outside the house.

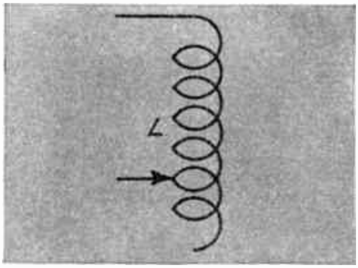




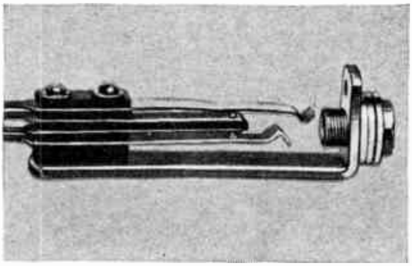
FIXED INDUCTANCE—The fixed inductance or coil is a continuous winding with two connections, one at the beginning and one at the end. It may take the form of the single-layer coil, bank-wound coil, spiderweb coil, honeycomb coil, etc. The purpose of the various forms of winding is to decrease the distributed capacity of the coil; such inherent capacity acts much the same as a fixed condenser across the coil and this gives the system a natural wavelength, which is an undesirable condition since we usually wish to control the wavelength by means of a variable condenser connected across the coil. The honeycomb coil is especially useful for receiving the long wavelengths, while the other forms of winding are more widely employed on the short and medium wavelengths.

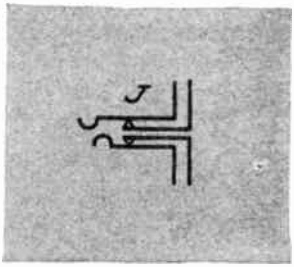
Some radio technicians prefer to show inductances as they are wound upon tubes, that is, showing the tube with characteristic lines over it to represent the wire. This is a laborious process in diagram making and it does not tell the layman any more than the simple loops shown in this particular diagram. The above is standard practice.





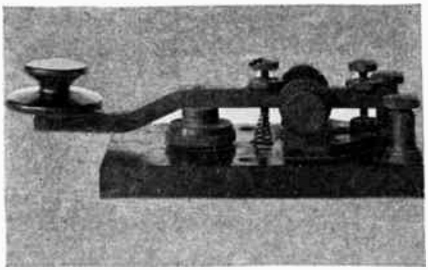
Variable Inductance—The variable inductance is merely a coil with provisions for using a part of the whole of it. There are two fundamental connections; one usually goes to the end of the coil and the other to a slider, clip, or inductance switch. If an inductance switch is used, taps are taken off the coil five to ten turns apart and connected to switch points. A switch arm makes contact with any one of these points, thus cutting in more or less of the coil. Sometimes two switches are provided at opposite ends of the coil, one for *tens of turns* and one for *single turns*. Then the two fundamental connections are to the two switch arms. The old two-slide tuning coil was a little different, in that it had one fixed connection at the end, and *also* two sliders, one for the primary circuit and one for varying the inductance included in the secondary circuit.

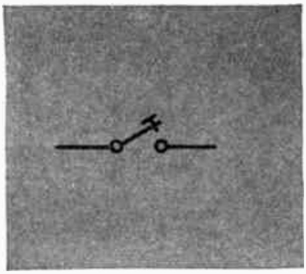




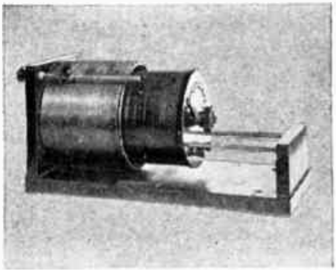
Telephone Jack—The telephone jack gives us a means of using either the detector, or one or more stages of amplification at will. The ordinary jack for all but the last stage of amplification has four terminals; the two outside terminals are connected in series in the plate circuit of the preceding tube, that is, one to the "B" battery positive and one to the plate of the tube; the two inside terminals are connected to the primary of the following amplifying transformer. When the plug is not inserted in the jack, the plate wire should make contact with the terminal marked P on the transformer and the "B" battery wire should make contact with the terminal B on the transformer, through the fingers of the jack. The last jack has two terminals and these are connected in series in the plate circuit of the preceding tube. The jack furnishes a convenient method for "plugging in" the headphones.

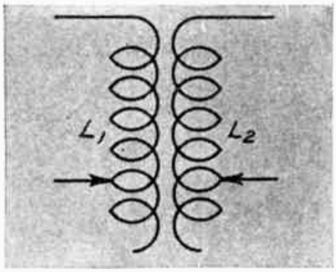
The reader will in his radio work find many other types of telephone jacks depicted in diagrams but the various springs and contacts will always be illustrated in the manner given.





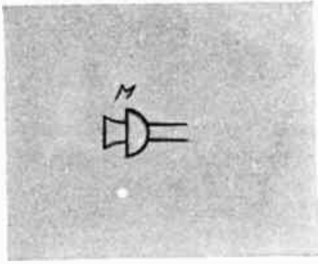
Key—The key is used for breaking up the high-frequency current into dots and dashes for radio telegraphy. In the old-time spark transmitters the keys were very ponderous and unwieldy due to the fact that they had to handle (directly) very large currents, being inserted in series with the primary circuit of the power transformer. However, with continuous-wave apparatus there are places where even a small key may be inserted so that it will control the energy from several large vacuum tubes. There are always two connections to the key, these being shown by the two wires running to it in the diagram.



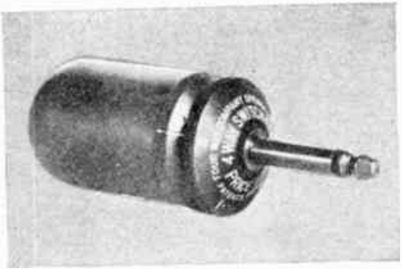


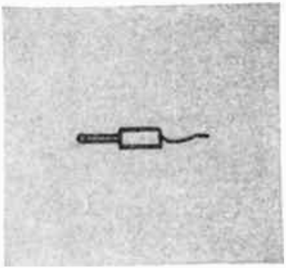
Loose Coupler—The loose coupler is an older and less convenient device than the vario-coupler, for coupling the primary and secondary circuits. The primary coil is stationary and is usually provided with a slider for varying the inductance by single turns. The secondary coil slides in and out of the primary to vary the coupling, and is provided with approximately half a dozen switch points to change its inductance value. There are two primary connections, one to the slider and one to one end of the coil. Also there are two secondary connections, one to the switch arm and one to one end of the coil. The construction of the loose coupler makes it inconvenient for panel mounting and it has gradually fallen into disuse.

Loose couplers take many other physical forms but electrically they all function the same and all types are indicated in diagrams in the conventional manner illustrated. It must be remembered that all of the various instruments shown in this series of pictures oftentimes take different mechanical forms. Regardless of this form the diagram used to represent the instrument is usually standardized in all radio publications.



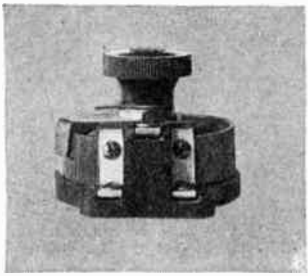
MICROPHONE—The ordinary carbon-grain microphone consists of two metal plates with a number of carbon grains between them. These two plates form the two connections to the microphone, and they are insulated from each other, of course, except through the path furnished by the carbon grains. To one of the plates the diaphragm of the microphone is attached and the varying pressure of the diaphragm (caused by the sound waves) is transferred to the carbon grains. This changes the resistance of the microphone and consequently the amount of current which is flowing through it, so that the amount of current at any instant is representative of the sound wave striking the diaphragm at that time. The symbol shown is practically standard.

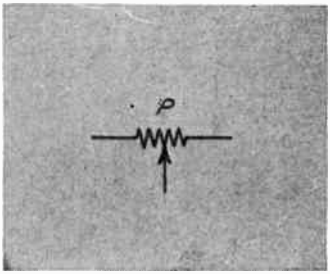




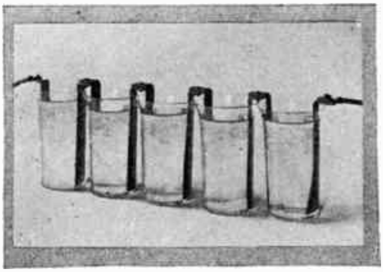
TELEPHONE PLUG—In connection with a jack, the telephone plug may be used to insert any given pair of telephones or any loudspeaker in the set instantly. There are two connections to the plug, one to the tip and one to the sleeve, and the two terminals of the telephones or the loudspeaker are merely joined to these. When a two-circuit jack is in the normal position, without the plug inserted, each outside spring makes contact with the corresponding inside spring and the circuit is completed through the following transformer. When the plug is inserted, contact between the outside and inside springs is broken, and the tip and sleeve of the plug make contact with the outside springs of the jack, completing the circuit through the telephones. This places the telephones in the plate circuit of the preceding tube and disconnects the succeeding stages from the telephones and other stages of amplification.

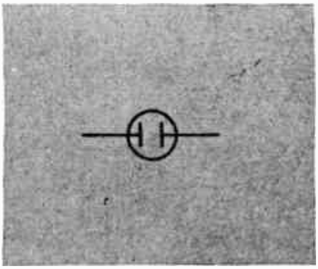
Sometimes telephone plugs are made to accommodate a large number of 'phone tips. There is no special way of representing such a plug in a diagram.





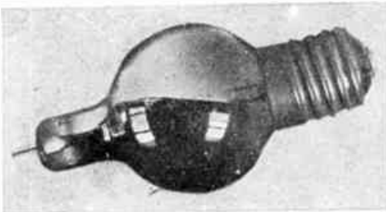
POTENTIOMETER—The theory of the potentiometer is based on the fact that the potential or voltage of a wire varies uniformly along its length from negative to positive, and that by tapping off at various points along the wire or resistance we can get any desired potential within the range of the battery. The two outside terminals of the potentiometer (ends of the winding) are connected across the "A" battery and the desired potential is obtained by moving the third connection (the pointer) to different points from negative to positive. There are two principal uses for the potentiometer, the first being to vary the plate potential of a soft detector tube by connecting the negative "B" battery lead to the pointer of the potentiometer, and the second to vary the grid potential of radio-frequency amplifying tubes by connecting the grid return to the pointer. This allows a six-volt variation in either position.

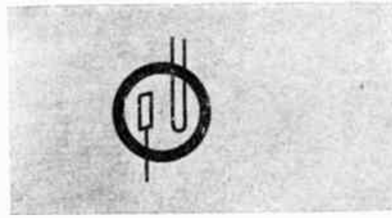




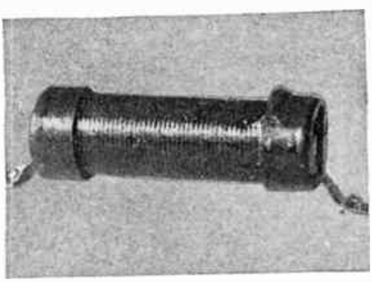
CHEMICAL RECTIFIER—The chemical rectifier cell usually consists of one lead and one aluminum electrode immersed in a saturated borax solution. For battery charging, two to four cells having large electrodes may be connected in parallel in order to carry the heavy current. On the other hand for rectifying the plate current for vacuum tubes, a number of cells that have smaller electrodes are connected in series, as the voltage is high and the current is low. The chemical rectifier is not very economical for battery charging as most often used, due to the fact that the current is most always cut down by a rheostat and a large part of the energy is lost *in* the rheostat in the form of heat. There are two connections to the rectifier, one to the positive aluminum electrode and one to the negative lead electrode.

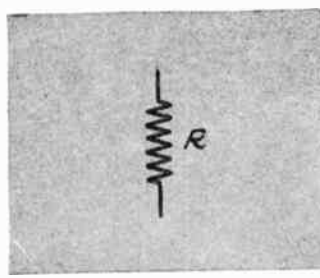
Chemical rectifiers of this type are often used to charge small B batteries but the reader will find that they require much attention.





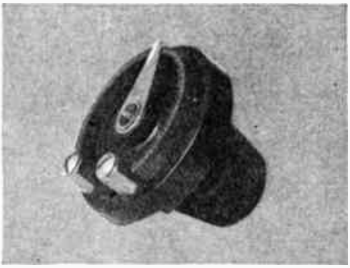
Rectifier Tube—The rectifier tube is a two-element tube and will always have three terminals. Two of these are for lighting the filament and the third is the plate terminal of the tube. The filament-lighting circuit is merely an auxiliary circuit; the connections of the rectifying circuit proper are to one of the filament terminals and the plate terminal of the rectifier tube. The source of current to be rectified is connected in series with the rectifier tube; since the current can only pass from the plate to the hot filament, the filament is always the positive pole and the plate the negative pole of the rectifier. Rectifiers range from the Tungar type (a low-voltage, high-current tube for battery charging) to the high-voltage rectifiers handling several thousand volts for the plate supply of large vacuum tubes that are used in transoceanic high-power telegraph transmitters. They will rectify high voltages.

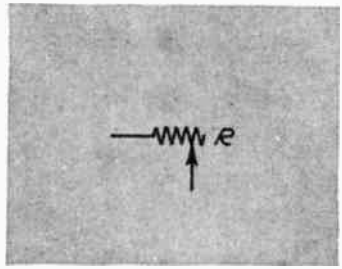




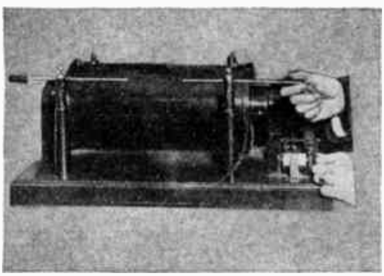
Fixed Resistance—The fixed resistance can be used to couple amplifier circuits together, being placed in the plate circuit of one tube and the voltage drop across it used to operate the succeeding tube. Resistance coupling is not economical because a large quantity of the plate-circuit energy is lost in the resistance in the form of heat. On the other hand it has the advantage of amplifying nearly all frequencies used in radio *uniformly*, and thus does not cause distorted signals. The fixed resistance has two terminals, one at each end of the resistance element. The element may take the form of a continuous winding of wire or may be made up of some high-resistance material such as carbon or graphite. It should generally be non-inductive; in some circuits this is imperative but in others it doesn't matter.

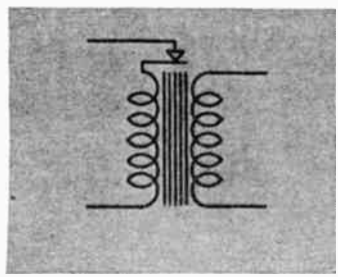
By non-inductive resistance we mean resistance in which the wire is wound back on itself so that the magnetism produced will be working in opposition. This is really the principle used in the variometer. Non-inductive resistances are used in alternating current.





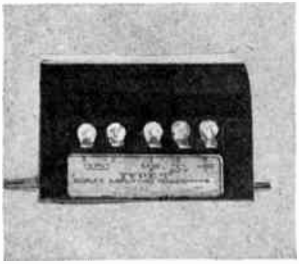
RHEOSTAT—As the voltage of a battery gradually decreases with use, all tubes are designed to operate at a voltage somewhat less than that of the battery they are to be used with. The rheostat should, therefore, have sufficient resistance to cut the battery voltage down to the proper tube rating. Also the current-carrying capacity of the rheostat should be large enough to prevent undue heating; for instance, an ordinary commercial 50-ohm rheostat would burn out immediately if used with a tube drawing one ampere or more. However, do not worry if the rheostat heats up to a certain extent, as that is the way the energy lost in it is dissipated. The rheostat has two connections, one to the pointer and one to one end of the winding. Use a rheostat with your tubes of the resistance specified by the manufacturer.

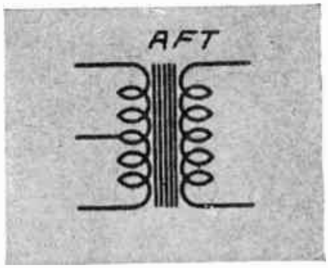




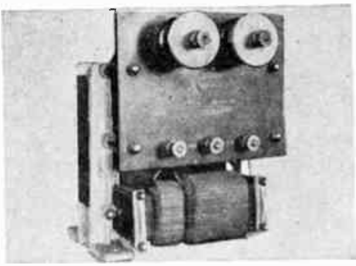
SPARK COIL—The spark coil is an instrument used to obtain a voltage high enough to jump a specified air gap, the discharge across the gap being used to send out waves at a radio frequency. The primary consists of a small number of turns and the secondary of many turns of fine wire, both being wound about a laminated iron core. A method of interrupting the primary circuit at regular intervals is provided, and this interruption gives us an alternating secondary current of very high voltage. This current is used to charge a condenser until the voltage is sufficient to break down the air of the spark gap and discharge across the gap. Generally there are four connections to the spark coil, two to the primary and two to the secondary. The interrupter is usually made integral with the coil and placed in the primary circuit. However, the interrupter may be separate if connected properly in the circuit.

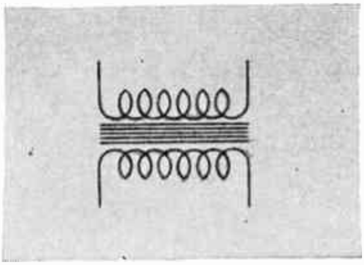
The spark coil is practically obsolete since it has always been a very inefficient producer of electric oscillations.





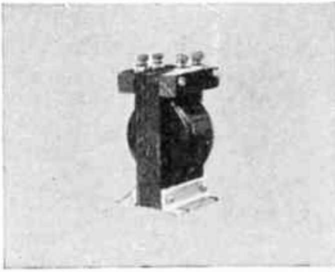
Push-pull Transformer—For each stage of push-pull amplification we must have a special audio-frequency, input transformer with a tap at the center point of the secondary winding, and also a special audio-frequency output transformer with a tap at the center point of the primary winding. Therefore the push-pull transformers are usually sold in pairs. Push-pull amplification varies the plate current of both tubes up and down from the normal, thus giving an increase in signal strength. In a stationary condition, that is without any signal being impressed on the tube, the direct current in one half of the output transformer opposes that in the other half and there is no flux in the core. With this condition we can use much higher voltages and get louder signals without distortion. This system is giving way to resistance amplification.

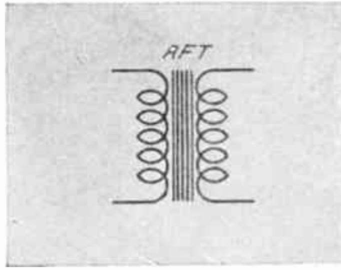




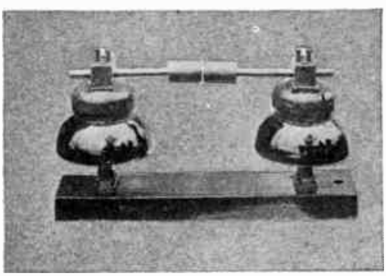
Transformers—The transformer has two separate coils, both wound about the same closed iron core. The primary is the side connected to the source of power and has two terminals. The secondary is the side from which power is to be drawn at some voltage either higher or lower than that impressed on the primary. It has two terminals or may be tapped at several points to obtain a selection of voltages. Therefore, it can be seen that the transformer is fundamentally a device for changing the voltage of the supply. When the voltage is cut down by utilizing the drop across a resistance much energy is lost in heat; on the contrary the efficiency of the transformer runs as high as 98 percent in the larger sizes. The transformer cannot be used on direct current.

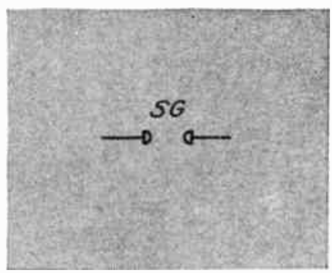
Transformers are used for many different purposes. Some step up the voltage and some step it down. Some increase the current while others diminish it. In any event transformers are always depicted substantially as shown. The primary can usually be recognized by heavy lines when the current is stepped up and the reverse when current is stepped down.





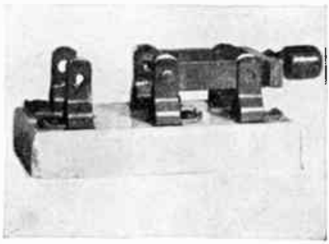
AUDIO-FREQUENCY TRANSFORMER—The audio-frequency transformer is merely a step-up transformer designed for voice-frequency currents. The primary is inserted in the plate circuit of one tube and the secondary in the grid circuit of the succeeding tube. Due to the step-up ratio, any change in the primary current and voltage produces a much larger swing in the grid voltage of the succeeding tube, and this causes a correspondingly greater change in the plate current of the same tube. The simple audio-frequency transformer has four terminals, two for the primary and two for the secondary. The general practice is to make the primary terminals P and B for the plate and "B" battery connections and the secondary terminals G and F for the grid and filament connections. A transformer should have such characteristics that it will amplify tones of all frequencies, within the audible range of the ear, with equal intensity. Transformers that do otherwise produce distortion.

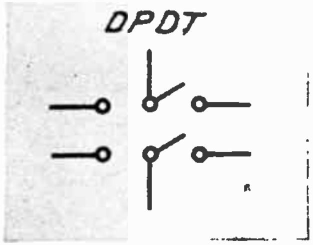




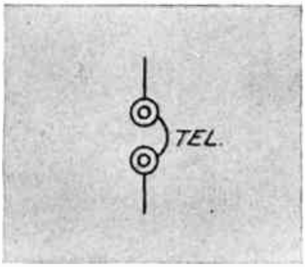
SPARK GAP—For any form of spark transmitter, some kind of spark gap must be provided. This is the point where the energy we put in the transmitter is changed from an audio frequency to radio frequency. The gap may be a plain two-electrode gap, a quenched gap, or a rotary gap. The various forms of spark gaps are used to give a better tone or note to the transmitter. For example, the rotary gap may be supplied with sufficient electrodes to produce 500 sparks a second, thus giving a note which is more pleasing and easier to read than the lower frequencies of the plain gap. The spark gap will always have two fundamental connections even if there are a large number of electrodes.

The reader will not find many spark gaps in radio diagrams at present because of the gradual passing of the spark method of producing electrical oscillations.



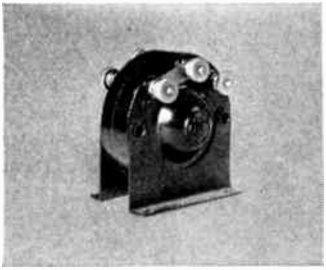


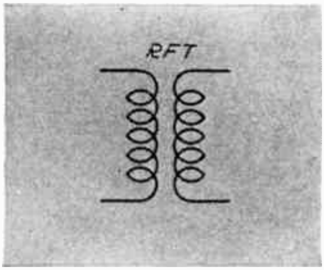
Switches—The most common switches used in radio are the following: a single-pole, single-throw (SPST) with two connections, single-pole, double-throw (SPDT) with three connections, double-pole, single-throw (DPST) with four connections and double-pole, double-throw (DPDT) with six connections. These switches are made up in standard from and also in a special anti-capacity type with the area of the switch parts reduced to a minimum. Of course there are also three and four-pole switches but their use is less common. Whatever the number of connections, it is merely necessary to count them on the diagram and make sure that the switch itself has the same number of connections and the same number of switch arms. Such switches may be used for antenna switches, battery chargers, and many other functions.



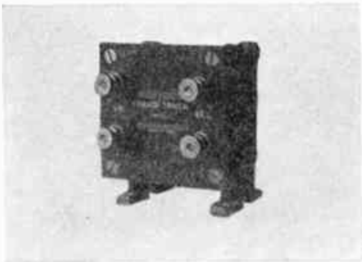
Telephones—A good pair of telephones is essential for reception; probably the best way of selecting them is to buy from a reliable manufacturer. There are two common types; in one the magnets act directly on the iron diaphragm and in the other they act on an iron armature which is mechanically connected to a mica or composition diaphragm. Either of these types is satisfactory if well made. The two telephone receivers are always connected in series, that is, one terminal of one 'phone is connected to one terminal of the other phone and the remaining two terminals are brought out for connections to the receiving set. For any good receiver, the telephone headpieces act as the mouthpiece and if they are of good design and quality the results will be good. If the telephones are inferior, however, reliable results cannot be expected. A good receiver deserves a good headset.

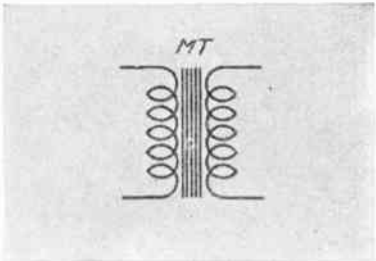
Fortunately the telephone is universally illustrated as we have it shown in the diagram. The telephone is the one instrument that has a practically uniform appearance.





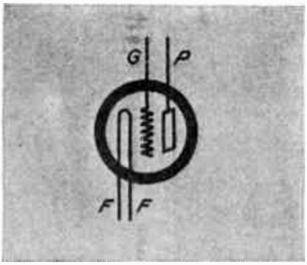
RADIO-FREQUENCY TRANSFORMER—The radio-frequency transformer operates on the same principle as the audio-frequency transformer, except that it is designed for high-frequency currents. It is often made with an air core, or at least with an open iron core. The radio-frequency transformer has four terminals, two for the primary and two for the secondary. The common practice is to mark the primary terminals P and B for the plate and "B"-battery connections, and the secondary terminals G and F for the grid and filament connections. Some transformers have a metal link for short-circuiting part of the winding, thus giving a wider wave-length range. Two or three steps of radio-frequency amplification are practically a necessity for loop operation. This type of transformer is not as efficient as the tuned type.



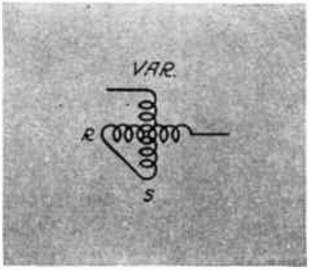


MODULATION TRANSFORMER—In order to couple together the microphone circuit and the grid circuit of a vacuum tube, a transformer must be used. Examples of this use are the grid-modulation, and Heising-modulation circuits. The modulation transformer is similar in appearance to the amplifying transformer, but usually has a higher step-up ratio. It has four terminals, two for the primary and two for the secondary. The primary winding of the modulation transformer is simply connected in series with the microphone and a suitable battery. The secondary winding is connected to the grid circuit of the oscillator tube in the case of grid modulation or to the grid circuit of the modulator tube in the case of Heising modulation. The transformers should be built to withstand rather high voltages.

Here we have practical proof of the simple way in which all transformers are shown diagramatically. The primary will always be connected with a source of current because it is this side of the transformer that receives the electrical impulses that are to be transformed to a higher or lower voltage.

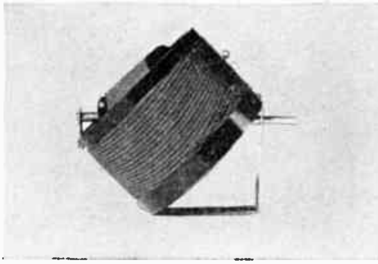


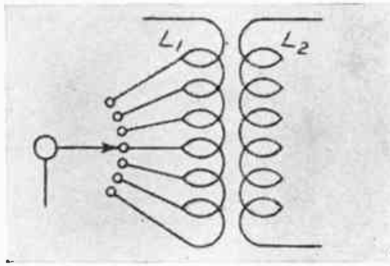
Vacuum Tube—The three-element vacuum tube has four terminals; two of these are the ends of the filament, the third is the grid, and the fourth is the plate. Since there are no designations for these terminals on the tube itself, it is imperative to purchase a suitable vacuum-tube socket and follow out the circuit from the letters on the same. The two filament terminals will be marked F, the grid G, and the plate P. These same letters have been placed on the diagrammatic vacuum-tube symbol shown, but will ordinarily be left off, as it is a simple matter to learn which element is which. The action of the vacuum tube cannot be treated here except to state that under normal operating conditions the telephone current flows from the plate to the filament, and that small changes in grid voltage will make comparatively large changes in the plate or telephone current. This process amplifies the currents passing through the telephones and produces louder signals.



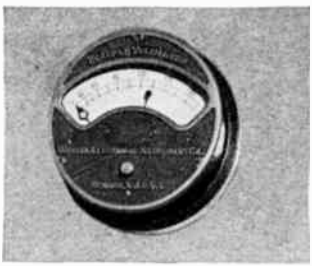
Variometer—The variometer provides a continuously variable inductance (within the range of the instrument); it consists of two coils connected in series and mounted so that one rotates within the other. When the current traverses the two coils in the same direction and when the axes of the two coils are parallel, the inductance of the variometer is maximum; when the current traverses the two coils in opposite directions and when the axes of the two coils are again parallel, the inductance of the variometer is minimum and should theoretically approach zero. There are two connections to the variometer, one to the end of each coil; the opposite ends of the two coils are connected together.

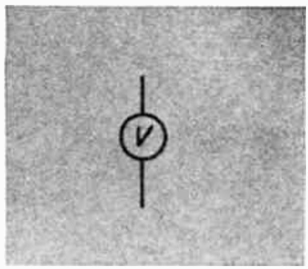
Here is another instrument that has not been standardized in diagrams unfortunate as it is. However, the variometer can be recognized by tracing the connection between the two coils used. It will be recalled that the variocoupler has two distinct windings not directly connected.





VARIOCOUPLER—The variocoupler is one of the most widely used instruments for coupling and tuning the primary and secondary circuits; it consists of a stationary primary coil, and a secondary coil rotating within the primary coil, so that the coupling between them may be varied. The primary of the variocoupler is provided with taps for changing the wavelength; there are two primary terminals, one to the wavelength switch and one to the end of the coil. The secondary of the variocoupler has a fixed number of turns and is always tuned by means of a variable condenser connected across the coil or by a variometer in series with it; there are two secondary terminals, one to each end of the coil. These secondary terminals are brought out through the bearings or through "pigtail" connections made to the coils of the instrument.





VOLTMETER—The voltmeter is an instrument for measuring the potential difference (voltage) between two points in a circuit, that is, how much higher the voltage is at one point than at the other. For instance, it might be connected across the "A" battery to measure the difference in voltage between the positive and negative terminals. A voltage measurement is the only satisfactory method of testing "B" batteries or of locating a bad unit among them. After the voltage of the 22½-volt unit has fallen below 16 it should be discarded. The same proportional drop can be applied to the larger units. The simple voltmeter will have two terminals for connecting to the two points where the voltage difference is to be measured. For "B" battery measurements the voltmeter should be of high resistance.

The voltmeter is really shown like the ammeter save for the fact that there is a "V" written across its face or beneath it in the diagram. Practically all types of meters are shown in this fashion.

From a reading of the foregoing the reader will notice that such instruments as the variable condenser, the variometer, the fixed condenser, the grid leak, the rheostat, tuning coil, choke coil, battery and others have only *two* terminals.

The potentiometer has *three* terminals.

Most types of transformers have four terminals—two for the primary winding and two for the secondary winding. Push and pull transformers, it will be noticed, have five connections.

Tube sockets have four connections, one marked G for the grid, one marked P for the plate, and the other two marked F for the filament connections.

Variocouplers have a number of taps (inductance terminals) for the primary and two connections for the secondary.

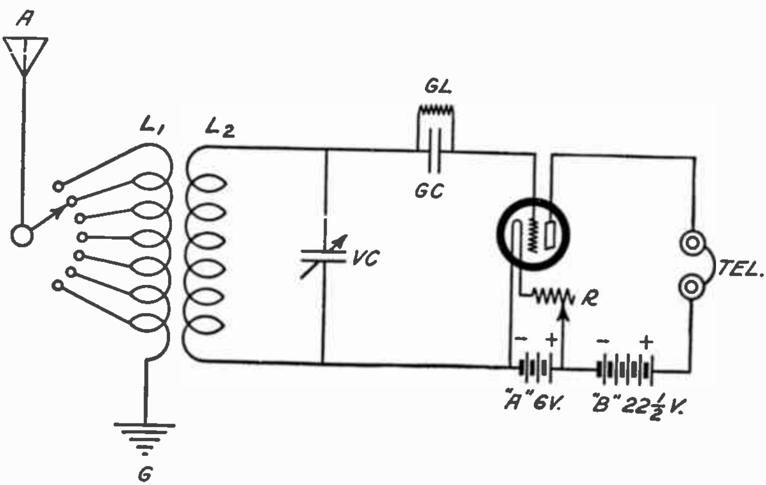
Some of the other more complicated accessories have a large number of terminals; among these are motor generators, tapped coils and power transformers.

Consider the specific case of a variable condenser; if you see the symbol for this instrument in a circuit diagram you will always find two lines (wires)running to it, one from each side. If you were to connect this instrument in that particular circuit you would only have to connect these two wires to the two terminals that you would find on the condenser. This same line of reasoning holds true for instruments with three terminals, four, or more terminals.

In a variocoupler the primary coil is always the larger outside coil and the secondary is the smaller inside coil.

In a transformer (radio-frequency or audio-frequency) the primary terminals are marked P for the plate, and B for the wire going to the "B" batteries. The secondary terminals are marked G, for the grid wire and F for the wire leading to the filament.

The symbol for the vacuum tube, it will be noticed, contains four lead wires. The upper left-hand wire is the grid lead and when connecting up a vacuum-tube circuit this wire should always be connected to the terminal marked G on the



A DRAWING FOR A STRAIGHT AUDION CIRCUIT

Unless you know what these symbols mean, this diagram is unintelligible. This part tells you how to read it.

tube socket. The upper right-hand wire is the plate lead and this should always be connected to the terminal marked P of the tube socket. The other two wire leads (in the diagram) are the filament connections and should be connected respectively to the terminals marked F on the tube socket.

Now let us study the diagram at the bottom of page 95.

This is a standard diagram for a straight audion circuit. We will first pick out the instruments that are used in this circuit. By referring to the upper left-hand portion of the diagram we will find the triangular-shaped symbol for the antenna. Directly below it we find the symbol for the variocoupler. And below this we find the symbol for the ground. Then connected to the secondary of the variocoupler we find the symbol for a variable condenser. And in the center of the diagram we find the symbol for a vacuum tube. Directly below this we find the symbol for a rheostat and an "A" battery. Connected between the grid of the tube and the variable condenser we find the symbols for a fixed condenser and a grid leak. To the right of the diagram at the top we find the symbol for the telephones and below this the symbol for a "B" battery. From this diagram, therefore, we learn that we need the following list of parts in order to make the set:

1—variocoupler;
1—variable condenser;
1—grid condenser;
1—grid leak;
1—vacuum tube;
1—vacuum-tube socket;
1—rheostat;
1—"A" battery (for lighting the filament);
1—pair of telephones;
1—"B" battery (for supplying the plate current).

The next thing to do would be to obtain these parts of suitable sizes to incorporate in the set. The sizes for the various instruments are almost always given in the text of the article of which the diagram is a part. These sizes include the proper capacities for the variable condensers and fixed condensers, the proper resistances for the grid leaks and rheostats, the proper type of tube to use for detector or amplifier and the proper voltages to use for the "A" batteries and "B" batteries.

To start wiring up a set like the one shown in the diagram the beginner should obtain the proper connecting wire, a soldering iron, some solder, soldering flux and a heavy red pencil.

A good layout for this particular set would be to mount the variocoupler at the left-hand end of the panel; place the variable condenser beside it, with the socket mounted alongside the variable condenser, at the right-hand end of the panel. The rheostat should be mounted on the panel directly in front of the vacuum-tube socket. The vacuum-tube socket should be mounted on the base with the plate and grid terminals turned toward the back of the set.

Now we should include on the left-hand end of the panel, two binding posts, one for the antenna and one for the ground. At the right-hand end of the panel should be mounted six binding posts, the top two being for the telephone, the second pair for the "B" battery, and the bottom two for the "A" battery.

After the instruments have been mounted on a panel in a manner which will keep the connecting wires as short as possible, we should commence the actual wiring.

From the diagram we see that there is a wire running from the antenna to the switch arm of the variocoupler. Cut a piece of wire long enough for this purpose and solder one end of it to the back of the antenna binding post of the set. Then run the wire as direct and neatly as possible to the shaft of the switch arm on the panel.

When this is completed *take the red pencil* and cover the line you have just completed (on the diagram) with a red line.

In looking at the diagram hereafter you will know that you have already completed this connection; it will be evident at a glance.

Now you will notice from the diagram that there is a wire running from the ground to the bottom end of the variocoupler. Connect this to the back of the ground binding post and also to the variocoupler end. Then trace over this line on the diagram *with the red pencil.*

There are five taps to be connected to the switch points on the panel, from the primary winding of the variocoupler. Make these connections one by one and each time you complete one trace it over on the diagram *with the red pencil.* The primary circuit is then complete.

The top end of the secondary is then run direct to one terminal of the variable condenser. Make this connection and *use the red pencil.* It will be noticed that there is a joint from this wire leading over from the wire you have just connected which runs to one side of the grid leak and one side of the grid condenser. Make this connection and trace over *with the red pencil.* Now connect a wire from the terminal marked G on the tube socket and run it to the opposite sides of the grid condenser and grid leak to the connection you have just completed. Cover this *with a red pencil line.*

To get back to the variocoupler, we notice that there is a wire running from its bottom end over to the negative "A" battery. Make this connection on your set and again cover on the diagram *with the red pencil.*

There are two branches from this wire, one to the remaining terminal of the variable condenser, and one to one of the terminals marked F on the tube socket. Make these connections separately, after which *use the red pencil.*

Now there is a connection running from the positive "A" battery over to the negative "B" battery and this requires a wire connecting your A binding post and your B negative on your set. This wire also has a branch running to the pointer on the rheostat. Connect these and *mark off* on the diagram.

The other terminal of the rheostat is connected to the remaining terminal marked F on the tube socket. Do this and *mark off* on the diagram *with the pencil.* There are now two connections left to complete the wiring. One is a wire from the "B" battery positive to the telephones and this requires the connection of the binding post marked B and the nearest telephone binding post. The other wire should be connected between the remaining telephone binding post and the terminal marked P on the tube socket. *Mark off* the two last connections *with the red pencil.*

Now look at the diagram again. Are there any connections left *uncovered by the red pencil?* If not, the set is correctly connected and you have succeeded in reading an electric diagram!

Try this out and you will find that even the most complicated circuits are subservient to your wishes and you will never have any trouble nor make any mistakes. There is nothing to it!

END OF SECTION III

SECTION IV

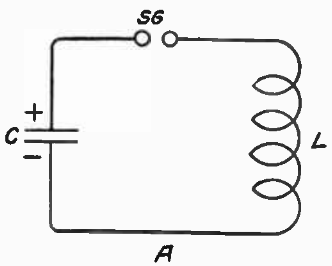
The Mechanics of Radio

Many of us who have walked past the radio cabin on a steamer have heard the crashing, sparking sounds that issue from the radio transmitter. Some of us have seen the sets in operation and most of us have perhaps turned away with the thought: "Well, radio certainly is a wonderful thing, and it must have taken some brain to work out the idea, but it's beyond me."

This, however, is not so. Anybody can understand the mechanics of radio if given the right instruction.

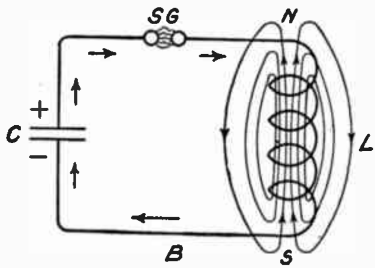
We must first become slightly familiar with two electrical instruments—the inductance or coil, and the condenser. We must learn that these two pieces of apparatus are storehouses of energy. The coil we find has the ability to store up electromagnetic energy. This means that the coil produces an electromagnetic field about itself that is similar to the field set up around a steel permanent magnet. The condenser on the other hand, by having all the electrons drawn off one plate and crowded on the other plate, becomes "charged." This causes one plate to be positive, and the other to be negative. The plate which contains all the electrons is the plate that is charged negatively. These two charges cause the "dielectric" or insulation between the two metal plates to be placed in a stressed or strained condition; in other words, an electrostatic field is set up in the insulation.

We will now connect up these two instruments with a spark gap and show how they, in combination, will cause



HOW CONDENSERS ARE CONNECTED

Figure A: This shows part of a radio transmitter circuit of the spark type. It contains a coil, a spark gap and a condenser.



A DISCHARGING CONDENSER

Figure B: The coil becomes energized, the condenser charges and discharges across the spark gap, producing a loud crackling noise.

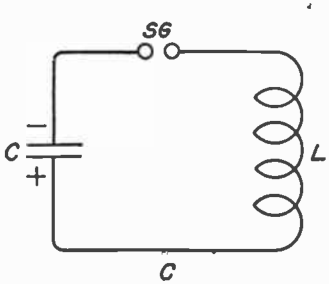
wave trains of high-frequency currents to be generated and how they also can be varied in size so that the frequency of the oscillations can be controlled at will, thus controlling the wavelength emitted from the transmitting set of which they form a part.

If we connect a wire to one plate of a condenser, which is made for high voltages, and which is diagrammatically shown at C in Figure A, and also connect the other end of this wire to one electrode of a spark gap SG, and connect the other plate of the condenser C to another wire which is attached to one end of a coil L, and further connect the other end of the coil to another wire which is in turn connected to the remaining electrode of the spark gap SG, we have connected up a regular oscillating circuit such as used by spark radio telegraph stations for generating the oscillations necessary for the production of the Hertzian or radio waves.

Now we will continue and make the circuit oscillate for our inspection in a very slow manner so that we may comprehend the workings clearly. Of course this will be unnatural, but it will serve to show us the functioning of the circuit in much the same way as motion pictures are slowed down so that the observer may see each individual action.

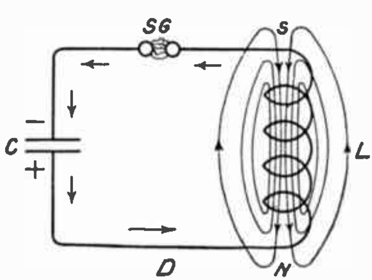
We will first place a charge on the condenser C; a positive charge on the upper plate and a negative charge on the lower plate, Figure A. As we may have already learned, a condenser when charged, contains a store of energy which is in the form of electrostatic electricity, or stationary electricity.

When a condenser is charged in this manner it tries to discharge and thus neutralize the charges on the plates. This discharge cannot take place unless the condenser has some external, electrically conducting path through which the electric current may run. This conducting path may be a wire attached from the positive plate to the negative plate. Inspection of Figure A shows that we have these conditions fulfilled except for one point—the air gap between the electrodes of the spark gap. Therefore, if we wish the electric charges on the condenser to discharge through the circuit we must place a high enough voltage on the plates so that the resistance of the air between the electrodes will be overcome and a spark allowed to jump across the gap. Then we have a complete conducting circuit from the



THE CHARGE REVERSED

Figure C: This diagram is the same as Fig. A save that the charge on the condenser plates are reversed.



ANOTHER DISCHARGING CONDENSER

Figure D: This diagram is also the same as Fig. B save that the condenser has the charges upon its plates reversed.

upper plate to the lower plate of the condenser and a current of electricity is caused to flow around through the circuit as indicated by the arrows and the spark shown jumping the gap in Figure B. This current is instantaneous and is shown as a positive impulse making up one half a cycle in Figure E.

We have learned that when a current is allowed to flow through a coil, a magnetic field is set up around the coil, which causes it to become an electromagnet with one end of a north polarity and the other end south, as shown at L in Figure B.

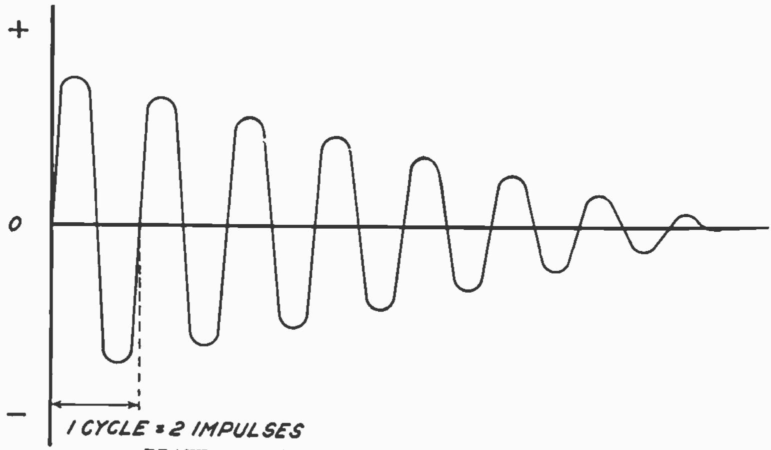
When the current has flowed through the circuit, the charges that were on the condenser C have become neutralized and therefore the current ceases. When this happens the magnetic field that has been set up around the coil L collapses; that is, the magnetic rings fall back on the surfaces of the wires and a peculiar effect is noticed; a voltage is induced in the coil which is positive in the direction that the current was running.

This means that the condenser C receives a reverse charge immediately after the current from the initial charge has ceased to flow.

This second charge places a positive potential on the bottom plate of the condenser and a negative charge on the top plate (see Figure C). This charge is not as strong as the first charge, however, because there is some energy lost due to the fact that the current must overcome the resistance of the wire and that of the air through which the spark must be forced.

When this second charge on the condenser reaches a high enough value to again break down the spark gap, a spark occurs across the gap and a second current flows through the circuit, in the opposite direction to the first current (see Figure D). This current forms a negative impulse which is shown in the diagram, Figure E, as the second impulse of the first cycle. Again the coil sets up a magnetic field around itself, only this time the top of the coil is of a south polarity and the bottom of the coil is north.

When this field collapses at the cessation of the second current the coil in-



DRAWING OF AN OSCILLATING DAMPED CURRENT

Figure E: How the current produced by the discharge of a condenser gradually falls to zero value. The time required for this action to take place is a very small fraction of a second.

duces the third charge on the condenser which is in the same direction as the original charge.

The same cycle of events then takes place and the current oscillates back and forth through the circuit one way and then the other, but the successive oscillations become weaker and weaker until they die out (see Figure E).

Remember, however, that in our study of these oscillations we have considered them as slow oscillations; in reality they take place in the twinkling of an eye—much faster in fact. One of these series of current wave trains, as they are called, would look to the human eye, like one single crackling spark across the gap. The modern radio transmitter uses frequencies up to 2,500,000 cycles a second, which means 5,000,000 reversing impulses a second, jumping the gap. Little wonder that they look like one single spark!

We now have a general idea of how this simple little circuit, composed of these simple instruments, can perform this miracle of electrical speed and motion without any mechanical moving parts. Now we shall see how we can control the frequency of these generated impulses, by varying either the size of the coil or the size of the condenser.

We may liken the condenser to a pitcher of water. We know that it we have a small pitcher, a certain sized stream of water will require a certain length of time to fill the pitcher. If we use a larger size of pitcher, and hold it under the same stream of water, it will take a greater length of time to fill it. It will also take a longer time to empty the larger pitcher than it will take to empty the small one.

We can also liken the coil to a coiled tube that we can pour the pitcher of water into. A certain length of time will be needed for the water to wind around through the convolutions of the coiled tube and finally find its way out of the bottom. If we make the tube twice as long, it will take twice as long for the water to run through.

Now apply this idea to the electrical circuit. If we use a larger condenser C, it will take longer for it to charge and discharge, making the currents that oscillate through the circuit to last longer. If they last longer, there cannot be as many each second. Therefore if we increase the capacity of the condenser we get fewer impulses a second, thus decreasing the frequency of the oscillations and increasing the wavelength that is emitted from the antenna to which this circuit is coupled.

Or we may get the same result by increasing the number of turns of wire in the coil, and the current will take longer to run through it, so to speak; again we have less impulses a second or a higher wavelength. Increasing either the capacity of the condenser or the inductance of the coil, increases the wavelength. This latter method is generally used for transmitting stations, as it does not vary the power of the set to such a great extent while changing the wavelength, as varying the size of the condenser varies the power greatly that the circuit uses. A given size of condenser will hold a given charge, and if it is varied in size the charge varies in size also.

The coils are generally made with a large number of turns of heavy wire on them and a sliding contact slides over the surface of the wire and picks out the desired number of turns to be left in the circuit to obtain a frequency that corresponds to the desired wavelength.

In this way radio transmitting stations are tuned to the wavelength that they are required to send out on by governmental regulation.

So we find that the whole scheme is, after all, simple. The only feature that made it seem mysterious was the fact that we had no way of telling just what took place when the sparks "jumped the gap," until we analyzed the whole process.

In a future part we will show how these impulses are transferred to the transmitting antenna; then we will see that the coil plays a double role in the radio circuit.

A radio wave is a vibration of the ether, that supposed substance that fills space.

There are many different kinds of vibrations that travel through the ether; that is to say, certain vibrations produce entirely different results than other vibrations.

Suppose we consider (Fig. F), for example, a flexible reed, fastened to a stationary base, as shown in the illustration. If we cause the reed to vibrate it will first take the position "A," and then swing back and past its original position to a third position "B," and then back to its original position again. Then the same series of movements will be gone through again. This complete set of movements is called a cycle. A cycle then, is composed of two impulses, one in one direction and another in a reverse direction.

Now if we cause the reed to vibrate at a speed of 16 cycles a second, the reed will cause a sound wave to be propagated in the immediate space surrounding it. This wave will make itself manifest to our senses in the form of a low humming sound. Close by the reed the sound will be fairly loud, but at a distance of fifty feet it may be inaudible.

If we increase the frequency (or speed of vibration), to 500 cycles a second, the low hum will increase in pitch until it will be a shrill whistle, like the high notes of an organ.

If we continuously increase the frequency of the oscillations, when we have the reed oscillating at a frequency of 25,000 cycles a second, the sound will have gotten so high that the human ear cannot hear it. In other words, the waves that are generated around the reed have gone out of the range of frequency that we call sound waves.

As the frequency is increased it will be soon noticed that the reed begins to get warm, until, finally, by placing the hand near it we "feel" the heat wave. This heat wave is of exactly the same nature as the sound wave except that it has a different frequency and produces different results. In one case we hear the sound, with a sound recording organ called the ear, and in the other case we feel the presence of heat by our sense of touch.

As the frequency of the little reed is increased beyond this point, the heat developed finally increases until the reed begins to glow a dull red color. Instantly the wave has become a light wave and it is visible to our eyes, but the heat is still felt. This shows that the ranges of heat and light overlap in the frequency scale.

Any further increase of frequency would mean destruction to the reed through overheating, but if we could imagine its frequency as increasing without burning up, the waves sent out would pass through the ranges of color and the X-ray.

To sum up the foregoing, different ranges of frequency, say 16 to 25,000 cycles, produce waves that we call sound, and another range produces heat, light and color. Another range produces X-rays, and a similar range produces waves which we call Hertzian waves, named after Hertz, the man who discovered their existence.

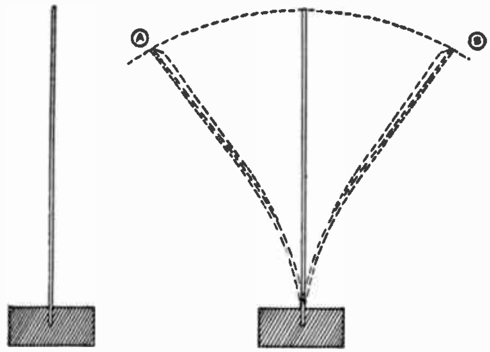
And these Hertzian waves are our radio waves. The frequency of the electricity that is used to generate them lies within the ranges of 10,000 to 3,000,000 cycles a second.

We now know what a sound wave is. Did we ever notice that the seats in a theatre are invariably arranged in circles? This is done to take advantage of the fact that all waves, such as sound waves, light, heat, and radio waves travel from a point outward in ever increasing circles.

You will get some idea of how sound waves travel by observing what happens when a stone is thrown into a pool of still water. A circular wave is at once formed around the spot where the stone hits the water. This circular ripple begins to travel outwards with its diameter ever getting larger until it dies out.

If we place a cork on the surface of the water near the spot where the stone had struck, it will bob up and down violently as the wave passes by. If the cork were to be placed on the water at a distance from the same spot, the vertical movement would be much less violent because the waves would be weaker after travelling this distance.

Or take another illustration: We know that a fire built in the woods is hot on all sides and will warm people standing on one side of it just as much as it will warm those on the other side. If we move closer to the fire the heat increases because the heat waves are stronger there; if we move away, the heat decreases. This also is because the waves weaken as they travel.



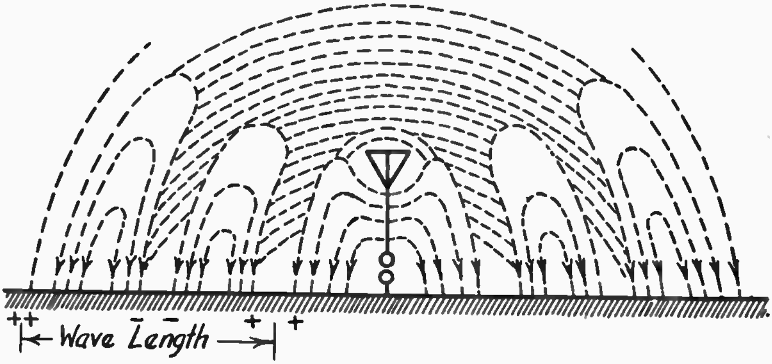
REED ANALOGY

Figure F: A vibrating reed produces the most simple form of sound wave.

The same general conditions hold true for radio waves. The transmitting station may be likened to the stone thrown into the water, and the receiving station may be likened to the corks on the surface of the water.

How radio waves are sent out is illustrated in Fig. G, which shows how they leave the antenna.

The antenna is shown, for simplicity, as a single wire vertical antenna with a spark gap as a generator of oscillations in series with the ground. For every given frequency of current jumping the gap, a wave of a certain definite length is radiated from the antenna. The



HOW WAVES LEAVE AERIALS

Figure G: Radio waves spread out from a transmitting antenna in much the same way as sound waves spread out from a vibrating reed. The dotted lines indicate the circular radio waves.

length of the wave is the distance between the start and finish of one complete wave, measured along the ground. All radio waves travel with the terrific speed of light, 300,000,000 metres a second. When we know this, the wavelength of a wave radiated from an antenna can easily be calculated if we also know the frequency of the oscillations in the antenna circuit.

A table of wavelengths used for radio communication is given below as a matter of interest, showing the frequency of the currents which cause them to be emitted from an antenna:

Wave length in meters	*Frequency in cycles a second*	*Type of station which uses each wavelength*
200	1,500,000	Amateur stations
300	1,000,000	Ship stations
360	834,000	Radio telephone broadcastingstations
450	667,000	Ship stations
600	500,000	Commercial ship and shore stations
1,000	300,000	U. S. Navy
1,400	214,300	Commercial traffic
2,600	115,400	Time signals
5,000	60,000	High powered commercial stations
10,000	30,000	High powered commercial stations
15,000	20,000	High powered commercial stations
20,000	15,000	High powered commercial stations
30,000	10,000	High powered commercial stations

Now let us consider how radio waves are received.

It will be noticed from the above table that as the frequency of the current in the antenna decreases, the length of the emitted wave increases.

We receive a radio wave when we erect an antenna with its insulated wires high in the air, and these wires get in the way of the advancing circular waves. When a series of waves strike the antenna they do not cause it to bob up and down like a cork, but they do produce a tangible result nevertheless. This result takes the shape of a feeble current induced in the receiving antenna which is an exact replica of the current in the transmitting antenna, but reproduced on a much smaller scale. It has the same frequency and is like it in every respect except in strength.

Thus we can readily see that it is not the electric current itself that travels through the ether, but that the electric current does start a disturbance in the ether in the form of a Hertzian wave which travels outwards in all directions in circles. And when these waves strike another antenna which is tuned to that particular wavelength, they will induce in that antenna a current similar to the transmitting current, only of decreased intensity.

What is a kilocycle? Why are radio waves now being measured in this new unit instead of the familiar wavelengths? What is frequency?

Of these questions let us take first what frequency is and what is its relation to wavelength.

Any wave whatsoever, a radio wave in the ether, a sound wave in the air, a water ripple on the surface of a pond, consists of a succession of pulses moving along one after another. Most waves have a succession of *regular* crests and troughs like ocean waves or like the electric wave, a picture of which is shown in Fig. H.

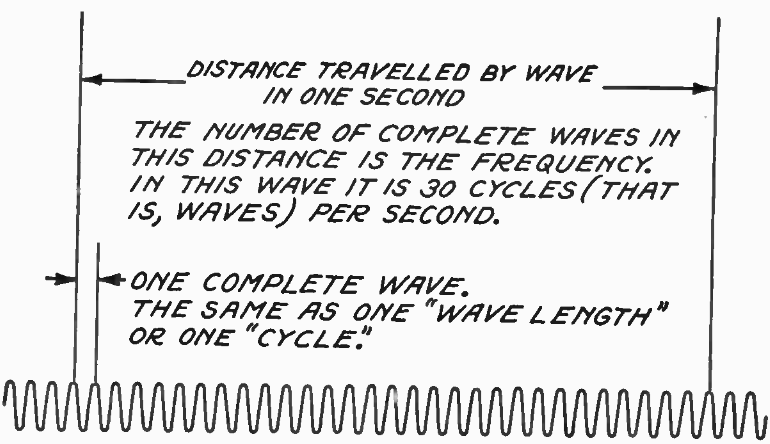
The part of the wave between one crest and the next following crest is called one complete wave. Its length—that is the distance between successive wave crests—is one wavelength. This is the familiar radio unit.

The *frequency* is merely the number of such complete waves that pass in one second, or what is the same thing, the number of wavelengths in the distance the wave moves in one second.

Consider the arrival of a moving wave at some fixed point; for example, the arrival of a sound wave at your ear.

The wave appears to your ear as a succession of regularly timed pulses, of the speed of radio waves. The speed of sound in water is about 1,500 meters a second. The fastest known speed for sound is in steel; it is about 5,300 meters a second.

Not only radio waves but all kinds of ether waves are designated most conveniently by their frequencies. The table on page 106 gives in form convenient for reference all the ether waves now known with their frequencies and the corresponding wavelengths in vacu-



WAVE LENGTH VS. FREQUENCY

Figure H: This diagram shows clearly the relation between wave length and frequency for the specific wave pictured at the bottom—in this instance the wave produced by the note of a flute.

TABLE OF ALL THE ETHER WAVES NOW KNOWN

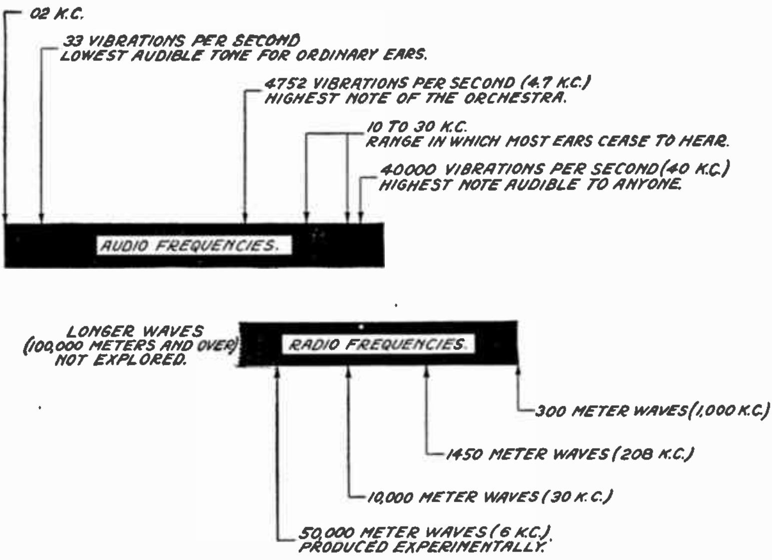
		FREQUENCY	WAVE LENGTH	
		.02 KILOCYCLE (20 VIBRATIONS PER SECOND)	15,000,000 METERS	
AUDIO FREQUENCY VIBRATIONS	10.6 OCTAVES			THE AUDIO FREQUENCY AND THE RADIO FREQUENCY OVER-LAP AS SHOWN IN ANOTHER DIAGRAM HEREWITH.
		30 KILOCYCLES	10,000 METERS	
USUAL RADIO WAVES	6.7 OCTAVES			HERE BELONG ALL ORDINARY RADIO WAVES.
		3,000 KILOCYCLES	100 METERS	
SHORT ELECTRIC WAVES	16.7 OCTAVES			THESE WAVES HAVE BEEN USED ONLY EXPERIMENTALLY. HERE BELONG, ALSO, THE RADIO HEAT WAVES RECENTLY DISCOVERED BY DR. E. H. NICHOLS. ALL THESE WAVES WILL PROBABLY BE QUITE IMPORTANT IN THE FUTURE.
		300,000,000 KILOCYCLES	.001 METER (10,000,000 ANGSTROM UNITS)	
HEAT WAVES	10.3 OCTAVES			ALSO CALLED THE INFRA-RED RAYS.
		387,000,000,000 K.C.	7750 ANGSTROM UNITS	
LIGHT WAVES	1 OCTAVE			
		759,000,000,000 K.C.	3900 ANGSTROM UNITS	
ULTRA-VIOLET LIGHT	3.7 OCTAVES			
		10,000,000,000,000 K.C.	300 ANGSTROM UNITS	
X-RAYS	11.6 OCTAVES			RAYS THAT PENETRATE MOST KINDS OF MATTER.
		30,000,000,000,000,000 K.C.	.1 ANGSTROM UNIT	
GAMMA RAYS	3.3 OCTAVES			FROM RADIUM
		300,000,000,000,000,000 K.C.	.01 ANGSTROM UNIT	

UNEXPLORED REGION, WAVES STILL SHORTER THAN GAMMA RAYS um. The term "octave" is borrowed from music. One octave means all the waves between any particular frequency and a frequency twice as great. For example, the first octave of the table includes all the waves between a frequency of 20 cycles a second and a frequency of 40 cycles a second; the second octave is from 40 to 80 cycles a second and so on.

The entire series of ether waves, from the longest radio waves to the shortest gamma rays, is now known without gaps. There was formerly a gap between the ultra-violet waves and the X rays, but this has been filled by the discovery of some very long X rays lying well within the ultra-violet range. The other former gap, between the heat waves and radio waves, was filled recently by the work of Nichols and Tear.

The divisions of the waves into radio waves, heat waves and light waves, are made merely for convenience. All the waves belong, really, to one unbroken series. Many of the divisions are overlapped, just as the heat waves overlap the short radio waves and the X rays overlap into the ultra-violet. A similar overlap of the audio frequencies and the radio frequencies is shown in the illustration on this page (Fig. I).

The ether waves that have been most studied by scientists are those of light. These differ from the longer and shorter waves only in that they happen to be perceived by the human eye. Physically all the waves are the same. The *color* of light depends upon its frequency, or, what is the same thing, upon its wavelength. The band of color in a rainbow, which scientists call the spectrum, is as follows (see next page):



RADIO FREQUENCIES THAT WE CAN HEAR

Figure I: The longer waves of radio overlap into the range of audio frequencies, as is shown in this diagram.

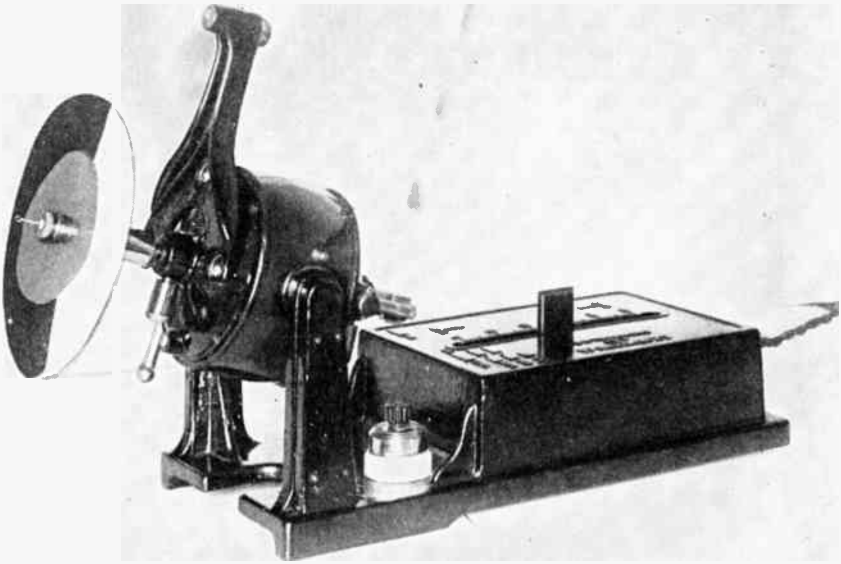
	Angstrom Units
Heat waves (invisible)	longer than 7,750
Red light	7,750 to 6,460
Orange light	6,460 to 5,900
Yellow light	5,900 to 5,600
Green light	5,600 to 4,900
Blue light	4,900 to 4,500
Violet light	4,500 to 3,900
Ultra-violet rays (invisible)	shorter than 3,900

The Angstrom unit used in this table and which is the common unit for the length of light waves, equals one ten-billionth of a meter. It is named after the celebrated Swedish scientist Dr. K. A. Angstrom, who was the first to study and chart the spectrum of sunlight.

Other units of length sometimes used in designating the wavelengths of ether waves, are the following:

1 meter.........equals 1,000 millimeters
1 millimeter.....equals 1,000 microns
1 micron........equals 1,000 double microns
1 double micron equals 10 Angstrom Units

The abbreviation for micron is the Greek letter mu (μ), that for the double micron is ($\mu\mu$); that for the Angstrom Unit is A. U. or sometimes merely A. A double micron is sometimes called a "micro-micron" or a "mille-micron."



HOW COLORED LIGHT WAVES ARE MIXED AND JUDGED

Figure J: One half of the colored rim on the edge of the disk is red, the other half is white. When the disk is rapidly revolved by the attached electric motor the light waves in the two portions of the disk blend in the eye, producing a shade of pink. In the other way the color-blends necessary to produce any desired shade of any color are worked out in the laboratory. Psychologists also use this same instrument to determine the way in which the human eye sees various mixtures of light of different colors.

SECTION V

Mechanics and Electrics of Tuning

RADIO currents of high frequency are usually generated in some form of closed circuit, which is tuned by varying either the inductance or the capacity in the circuit or both. These currents must, however, be supplied to the antenna circuit, in some way or other, before they can be used for the propagation of Hertzian or radio waves through space, thus making possible radio telegraphy and telephony.

The device used for this purpose is called a "transformer." When it is used for transmitting it is usually called an "oscillation transformer," and when used in a receiving set, it is known as a "loose coupler" or "variocoupler."

Before we take up the devices used for high-frequency currents, let us study the ordinary low frequency transformer such as is used for lighting our homes.

Such a transformer consists of three main parts; a primary winding, a secondary winding, and an iron core. The core is usually made of iron sheets built up in the form of a square "ring," or hollow square. The primary winding is then wound over one side of this square, using the iron for a core, and the secondary is wound over the opposite side of the square, also using the iron for the core. Such a transformer is shown in Fig. B.

Now if we cause an alternating current or a pulsating direct current to flow through the primary winding, by connecting the two ends of the primary wire to an alternating current generator or to a direct current generator, with a device for breaking up the direct current into impulses, we will cause the iron core of the transformer to become magnetized. The magnetic flux will flow around through the "legs," and the direction of its flow will be governed by the direction of the current flowing through the primary coil.

We have already learned that if insulated wire is wound on a soft iron core and a current of electricity is caused to flow through the winding, the core will become magnetized. If a similar winding and core were suddenly to be placed near enough to a permanent magnet for the iron core to become magnetized externally for an instant, the reverse action would take place, and a current would thus be induced in the winding.

To return to our transformer; when the core is magnetized by the current flowing through the primary winding, the magnetic flux flows around through the core and passes through the center of the secondary winding. At this instant a current is induced in the secondary winding that corresponds exactly with the current that flows through the primary winding. This effect is called electromagnetic induction. The primary winding changes the electric current into magnetic energy; the core carries the magnetic energy around to the secondary coil, and the secondary changes the magnetic energy back into an electric current.

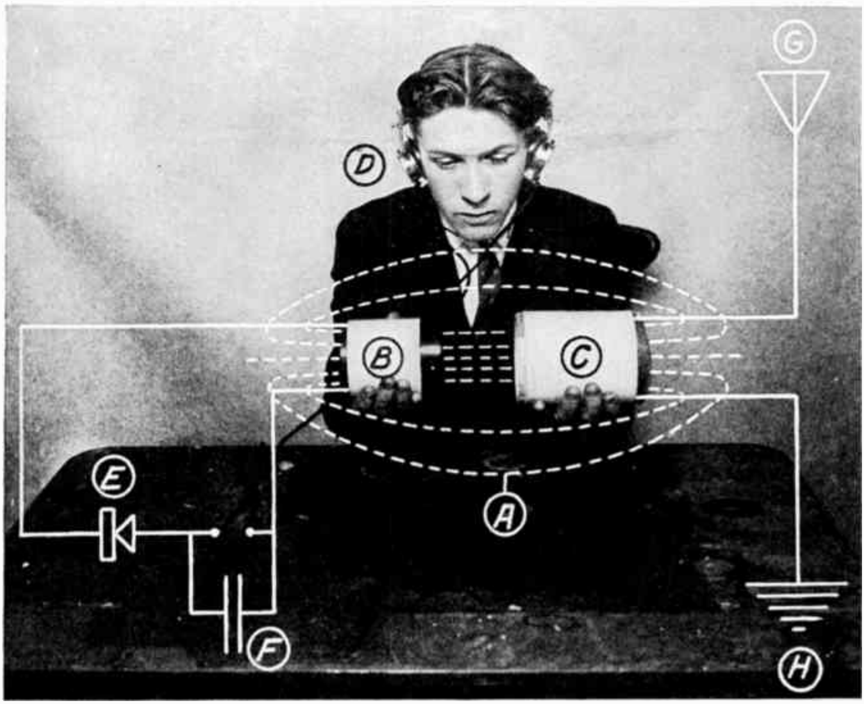
In this way electric currents can be transferred from one circuit to another without any actual connection between the wires of the two circuits. When two circuits are thus connected together by means of a transformer, they are said to be "magnetically coupled" together.

Radio circuits are also coupled together in much the same manner, but the transformers used for coupling radio circuits do not have iron cores. They use air cores. Iron cores are used with low-frequency currents, while for high-frequency currents air cores are used.

In transformers used for coupling radio circuits, the windings are wound on insulating tubes. Such a coil is shown in Fig. C.

If we take two such coils, one for the primary and one for the secondary and place them end to end as shown in Fig. A and cause a radio current to flow through the primary coil, the magnetic field surrounding the primary coil will envelop the secondary coil, passing through it and causing a current to flow through the secondary coil.

If, however, we should place the secondary coil at right angles to the primary



WHAT THE MAGNETIC ENERGY CIRCULATING AROUND RECEIVING COILS LOOKS LIKE

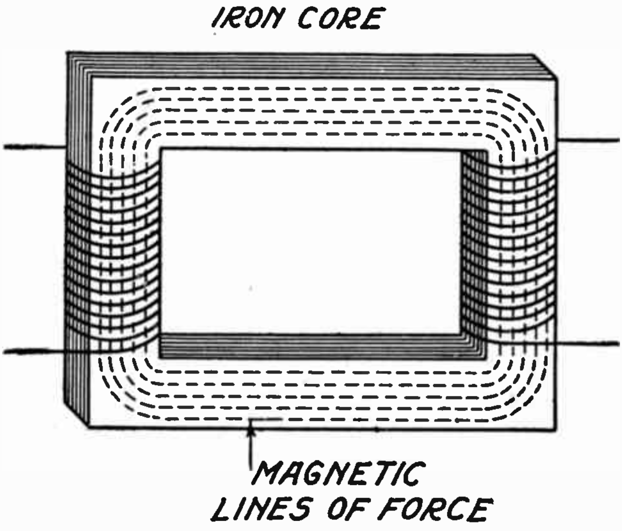
Figure A: If the human eye could perceive lines of electromagnetic force, it would see the phenomenon shown in this diagram. A are the lines of force generated by the primary coil C, which induce currents in the secondary coil B. D are the head telephones; E the crystal detector; F the fixed telephone condenser; G the antenna and H the ground connection.

coil as in the annexed Fig. E (B) page 114, there will be little or no current induced in the secondary coil as the magnetic flux does not flow in the proper direction through it. In most radio sets, the secondary winding rotates, and by rotating the knob on the set which is attached to this coil, the coupling is varied.

In some sets the secondary coil slides in and out of the primary coil, and the coupling is varied in this way. When the secondary coil is in a position that allows all of the magnetic flux to flow through it, the two circuits thus coupled are said to be "closely coupled," and when the secondary coil is placed in a position that allows little or no magnetic flux to flow through it, they are "loosely coupled." When a transmitting or a receiving set is coupled loosely to the antenna circuit, it sends out a sharper wave or receives with much sharper tuning, than a set that is closely coupled.

An oscillating circuit comprises a condenser, a spark gap, and an inductance or coil. The coil serves a double purpose. It tunes the circuit to the desired wavelength, and also serves as the primary coil of an oscillation transformer. The secondary coil receives the oscillations from the primary coil by electromagnetic induction, and at the same time tunes the antenna circuit. The secondary coil is connected in series with the antenna and ground. In this way the antenna circuit is energized and the Hertzian waves are emitted from the antenna.

A variometer, which consists of two coils connected in series, is often used for tuning a circuit. One coil is stationary and is called the "stator"; the other coil rotates inside it and is called the



PICTURE-DIAGRAM OF A TRANSFORMER

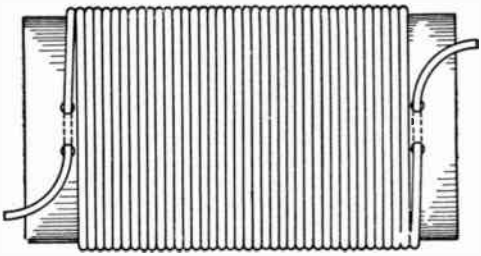
Figure B: How an ordinary transformer transfers electric current from one circuit to another by means of two coils and an iron core.

"rotor." In using this device to tune a circuit, when the coils are rotated so that the electromagnetic fields of the two coils are opposing (as Fig. D), the two fields acting against each other do not allow any electromagnetic energy to be stored up, or in other words their mutual induction is theoretically zero.

A coil of this type set in this position would respond to very low wavelengths.

Thus we see how the coil is used in radio circuits, and that it serves the double purpose of tuning the circuits while at the same time it couples them together, or transfers the electricity from one circuit to the other.

While the subject of wave production and reception has been briefly treated previously, the importance of the matter is so great as to make further study justified. Perhaps there is no better way of grasping the real fundamentals of tuning and wave production than to go back over the original work of Professor Heinrich Hertz, the young German student who first discovered the secrets of radio transmission and reception.

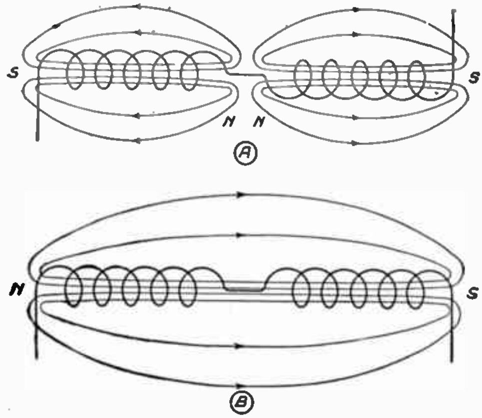


A SMALL INDUCTANCE
Figure C: A coil of the type used for transferring currents from one radio circuit to another.

If the rotor be turned so that its field be additive with the stator, as shown in Fig. D, the two fields will act with each other to store up electromagnetic energy, and the mutual induction will be at a maximum. In this position the variometer will respond to a high wavelength.

By slowly rotating the rotor from the first position to the last mentioned position, the variometer can be used for tuning and will pass through the various wavelengths that it is designed to listen in on. The variometer is used for tuning in receiving sets, and Fig. F shows two variometers used to tune the primary and secondary circuits of a receiving set. The other two coils shown in the circuit are the primary and secondary coils of the loose coupler, or variocoupler.

There is a romantic side to Hertz' work and, although it has nothing in particular to do with the purely practical phases of the subject we are considering, it does form one of the most fascinating side lights in the whole history of communication without wires. This is so because it involves a great figure in American life; Thomas A. Edison. Thomas A. Edison not only discovered the principle of the modern vacuum tube, as we shall see later, but he was responsible for setting off the spark of genius in young Hertz, whose work was



POSITION OF COILS

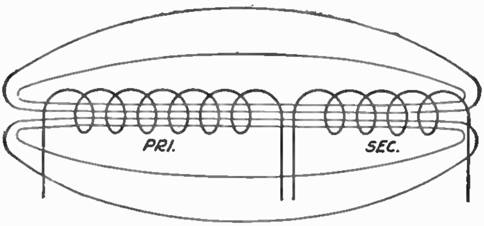
Figure D: A shows two coils connected in series with the windings opposing; with this connection the coils respond to low wavelengths. B shows the coils with the windings additive. This device is called a variometer.

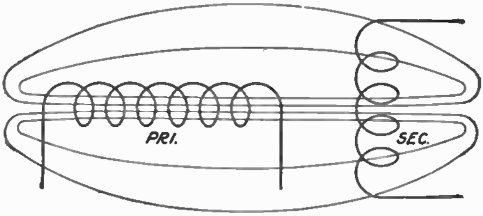
the foundation of the great art of radio telegraphy and telephony.

In the early 80's, Edison was exhibiting his electric lights and scientific curiosities at the Paris Exposition. In his booth he had the apparatus necessary for the execution of an experiment that had caused him a great deal of amusement and wonder back in his American laboratory. On one side of the booth there stood on a pedestal a small black box containing nothing more than a loop of wire connected to a small spark gap. The box was so arranged that the spark that passed across the gap could be viewed only from the outside through a small peephole. On the opposite side of the stage, Edison had placed a spark coil, which is merely a high-voltage transformer working on an interrupted direct current circuit. Of course, the spark coil was provided with its own spark gap and when the primary circuit of the coil was closed, a high pressure discharge would take place across the gap. When this was done, however, the little gap in the black box on the opposite side of the booth also responded and a tiny discharge crackled between the metal electrodes.

To the scientists of Europe, and there were some very great ones at the time, this Edisonian experiment was the most intriguing feature of the whole exposition. The little black box was the center of a great deal of attraction as the scientific generalissimos of the Continent crowded about it seeking to explain in their own minds the *modus operandi*. An actual transfer of energy was taking place under their very eyes and noses—there was a connection over space between two widely separated points—but no one in the group ventured a statement as to the mechanism of this marvelous feat.

One day, before the exposition had closed, a thin, retiring young man about twenty-seven years old was wandering through the aisles keenly absorbed in the details of the more scientific appurtenances. This young man naturally





INDUCTIVE RELATIONSHIP

Figure E: Shows two coils placed in inductive relations to each other; large currents are induced in the secondary from the primary. B shows the coils in non-conductive relation. This device is called a loose coupler.

gravitated toward Edison's booth and there found the experiments that had baffled the older scientific heads. This young man was none other than Heinrich Hertz, and when young Hertz viewed this spark in the little black box his mind flashed back to the year 1860, the year in which Prof. James Clerk Maxwell, the Scotch physicist, promulgated his startling mathematical treatment on the electromagnetic wave theory. Although Maxwell had never heard of radio waves, he gave reasons for their existence in cold mathematics and when Hertz looked through the peephole in the little box he was pretty sure he was looking at a phenomenon that could be accounted for by Maxwell's penetrating figures.

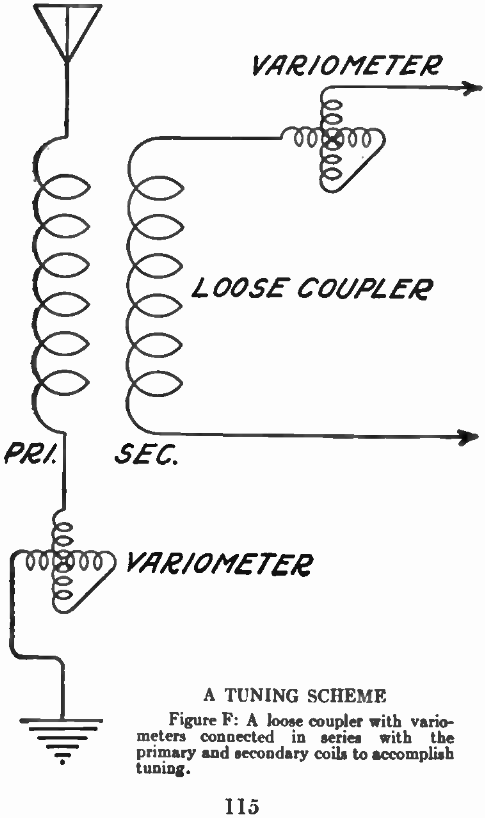
Hertz, inspired and twitching to satisfy a consuming scientific curiosity, immediately returned to the University of Bohn (where he had graduated) to begin what later proved to be the classical experiments from which the whole radio art blossomed.

If we follow closely an outline of Hertz' activity we shall gain from it a fairly accurate mental picture of how waves are transmitted and received. Not only this, but we shall gain a presentable idea of the underlying theory.

The simple devices used by Hertz are illustrated in Fig. G. The transmitter consisted merely of a conventional type of spark coil provided with an adjustable spark gap. This was the Hertzian transmitter. It was the device that set up electrical "splashes" in this vast all-pervading pool of highly attenuated stuff that we call the ether. The receiver was a modification of Edison's first contraption and it took the form of a loop of wire provided with two little brass knobs at each end. An insulated handle provided a means for carrying it about the laboratory to get the effect of different positions and localities. This was the receiving element, and, since it greatly resembled the characteristic antenna of the butterfly, Hertz decided to name it after this and the name survives to this very day.

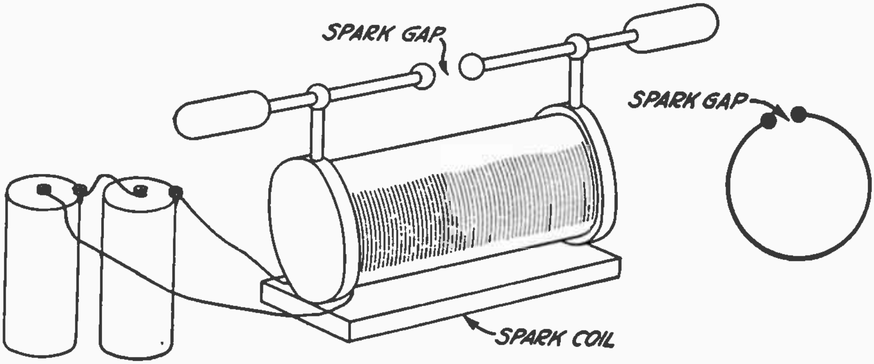
When Hertz set his spark coil in action and walked about the laboratory adjusting this antenna by moving the brass knobs closer and farther apart, a position would finally be reached where a small spark would pass across the gap indicating that the receiving outfit was in exact *resonance* or *in tune* with the very crude transmitter.

Hertz was a highly imaginative investigator and he was not satisfied to merely duplicate what must have been to Edison only a novel experiment. Hertz aimed to reveal the properties of these waves that he had discovered. At least he was positive that he was dealing with a wave phenomenon because of the peculiar actions of the transmitter and receiver and their need of being in resonance with each other. As a matter of fact, he wanted to show that these long waves had identically the same nature as the short ether waves of light. If his theory held true it was evident that these longer ether waves should possess the same properties as the shorter ones and that they, like the



A TUNING SCHEME

Figure F: A loose coupler with variometers connected in series with the primary and secondary coils to accomplish tuning.



HISTORY-MAKING RADIO APPARATUS

Figure G: This cut shows the simple but highly ingenious apparatus employed by Hertz in his original experiments at the University of Bohn, Germany. Electromagnetic waves were set up with the spark coil and detected with the simple loop of wire illustrated at the right of the drawing. When the loop was in tune, a spark appeared across the gap. Hertz called the receiving loop an antenna because it resembled the antenna of a butterfly. This term has been held since that time.

shorter ones, should be capable of reflection, refraction and polarization. By setting up a reflector of proper size, Hertz found that he was able to direct these waves about the laboratory with impunity. He could send them shooting in this direction or that in searchlight-like fashion. Not only this, but by using a huge prism of pitch he was able to bend them in the same manner that light waves are bent when they pass through a glass prism. Hertz ended these classical experiments firm in the belief that he had discovered the big brothers of the little light waves that effect the optic nerve of the animal eye.

The tuning fundamentals of Hertz' transmitter and receiver are extremely simple. By measuring the distance from the end of one of the electrodes on the transmitter to the end of the other he was able to determine the approximate physical dimensions of a receiver that would be in resonance or in tune with the transmitter. Hertz knew that the length of the wave emitted by this simple contrivance would depend largely upon the physical dimensions of the spark gap and electrodes. Let us assume, for argument's sake, that the distance between the ends of the electrodes was two feet. If the total length of the wire comprising the receiving loop was made two feet, it would be in resonance or in tune with the transmitter.

By increasing the length of the electrodes or spark gap, Hertz was able to vary the length of the wave emitted. He knew he was varying the length because he threw his receiver out of tune each time he increased the physical dimensions of the transmitter.

After reading the above, we come to the simple conclusion that radio tuning is, after all, very much like the experiments that we conducted with tuning forks and taut wires back in the high school physics class. It will be recalled that if two piano wires of exactly the same length are placed side by side, one will pick up the vibrations of the other even though it is not touched.

Our previous experience with elec-

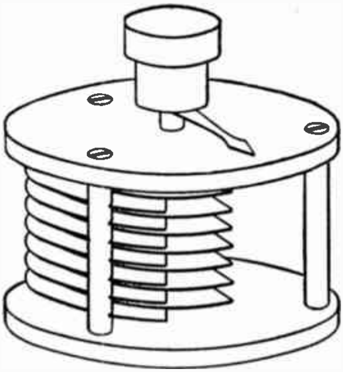
FACTS ABOUT A SIMPLE AERIAL SYSTEM

Figure H: The wavelength of an aerial system depends upon several factors, height being an important consideration as well as length. A high aerial not only means lower capacity (the electrical capacity existing between the aerial and the ground) but it also means a longer lead-in wire which is part of the aerial system and must be added in when calculations in wavelength are made. The aerial is measured not from points A and B as might be expected, but from A to C, which also includes the ground. The natural wavelength of the aerial system should never be greater than the wave to be received; that is the length in meters of the wire between points A and C should never be greater than the wavelength of the broadcasting stations to be received from.

trical condensers taught us that they might be charged and discharged and that this action depended not only upon their size but upon the voltage and frequency of the charging current. By using a condenser in connection with his very simple transmitter, Hertz found that he was able to control the wavelength. When a large condenser was used, the length of the wave emitted was made longer and when a small condenser was used it was made shorter. This can be easily understood, for, when the condenser is inserted, the electrical dimensions of the system are changed and this is equivalent to changing the physical dimensions. An interval of time is necessary to charge and discharge a condenser. This interval of time, as before stated, will depend upon the size of the condenser charging and the voltage and frequency of the current. When Hertz inserted the condenser he was no longer depending entirely upon the physical dimensions of his circuit. He also considered as a factor the rate at which the condenser charged and discharged.

Hertz also knew that he could make waves longer by putting more wire in the circuit because it would take a current longer to get around the circuit, and since the wave it produced depended upon the frequency, it would be longer. This would be just like increasing the length of a piano wire. It will be seen that when condensers and coils are inserted in transmitter circuits to increase the wave length, proportionate changes have to be made in the receiving circuit before it can be placed in resonance or in tune with the transmitter. What we really do when we place condensers and coils in radio circuits is to change the frequency of the current flowing and this always changes the wavelength because the wavelength depends entirely upon frequency.

Let us take into consideration the case of an aerial wire connected to the ground (Fig. H). The wavelength of this receiving antenna will depend almost entirely upon the distance between points A and C. The aerial proper runs only between points A and B. However, in such cases, the length of the ground wire must also be included with any calculations pertaining to the wavelength of



CONSTRUCTION OF THE VARIABLE CONDENSER

Figure I: A variable tuning condenser with which it is possible to make changes in capacity between certain limits, depending upon the number of plates in the condenser, the distance separating them and the general constructional features.

the system. For convenience sake, this antenna system will be said to have a "natural period" of 260 meters. By "natural period" we mean the wave-length to which the antenna system would be naturally tuned without any tuning devices. If such a simple antenna should be connected to a detecting device of some nature, the reception from 260 meter broadcast stations would be possible. This system, however, would be insensitive to the vibrations set up by the 316 meter broadcast stations or by any broadcast station with either a higher or lower wave-length. Of course it would be possible to climb up to the roof and change the amount of wire in the aerial but this would not only be an impractical but a totally unnecessary action. All that we need to do in such a case is to place a coil of wire in connection with the aerial, not on the roof, but in the receiving set used in connection with the aerial. This coil of wire is made variable by arranging its turns so that a small metal slider connected with the aerial may make contact with each individual turn. By moving this slider up and down the coil we may, without going on the roof and with very small exertion, add or subtract wire from the antenna system at the same time increasing or decreasing its length and consequently its response to waves of various lengths.

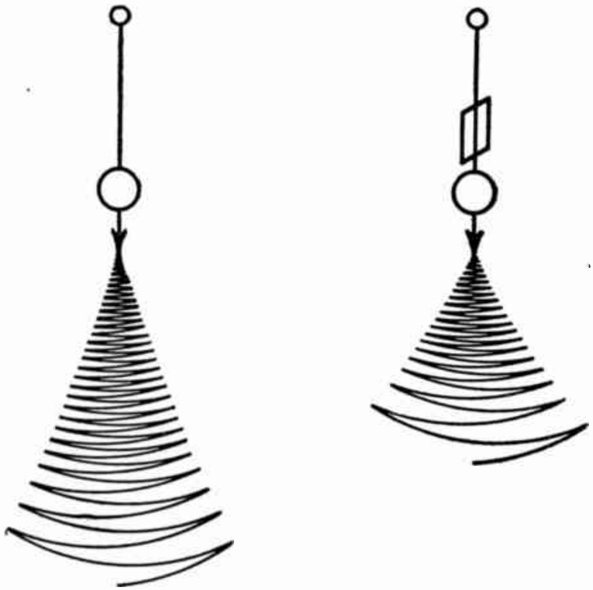
Condensers affect the wave length of receivers as well as transmitters and here we have another element of tuned circuits. It is evident from the outset that a condenser with a fixed capacity, that is a condenser able to hold a definite amount of electricity, would not be suitable for tuning because it would make only one definite change. A condenser with a variable capacity must be used for this purpose and we find in Fig. I a condenser of this type. Here we have a set of stationary and movable plates so arranged that the movable plates are sandwiched in between the stationary ones by turning the knob. The movable plates are kept out of direct contact with the stationary set by air separation and through the use of a suitable dielectric or insulating material. By turning the knob of the condenser, a continuously variable capacity is obtainable, and capacity can either be added or taken from a circuit by this simple action.

There is still another factor that will change the wavelength of a system and this is electrical resistance. Although resistance, due to its destructively inefficient effects, is not used for purposes of tuning, it is necessary that the student should have a knowledge of the manner in which it changes the frequency of alternating electric currents.

In our water analogy (Part II) we saw that the only force opposing the flow of water—hence something to be made as low as possible — is the friction in the pipe. In electric circuits, resistance plays the same role—it uses up the energy in the production of heat which in most radio instruments is to be avoided.

Forcing current through the heater coil of an electric iron produces heat energy from electric energy. The filament of an ordinary incandescent lamp becomes hot and glows for the same reason.

The phenomena considered up to this point have been true of "direct current" resistance, that is, the resistance offered to a steady flow of electricity. In radio, however, we are not dealing with steady currents, but with currents that reverse their direction of flow many, many times a second. Other forces



HOW THE OSCILLATIONS OF A PENDULUM ARE DAMPED

Figure J: The wind-vane attached to the pendulum at the left increases the air resistance and damps the oscillations of the pendulum. In an analogous way, electric resistance in a circuit damps out the electric oscillations of an alternating current.

come into play as soon as we leave the realm of steady currents, and jump into radio-frequency circuits.

At 300 meters, the current reverses its direction twice each cycle or two million times a second. Instead of sticking to the "straight and narrow" the current seems to try to get away from the wire. Like water on a rapidly rotating grindstone, it moves toward the outside of the wire. At very high frequencies, that is, at low wavelengths, the current is actually carried in a thin layer on the outside of the wire or other conductor.

This phenomenon is known as the "skin effect." The crowding of the current to the outside cuts down the effective cross section of the wire which increases the effective resistance.

Litzendraht wire, commonly known as "litz," was originated to overcome this increase of resistance with frequency. This wire is composed of many strands of fine wire, each insulated from the other. Litz is not effective unless great care is taken to see that each strand is cleaned and soldered when making connections. Broken wires within the cable destroy its effectiveness at once. With currents corresponding to a 1,000-meter wave, this stranded wire is particularly useful, while at extreme low wavelengths the current reverses so frequently that the advantages of stranding the wire are not so apparent.

At 200 meters, 99 per cent of the current is carried in a thin shell on the outside of the conductor. The thickness of this surface layer is about .009 inch. For this reason copper tubing is often used for heavy high-frequency currents; the hollow conductor has approximately the same high-frequency resistance as a solid wire.

Just as mechanical friction is the bane of all engineers, electrical resistance, except where heat is required, is a thing to be avoided by electrical engineers. It is not sufficient in designing a coil to go to a wire table, pick out a size of wire that has a low direct-current resistance, and wind up a coil. The problem is one of winding a coil that will have a low resistance to *high-frequency currents*—and that is a task which has bothered even the best of engineers.

The effect of resistance in high-frequency circuits is to damp out the oscillations that exist in the circuit, and such damping out is not advisable. An analogous effect may be seen by counting the number of oscillations a pendulum makes before and after hanging a vane on the bob, so that the air resistance is increased. (Fig. J, Page 119).

The immediate result of adding resistance to a radio circuit is to broaden its tuning. For instance, the two curves shown (Fig K) here are "resonance curves" of a small receiving set. It will be seen that for a given wavelength (350 meters) the amount of current is large. On either side of this peak the current falls off rapidly, so that wavelengths lower and higher than 350 will cause little interference.

The other curve shows at once what happens when resistance is added to a high-frequency circuit. Signals of lower and higher wavelengths are much more noticeable than in the first case.

How are we to avoid resistance in a circuit, say in a receiving set?

A complete answer involves the mutual effects of circuits on each other, which is a matter that we will discuss under inductance. There are, however, a few practical rules to bear in mind, though, like many rules, they frequently fail:

1. Make only single-layer coils—or if more than one layer is necessary, use a bank winding.

2. Space solid wires about the distance of the diameter of the wire. Do not space Litz wire—wind turns closely together.

3. Avoid taps.

4. Avoid larger coils than necessary. Do not expect a coil large enough to tune to waves of 3,000 meters to do good work on 300 meters.

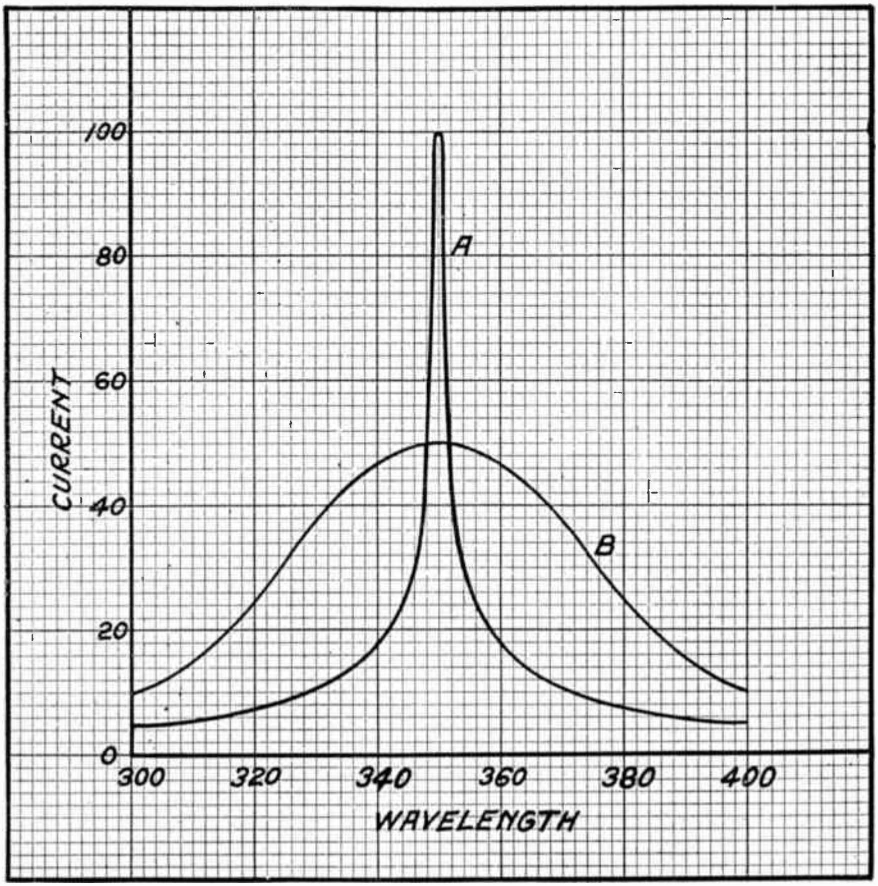
5. Use small tubes and many turns rather than large tubes and few turns.

6. Make leads short and of the same size of wire as the coil.

7. Choose the size of wire carefully.

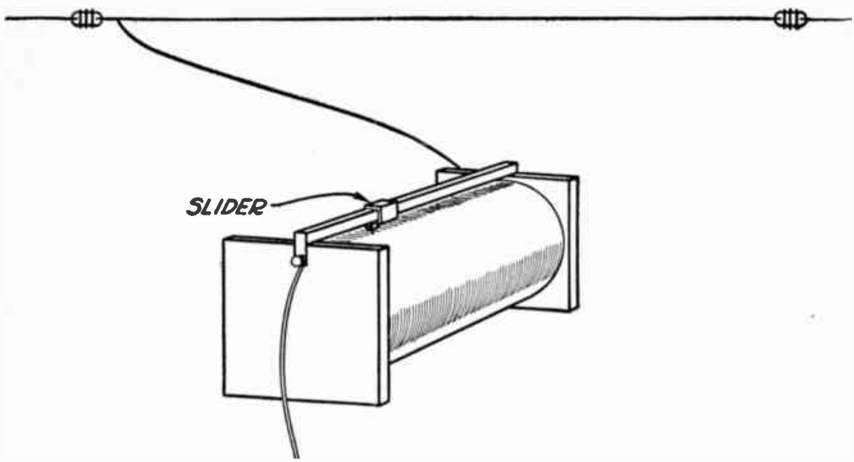
It is a safe rule to use wire between the sizes of No. 18 to No. 30, although it must be admitted that tuners made of smaller or larger wire than these limits sometimes work and work well.

We are now ready to take up the subject of tuning devices and the first one that comes to our attention, because of its simplicity, is the single-slide tuning coil. Although the single-slide tuning



HOW RESISTANCE IN A CIRCUIT AFFECTS TUNING

Figure K: Resonance curve A corresponds to a circuit that has little resistance. The tuning is sharp on a wavelength of 350 meters. Curve B represents a circuit containing more resistance. The resonance is less sharp and the tuning is broadened.



THE SINGLE-SLIDE TUNER

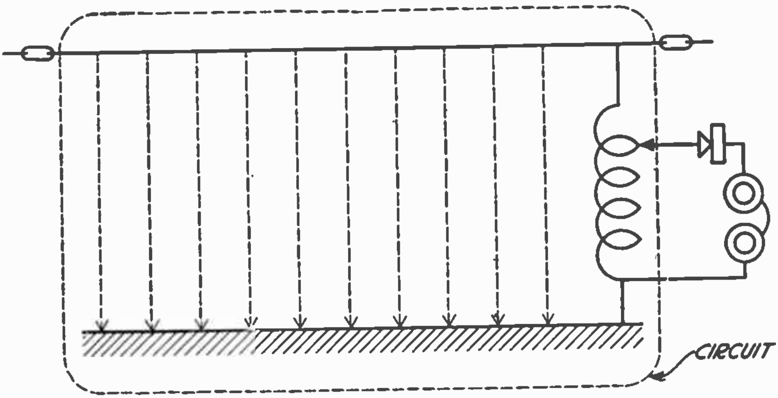
Figure L: How the simple single-slide tuning coil is connected to an aerial to form a variable portion of it.

coil was a much used device in the early days of radio it is now practically obsolete having given place to more efficient devices for the bringing about of resonance. As might be expected by the reader who has carefully followed the foregoing matter, the old fashioned single-slide tuning coils were directly connected to one end of the antenna and were, in effect, merely a concentrated part of the antenna system in general. For that matter, every tuning device is a concentrated part of the aerial system but it seems more logical to look upon the single-slide tuner in this way because of its extremely simple construction. One of our accompanying sketches (Fig. L) shows the method of connecting the single-slide tuner in the aerial system. Here it will be seen that the slide or the movable contact, which makes connection with the turns of wire upon the cylinder, is connected with the ground and that by moving this slide, wire may be added or taken from the aerial.

A tuning coil, or for that matter, a tuning device of any kind, connected in the manner shown is said to be in the antenna or aerial circuit. It is well to remember this for radio literature of all kinds makes reference to the antenna circuit.

While there are a number of different ways of connecting even this simple single slide tuner, it is useless to consider them because of the technical standing of this form of tuning device. However, by viewing Fig. M, page 123, the student will be able to grasp a fundamental which will show the logic of referring to a tuning coil and an aerial as a circuit. In the past, our conception of a circuit has generally involved a complete metallic path from the positive side of a source of current like a battery or a generator back to the negative side.

If we will recall the explanation of a condenser, we shall see that the aerial and the ground with the dielectric, air, in between really forms a condenser of small capacity. Thus a circuit is established taking the route shown in Fig. M.



THE CAPACITY BETWEEN AERIAL AND GROUND

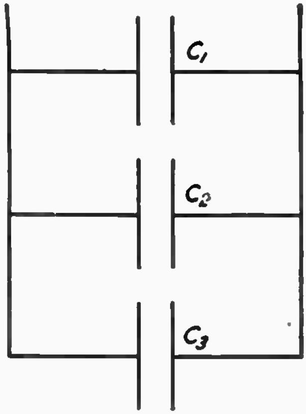
Figure M: The dotted lines represent the capacity existing between the aerial and ground of any aerial system.

There is also a second circuit involving the tuning coil, the crystal detector and the receiving telephones. At the same time it will be seen that an antenna circuit is not merely a circuit containing inductance or wire. It must, for the reasons given, contain some capacity. The amount of this capacity will depend upon the height of the aerial and its size. If the aerial is very small and very high it will have an insignificant capacity and vice versa.

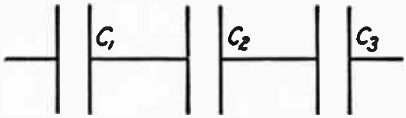
Aerials of large capacities are, of course, more susceptible to longer waves than are shorter aerials. They are susceptible to longer waves not only because of a large capacity but because of a great amount of inductance. It often happens that the amateur experimenter or radio fan is unable to put his equipment in resonance with a distant transmitter of low wavelength because the "natural period" of his antenna system is safely above the wave which he desires to receive. His antenna may have a natural wavelength of 300 meters and the wave he wishes to receive may be as low as 215 meters.

The treatment of this problem allows us to put into actual practice some of the facts we absorbed earlier in the course concerning the connections of condensers and how these connections affect the combined capacities. For instance, it was said that connecting condensers in series reduced the capacity of the group. Two one microfarad condensers connected in series (illustrated again in Figure N) result in an actual combined capacity of ½ microfarad. If the condensers were connected in multiple or parallel, the capacity would be added and there would be available a total capacity of two microfarads.

By taking advantage of this peculiarity of electrostatic condensers we may very conveniently reduce the capacity and thereby the natural period or natural wavelength of an antenna circuit by merely placing in series with the aerial and the tuning device a small condenser of either a fixed or variable type. Of course, with the variable type finer adjustments may be made in tuning and greater selectivity or separation of wavelengths is attainable. What we really



CONDENSERS IN MULTIPLE



CONDENSERS IN SERIES

HOW TO CONNECT CONDENSERS

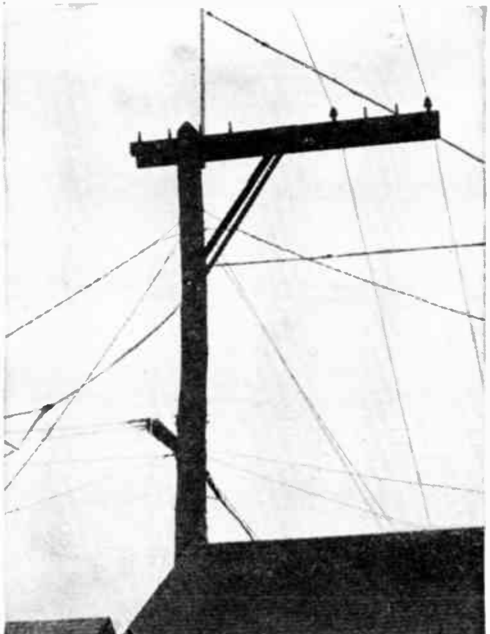
Figure N: The above directions must always be followed if condensers are to be connected in groups to give different capacities.

do here is to place a capacity in series with the existing capacity between the aerial and the ground. This always results in reducing the wavelength because the *total capacity is made smaller*.

If it is found that an antenna system, or technically an antenna circuit, will not respond to a long wavelength there is another way that may be resorted to in boosting the wavelength to a point where the longer wave will be successfully entrapped. It would be necessary only to wind a few turns (actual number of turns will depend upon the increase desired) of wire upon a cardboard tube which would be inserted any place between the aerial and the ground. Such a coil is technically known as a *loading coil*. It really is a wavelength booster.

Before passing on to the more involved systems of tuning radio receivers, it would be wise to treat more thoroughly the practical features of antenna erection and construction. Here at last is a point where the practical mixes freely with the theoretical. Since the antenna is essentially one plate of an electrostatic condenser, it is evident that it must be properly insulated from the other plate, the ground. If there is any considerable leak between the aerial and the ground, the condenser will be more or less ineffective and the receiving set will fail to take in the largest amount of energy possible. This will result in low efficiency and poor selectivity. Aside from the aerial forming a part of the condenser, it must also be remembered that there is induced in it an actual measurable electric current, for when these rapidly moving radio waves strike something that is attuned to them they are immediately reconverted back into electric currents of a very small value.

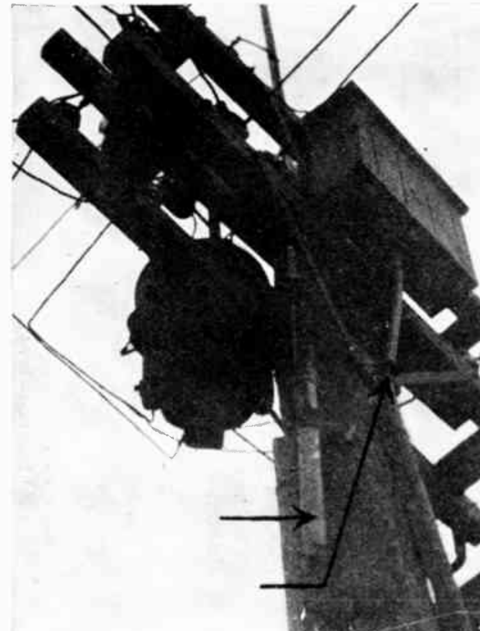
Insulators used to hold antenna out of electrical contact with their surroundings should be of the best possible quality to prevent leakage. They must also be chosen with some idea as to their resistivity to weather conditions. Glass



Courtesy of New Jersey Accident Prevention Committee

DON'T STRING UP YOUR ANTENNA WHERE IT MAY TOUCH OTHER WIRES

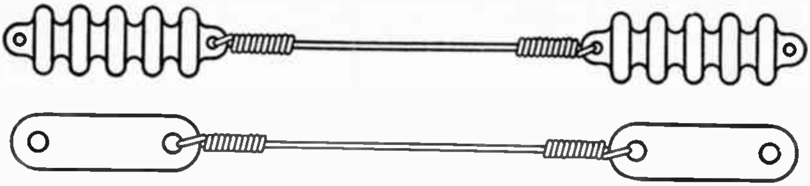
Figure O: You involve risk when you place an antenna in a maze of wires like the one shown above.



Courtesy of New Jersey Accident Prevention Committee

DON'T RIG ANTENNA ON ELECTRIC LIGHT POLES

Figure P: The short arrow points out an antenna supporting-pipe that passes close to power lines. The long arrow indicates an antenna pulley attached to a cable.



HOW TO USE INSULATORS

Figure Q: The use of insulators in tandem. The insulators above are made especially for aerial use while the lower cut shows how ordinary insulators used in house wiring may be pressed into service. Many other types of insulators are used but the corrugated porcelain type shown at the top is in great favor.

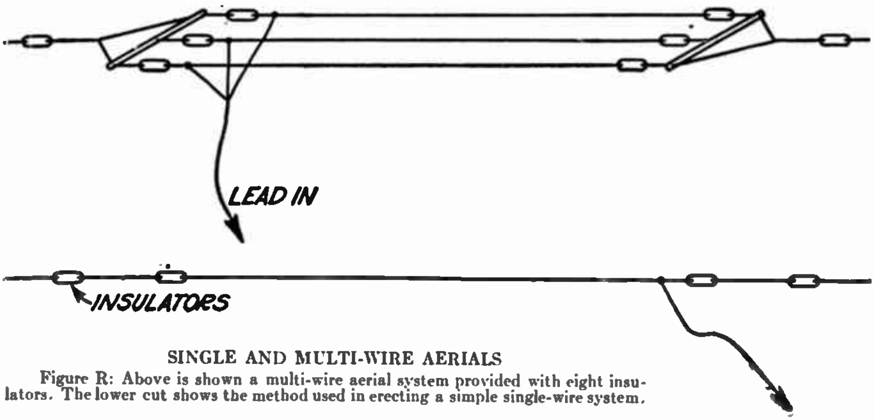
and porcelain are not only excellent insulators but they are able to withstand the worst attacks of the elements for many years without showing signs of appreciable electrical depreciation. Insulators, when used in connection with a single wire, which is usually the type employed for broadcast reception, are ordinarily placed in tandem. These will be found illustrated in Fig. Q. The reader will also notice (Fig. R) the general method employed in making multi-wire antennae. The wave length of a multi-wire antenna depends largely upon the method of connecting the wires. If four wires are used and connected at their ends in the form shown, the wavelength will be a little greater than that of one wire for there will be a greater capacity due to the increased area.

Single wire antennae used for broadcast reception should have a total length, excluding the tuning devices but including the ground wire, of about 150 feet. This does not mean, of course, that signals cannot be received on a 50-foot antenna or a 25-foot antenna. It simply means that greatest efficiency would result with the longer antenna because it will, so to speak, obtain a larger "grip" on the ether. The more wire (within definite limits), generally speaking, that is exposed to the waves, the greater the induced current will be.

Indoor antennae cannot be as efficient as antennae placed directly in the path of approaching waves. While it is true that electromagnetic waves can penetrate solid matter with ease, they always do so at a sacrifice in energy. Unless an ultra-sensitive receiving set is used, it is not advisable to employ an inside antenna of the type mentioned.

In designing and erecting an antenna it is important that the constructor consider the effect of placing the antenna in various directions. There is well substantiated experimental proof which shows that aerials receive best in the direction in which they are pointed. This "directive effect" is most pronounced when the far end of the antenna wire is higher than the other end. It sometimes happens that a transmitting station that eludes the antenna in one position can be received from by effecting a change in the direction of the aerial.

Some advice on the type of wire to use in aerials may not come amiss. Iron, steel or any other wire with a high resistance must be avoided if the efficiency of the receiving set is to be brought up to the highest possible level. The wire used should be of copper with a fair sized diameter. If bare copper wire is used, a single piece about No. 14 gauge is preferable. Smaller gauges used in large spans are apt to succumb to belligerent winds. Stranded copper wire, which is made up of a half dozen or more of independent wires twisted together, is

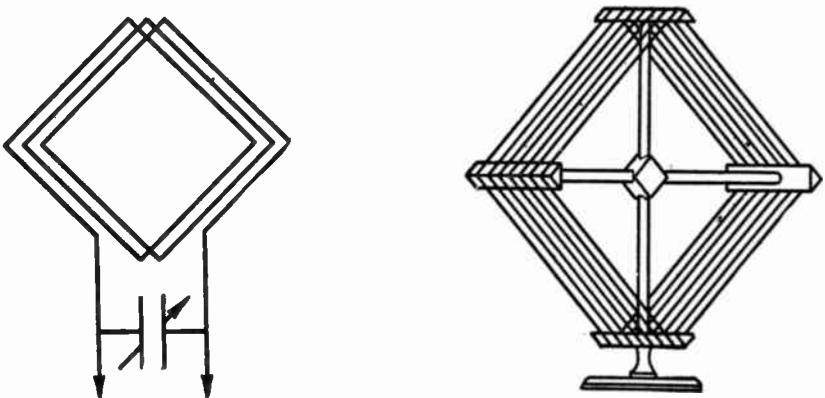


SINGLE AND MULTI-WIRE AERIALS

Figure R: Above is shown a multi-wire aerial system provided with eight insulators. The lower cut shows the method used in erecting a simple single-wire system.

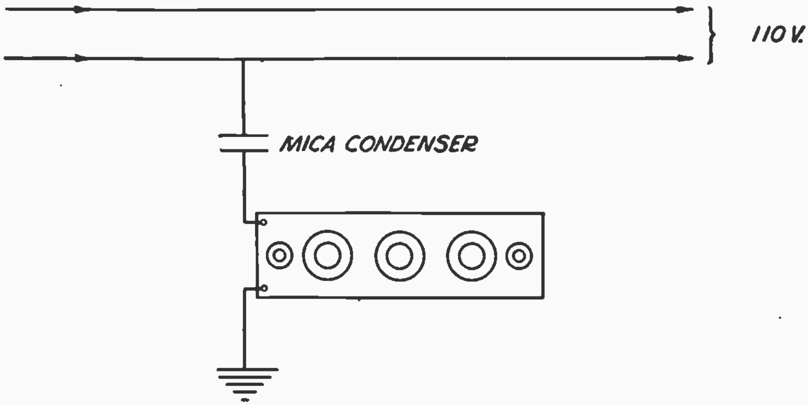
best both from the electrical and mechanical standpoint.

There is a system of using the electric light wires of a building as an antenna and, while this principle does not work out in all cases, due to peculiar local conditions, it is worth trying. It would be disastrous and highly dangerous to connect a radio set directly to an electric light socket, but it has been found that a small condenser, while it will effectively choke off the low-frequency currents in the lighting circuit, will permit the high frequency currents of radio to pass with little resistance. The inquisitive reader, remembering that condensers transmit current, will probably wonder why the current from the lighting circuit is not able to pass through with the radio-frequency currents. Perhaps a small amount of it does, but it is not appreciable and certainly not enough to be considered. If a great quantity of current was to be taken from an alternating lighting circuit through a condenser, the condenser



HOW TO TUNE A LOOP

Figure S: At the left is shown the method of connecting a variable condenser to a loop aerial for tuning purposes. The cut on the right shows the conventional construction for loop aerials.



THE LIGHTING WIRES AS AN AERIAL

Figure T: How it is possible, using a small fixed condenser, to connect an ordinary receiving set to the lighting circuit. Long distance reception is attained with such an arrangement.

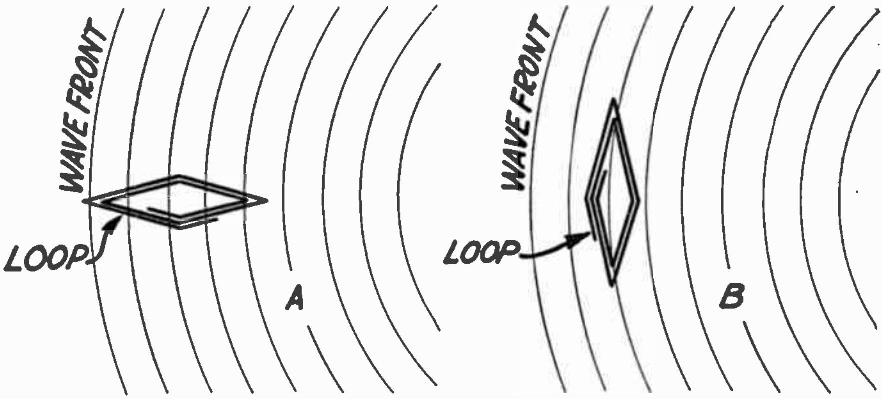
would have to be of tremendous capacity due to the low frequency.

The success of connecting a receiving set to a lighting circuit through the medium of a fixed mica condenser depends upon the fact that every lighting circuit in any building absorbs a certain amount of the energy from passing radio waves. By suitably connecting a receiving set to this lighting circuit, this energy may be made available in the form of music and speech.

There is still another type of indoor aerial, the loop. The loop is sort of a concentrated antenna wound upon (and insulated from) a frame in the form of a coil. As in the case of an outside antenna, the wavelength of an indoor loop depends largely upon the number of turns it carries. The fewer the turns, the lower the wavelength and vice versa. (Refer to Fig. S, page 127).

The loop is really a magnetic type of antenna. It functions as a coil of wire functions when it is brought into a field of magnetism produced by an alternating current source. While it has a measurable capacity it is not as high as that of an outdoor antenna. Loops are usually tuned by varying the number of turns they contain through the medium of a switch or by shunting a variable condenser across their terminals as in Fig. S. There is another factor, too, that determines the efficiency of loop reception and this is the position of the loop in regard to the direction of the approaching waves. It has been found that loops have marked directive effects and that they receive best when placed in certain definite positions. This fact brings us to a simple electrical rule, an understanding of which will not only permit us to use a loop with intelligence, but which can be applied practically in reducing interference from extraneous sources.

It has been shown that coils of wire pick up and convert electromagnetic waves best when they are placed in a certain definite position with regard to the waves. When a coil of wire is placed in the position illustrated at B, Fig. U, minimum energy will be received. If the loop is turned so that it points di-



LOOPS AND HOW THEY INTERCEPT WAVES

Figure U: At A, the loop is positioned so at to intercept the maximum amount of radio energy. When in this position, it will be pointing directly at the radio station doing the transmitting. B illustrates the position of minimum sensitivity.

rectly to the transmitting station, maximum energy will be induced in it.

By employing a system of loops, the Navy Department of the United States has been able to devise a workable scheme for the location of ships at sea. This rule of the loop is more or less invariable and if the direction of a transmitting station is known, the operator will have little or no trouble in receiving from it if he places his loop so that it will point in the general direction of the station. The tuning effect of the loops, will at once be evident when a loop is turned during reception. The strength of the reproduced sound will vary all the way from great audibility to practical inaudibility by turning the loop 90 degrees.

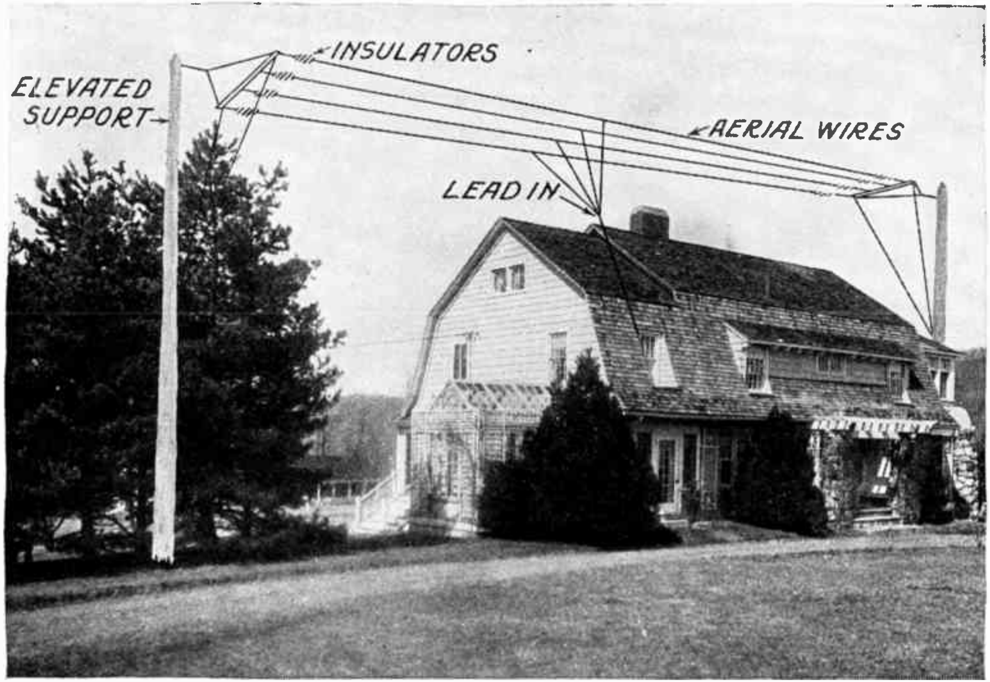
By employing some tricks of the trade it is possible to receive over comparatively great distances by using highly sensitive receivers minus the conventional aerial. As a matter of fact, the systems that we are about to describe* do not use aerials at all. While reception by means of these methods will be found very satisfactory considering the conditions, the novice using them should not expect to duplicate the performance of outdoor antenna systems.

"Many circuits of one sort or another have been devised which enable broadcast reception without the use of an antenna. Mainly these have been comprised of multi-stage amplifiers of the radio-frequency type; and no general attempts have been made to take advantage of the inherent sensitivity of regenerative circuits in conjunction with 'antenna-less' outfits.

"In passing, two interesting facts might be observed. (1) The cheapest and most effective form of radio amplification which has been devised for use in conjunction with an antenna-less radio receiver may be constructed at a cost of a few dollars. It is comprised of an average-sized antenna and a good earth connection.

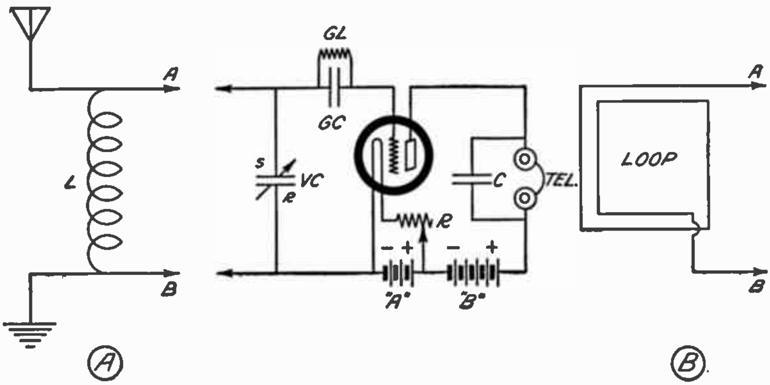
"(2) As compared to hazards involved by telephone and electric light connection due to lightning or other cause, the lightning hazard of an antenna is, at least, small.

* They are outlined by the famous radio experimenter, Paul Godley.



PUTTING UP A BIG TRANSMITTING AERIAL

Figure V: A good method of erecting a large transmitting aerial system. The student will notice special guy wires arranged at each end of the aerial to prevent it from swaying in the wind. This not only increases its resistance to the elements but adds to its electrical efficiency.

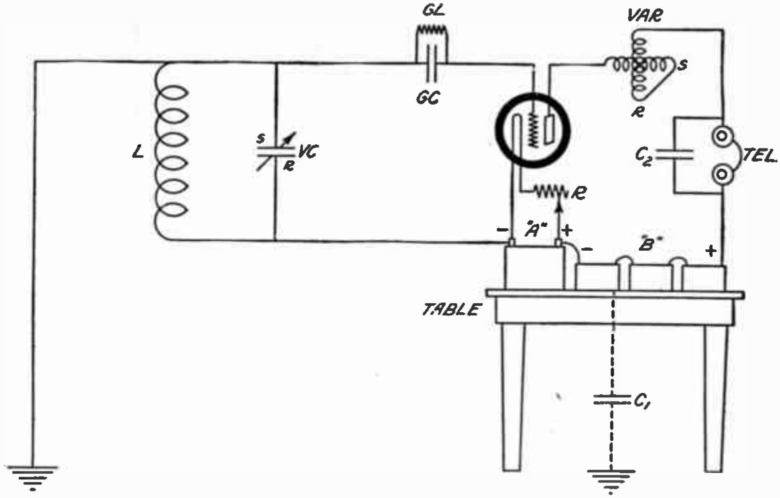


TWO PICK-UP SYSTEMS

Figure W: The potential developed across the terminals A and B of coil L (shown at "A" in connection with an outdoor antenna) are of enormously greater amplitudes than these developed across A and B of the loop antenna (shown at "B"). If either of these two pick-up systems were used with the vacuum-tube detector circuit (shown in the middle of the diagram), scheme "A" would therefore be immeasurably better.

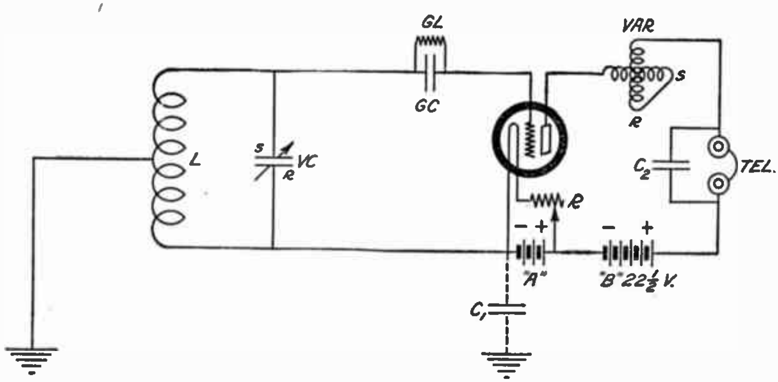
"Multi-stage radio-frequency units depend as a rule for excitation upon the current collected by a loop antenna consisting of a few turns of wire on a square frame, two feet or so on a side, and almost invariably the circuits call for a ground connection. Upon trying circuits of this sort, it is immediately learned by the experimenter that if the ground connection is left off the strength of the received signal is materially weakened. From this it must be assumed that all of the energy which excites the outfit does not come to it through the loop antenna; that the ground connection in itself is in some manner acting as an antenna; that currents are being generated in the earth and fed up to the receiver through the ground connection.

"It takes but a moment for even the uninitiated experimenter to prove to his own satisfaction that the currents generated in the loop antenna, such as that described briefly above, are small indeed as compared to those generated in an overhead antenna of average dimensions. In other words, the difference of potential which exists between the points A, and B, in the antenna circuit (left hand side Figure W) are quite large as compared to those differences in potential existing between points A, and B, in the right hand side of Figure W. The ratio of those potentials will run somewhere in the neighborhood of one hundred to one. If the ground connection is run directly to the grid of the vacuum tube (as shown in Figure X) and if proper compensation is made in the tuning element of Figure X so as to allow for the change in wavelength which results, surprisingly large values of signal will be fed into the outfit as compared to those fed into it by the loop alone. The ratio of the signal potentials picked up on the average ground connection, as compared to those picked up by the average antenna, is about twenty to one in favor of the antenna. This ratio will vary a great deal, however, depending upon the type of ground connection. Where the ground connection is a long one, the energy picked up



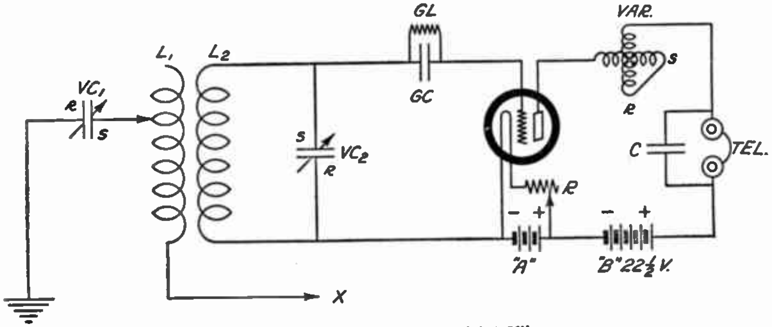
GETTING GREATER SIGNAL STRENGTH

Figure X: If the grid side of the loop or tuning inductance is attached to ground and the tuning of VC varied to take care of the change in wave-length, a much greater signal will be obtained than without the grouud.



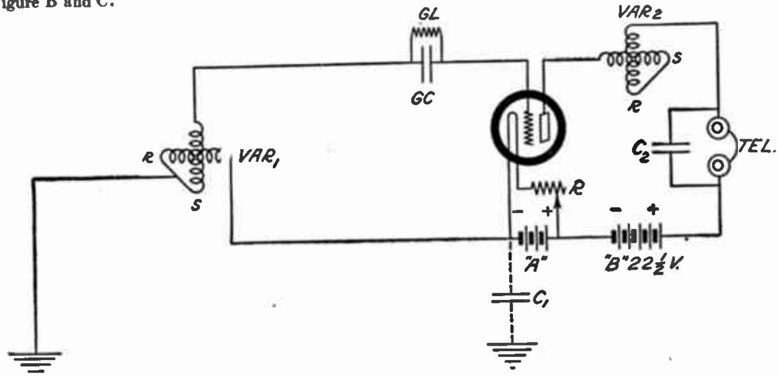
GROUNDING THE CENTER OF THE GROUP

Figure Y: A still greater signal may be obtained by this method of grounding in which the ground is taken off somewhere in the middle of the loop or tuning inductance



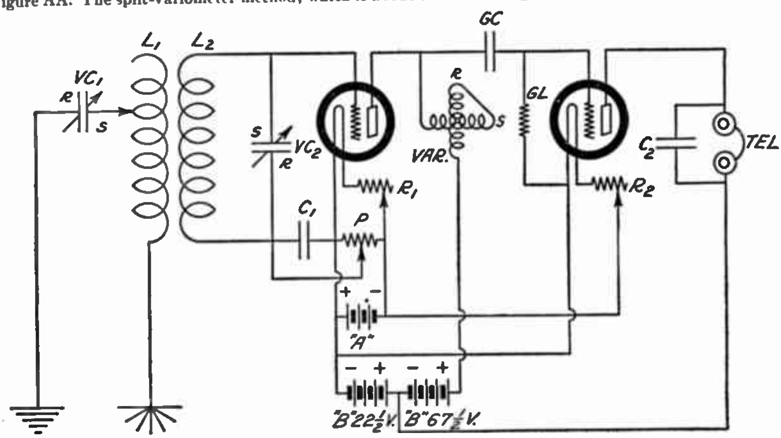
OVERCOMING "BODY CAPACITY"

Figure Z: This circuit overcomes the inherent body-capacity troubles encountered in the circuits of Figure B and C.



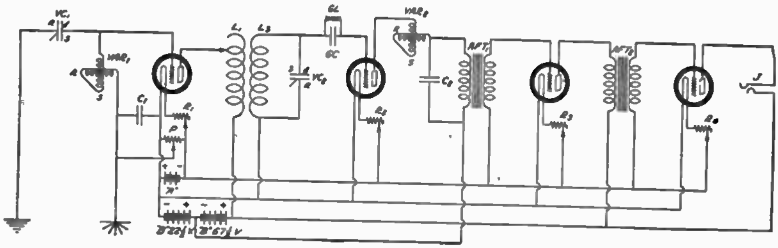
SPLIT VARIOMETER METHOD

Figure AA: The split-variometer method, which is about the same thing as shown in Figure C.



USING R. F. AMPLIFICATION

Figure BB: One stage of tuned, regenerative, radio-frequency amplification



THE MOST EFFICIENT CIRCUIT

Figure CC: The best circuit arrangement of all to use. This is a standard three-circuit regenerative receiver, with the tuned ground circuit, one stage of radio-frequency amplification and two stages of audio-frequency amplification. This is an exceptionally sensitive set-up and works splendidly with this antennaless system.

will be *greater*; if the ground connection is a short one, it will be *less*. In the average home, however, this ratio of approximately twenty to one will hold true.

Connecting the ground to the grid of the vacuum tube is *not* desirable, however, for the reason that the size of the capacity C-1, is large. (This capacity C-1, is formed by the receiver and its battery which go to make up one plate of a condenser, and the ground which forms the other plate. The insulating material, air, or whatever it may be, between the receiver and the earth, forms the dielectric. Its value will, of course, vary, depending upon the location of the receiver with respect to the earth.)

"A better method of connection is that shown in Figure CC, where a tap is taken out of the center of the grid inductance and grounded. This, however, has not completely eliminated the difficulty of the shunt capacity; furthermore, both the methods of Figure X and Figure Y place the filament circuit of the receiver at a potential considerably above earth potential, which results in serious difficulties as soon as one attempts to tune the outfit, as the operator's body in approaching the receiver will alter the value of the capacity C-1, in either case, with the usual baffling result.

"The circuit shown in Figure Z overcomes these difficulties and results in the same signal strength. Figure Z is easily arranged in conjunction with any standard three-circuit receiver and may be set up without any great amount of difficulty when using a single-circuit receiver (merely by supplying and coupling an extra inductance L-1).

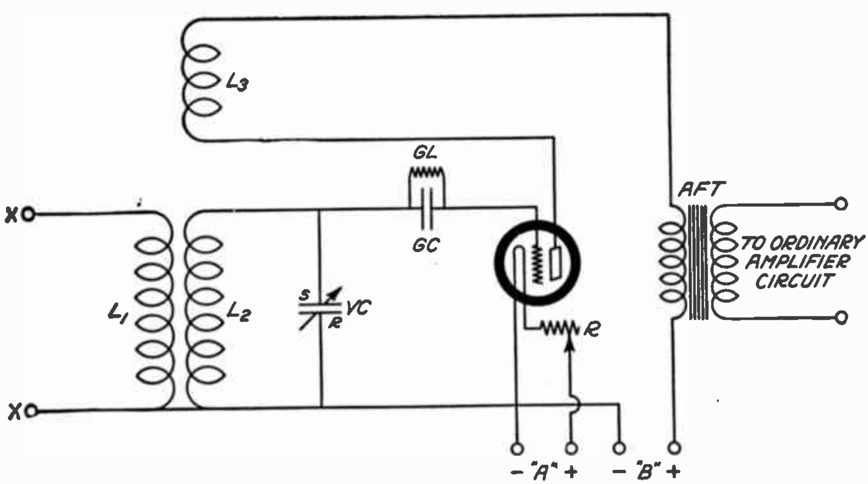
"Figure AA indicates a method of utilizing the earth pick-up where the receiver is comprised of two variometers, one in the grid circuit and one in the plate circuit. In this case, the earth is connected to the mid-point of the grid variometer."

While there are many extraneous sources of interference with radio reception, aside from the lack of sensitivity in many poorly designed receivers, most of these obnoxious interruptions and irritating cacophonies may be eliminated by taking advantage of certain definite electrical laws.

Interference from power lines is more or less chronic in small towns where heavy sources of current surge through wires on telegraph poles. This interference is due not only to leakage from the power lines but to direct inductive effects. In the case of leakage, a noise is produced in the receiver very much like that produced by static. It may not appear with any regularity and at times only when the weather is damp or rainy. There is little that the radio student can do to overcome such annoying noises. Certainly he should by no means risk his life investigating the insulators on the poles near the house. Power lines that cause chronic interference of this nature usually carry a death-dealing current that burns human flesh immediately it comes in contact with it.

The power companies throughout the country have in general bent every effort to keep interference of this nature down to a minimum. It seems that they are not only desirous of keeping informed regarding leaks in their lines but that they also have a genuine desire to establish peace and tranquility in the ethereal world. If chronic cases are reported to them, an effort will be made to seek out the character of the trouble. It often happens, however, that the exact source of interference of this nature is most difficult to locate. If the power company cannot find it, it behooves the troubled person to set about to locate it himself. If the following directions are carefully carried out, a simple and effective means of searching out this form of annoyance will be available.

A trouble finder must be portable and it must employ a loop antenna or receptor. The most essential factor is the directional property of this loop antenna. If the loop antenna is directional in its effect, the source of interference may be located by direct tracing or by triangulation; that is, by taking a bearing with the loop receiver from two or more different points in the zone of interference and drawing lines on a map of the city, one from each point



THE WIRING DIAGRAM OF THE INTERFERENCE LOCATOR

Figure CC2: The terminals marked X connect to the loop. The circuit is the ordinary three-coil tickler hookup. Any other good circuit can be used provided it is arranged to tune the wavelengths below the broadcasting, so that the interference can be received without the music or lectures.

where a bearing is taken, in the direction in which the loop antenna points, and the source of the interference will be found at the point of intersection of these lines.

A common type of power-line interference is that produced by an arc in a circuit due to leakage from one circuit to another, from a circuit to the ground, or to a poor connection. This arc tends to set up currents which feed back through other power lines, with the result that the interference is noticeable over a wide area, although the maximum interference will be noted in the immediate vicinity of that part of the circuit which is arcing. With an ordinary receiver that employs a loop antenna, it is often difficult to locate the source of interference by triangulation, due to the fact that the interference is prevalent over such a wide area and affects the receiving circuit direct or through the battery and telephone leads, thus tending to destroy the directional property of the loop antenna. It is, therefore, essential that a receiver be employed which will not be affected by disturbances except through the medium of the loop antenna. A receiver of this type has recently been used in an investigation of power-line interference in a Georgia city.

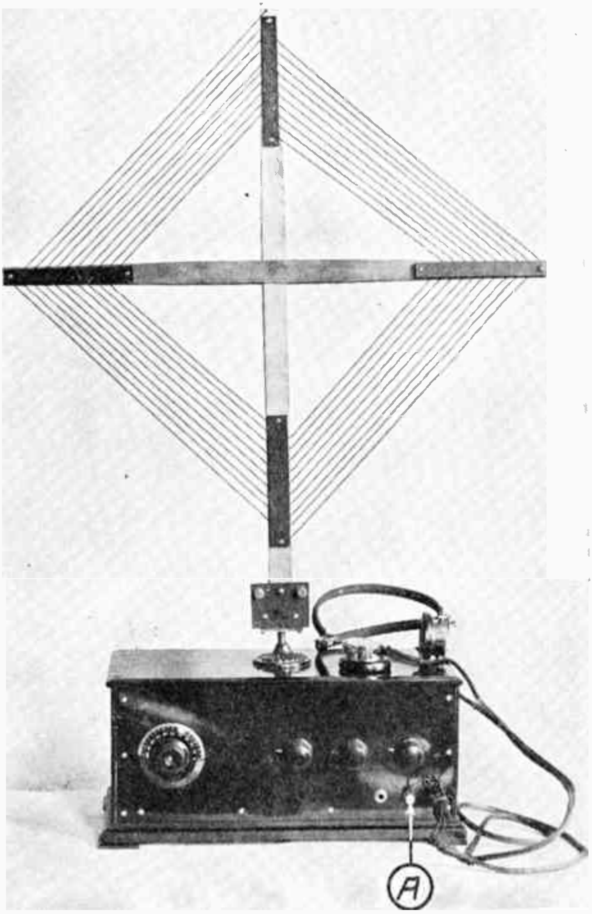
The wiring diagram of the trouble locator is shown. The primary and tickler coils are wound in the same manner as the coils in a "low-loss" tuner, of No. 18 cotton-covered wire, 3¼ inches in diameter, the primary having 5 turns and the tickler 12 turns. The secondary is wound on a 4-inch cardboard tube in the ordinary way, of No. 18 cotton-covered wire, having 23 turns. A .0005 mfd. variable condenser is shunted across the secondary.

The general construction of the loop antenna is also shown in Fig. DD.

The thorough shielding of the receiver should be noted from the illustration. The inside of the receiver cabinet is lined on all sides with tin and all battery and telephone leads are covered with copper braid connected to the shielding inside of the cabinet. The shielding around the telephone leads is connected to a binding post between the telephone jacks, the binding post being connected to the shielding inside of the receiver cabinet.

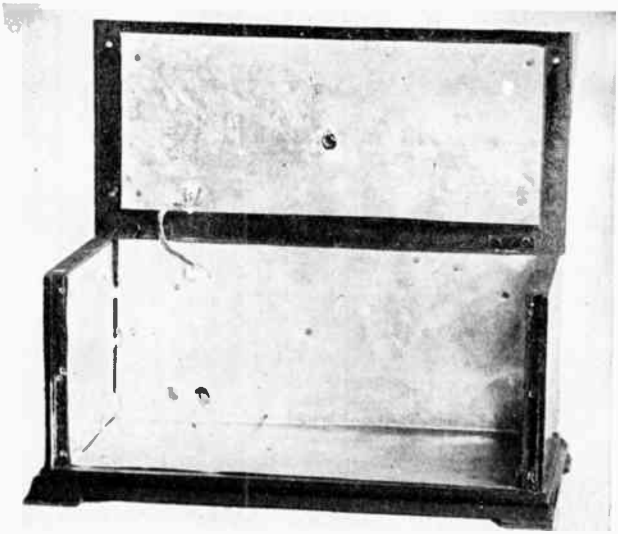
The first test was made with an ordinary loop receiver, with which the interference was traced to a street lighting circuit, which, when cut off, eliminated the interference. This circuit, however, is twenty miles long and the power company had no means available for locating the exact point in the circuit from which the interference came and the loop receiver being used was not sufficiently directional to locate it. A power-line expert was then sent to this city but was unable to locate the exact source of the trouble, although exhaustive tests were made of lights, insulators, generators and other equipment under suspicion. These tests, however, developed some interesting facts and after comparing notes on these two tests it was decided to construct the receiver referred to above.

Another test was then made using this thoroughly shielded receiver. The interference was found to be greater in one section of the city and the point of maximum intensity was found by listening on various broadcast receivers in the vicinity. Maximum interference was noted at the residence of a broadcast listener two blocks from the point where the defect in the lines was ultimately found. At this point, using a receiver employing three stages of radio-frequence amplification, detector and two



A SET THAT LOCATES POWER-LINE INTERFERENCE

Figure DD: The binding post A, between the two jacks, is grounded on the shielding inside the cabinet so that an extra wire connected to the copper braid that is wound around the 'phone cords may be grounded to the inside shield.



COMPLETE SHIELDING MAKES THE LOOP SHARPLY DIRECTIONAL

Figure EE: Shielding may be of doubtful value in many types of receiving sets, but it is essential in locating interference. The cabinet shown above is completely lined with sheet metal. The top section is electrically connected to the rest of the shield by the piece of copper braid, as shown.

stages of audio-frequency amplification, connected to a loudspeaker, the disturbance could be heard for nearly two city blocks, completely drowning out all broadcasting stations.

The shielded receiver was mounted in an automobile and the maximum signal strength was noted when the loop receptor was pointed directly down the street. As a 13,000-volt transformer was located in the center of the street about five blocks away, the automobile was moved in that direction, but upon arriving at the transformer it was noted that the signal strength had decreased and the loop receptor pointed back up the street. Several trips were made up and down the street between two of these transformers until the car was finally stopped about two blocks below the residence of the broadcast listener, directly in front of a suspended street light, where it was found that the signal strength was at its maximum.

A pole was secured and when this light was tapped the interference varied from nearly minimum to maximum as the light swung from its support; this variation was noted on both the portable loop receiver and also on the receiver located in the residence of the broadcast listener two blocks away. The car was moved about one block, first to the right and then to the left of the light, and new bearings taken; and in each instance the loop pointed directly toward this light.

A lineman was secured who shorted the light, which was a high-voltage series lighting circuit. But this did not remove the interference. The outlet to this light was then shorted on the pole and the circuit leading to the light entirely cut out, but this also failed to eliminate the trouble, although tapping the light caused the strength of the interference to vary as first found. The lineman shook the various wires attached to the pole below the 13,000 volt line; it was found that the interference stopped when the steel guy wire, supporting the street light, was raised. This guy was found to be lying across a 2,300-volt primary circuit, causing an arc. The light, swinging in the wind at times, apparently accounted for the intermittent nature of the interference.

The tests were started at 8.00 P.M. and the trouble was located about midnight; a lineman was secured and the trouble remedied about 3.30 A.M. About eight hours were required for the test. It will be found in such cases that patience is as much a necessity as the proper type of equipment.

The circuit employed in a receiver used for this purpose was not found to be important, so long as sufficient amplification is employed, two stages being preferred, and the wavelength range is low enough to avoid interference from local transmitting stations.

The shielding, however, is extremely important. Isolating the receiver in this manner, but not connecting any part of it to the shielding, tends to increase the directional properties of the loop receptor, which is a vital factor in locating any type of interference.

Interference from power lines is sometimes characterized by a constant and loud hum of undiminishing amplitude. If the power line is close by, this hum is of sufficient magnitude to be heard over reception. Unfortunately, few remedies can be applied to eliminate such trouble. In some instances this "AC hum" as it is often called, is produced because the antenna runs parallel with the power lines. The inductive relationship in such cases is ideal for a maximum amount of current will be transferred from one circuit to another inductively when the wires run parallel. About the best thing that the novice can do is to run his antenna *at right angles to the power lines*. This should diminish, if not eliminate, the noise. If it does not diminish it sufficiently, the next best thing to do is to shorten the antenna for larger antennae usually pick up a greater volume of current.

While speaking about power lines, the student is warned against running his aerial system over any wires carrying electric current. This includes lighting service wires, for, while 110 volts is not looked upon as fatal, surges in power lines and defects in transformers often cause the voltage in such service wires to rise to a very high value. Furthermore, if the aerial wire should drop in a windstorm and accidentally short circuit the service line, heavy electrical damage would probably result. Not only this, but a person operating the receiver might receive a dangerous shock and all of the vacuum tubes and perhaps the transformers in the receiver would be burned out.

It must be remembered that electric light systems are grounded as well as radio circuits and that should the aerial come in contact with only one side of a power circuit, a short circuit would be produced. There is also a possibility that such a short circuit would produce a fire if the aerial dropped during the absence of the family.

It is odd how the mention of outside aerials usually brings to the mind of the novice the subject of lightning. It seems that there is an inborn fear of lightning in the human race. It is unfortunate, too, that misinformation often spreads more rapidly than true knowledge and this has been the case in connection with lightning and radio.

Lightning, like other dangers we face, appears worse than it is. Of course, the probability of danger has been well advertised from the standpoint of public safety by the Board of Underwriters and from the business standpoint by manufacturers of lightning arresters.

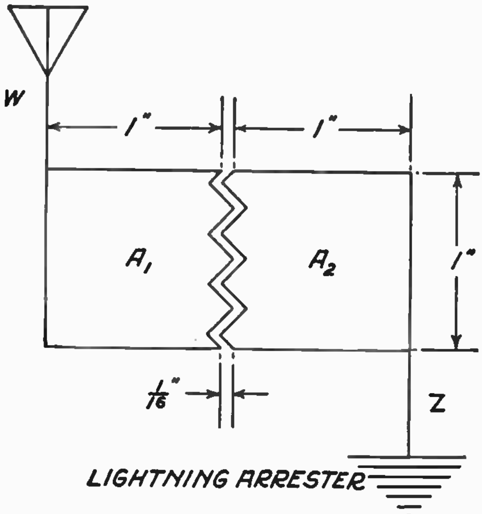
Fears disappear with knowledge of the facts. The facts that relate to the possibility of lightning striking an antenna are of two groups: facts of experience and facts of science.

As to facts of experience:

After twenty years of radio, there are but few cases on record of antennae being struck by lightning. It is nonsense to attribute to a radio antenna the power to attract or change the course of a lightning discharge of billions of volts.

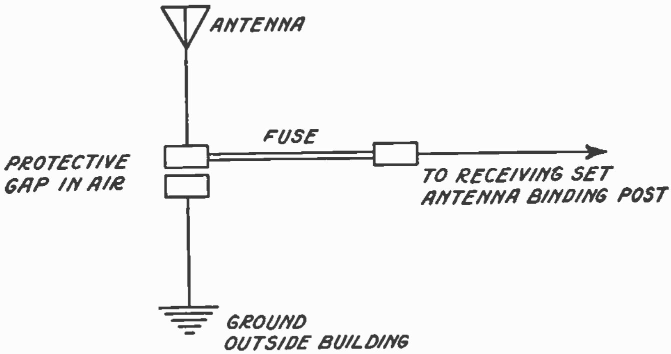
Here are a few of the facts of science:

Most visible lightning discharges take place between clouds of different potentials. If every flash seen during a storm were grounded to earth in the form of a direct discharge, a thunderstorm would invariably be accompanied by tremendous damage, but instead of this, most of the charges gathered on clouds are dissipated through a continuous stream of leakage between the earth and the clouds. Nature with her usual foresight, always accompanies high humidity and heavy rain with a highly charged cloud atmosphere. In this way she punctures the insulation of air between the clouds and the earth by a continuous stream of minute conducting bodies, each highly charged. Some of these continually dis-



SIMPLE ARRESTOR

Figure FF: An air gap lightning protector can be made of two pieces of brass plate as shown above. These should be mounted on a suitable insulated base and the receiving set should be connected across W and Z.



LIGHTNING FUSE

Figure GG: This lightning protector has a fuse leading into the instruments. If lightning should strike, the long fuse would blow out and the electrical discharge would take place through the gap.

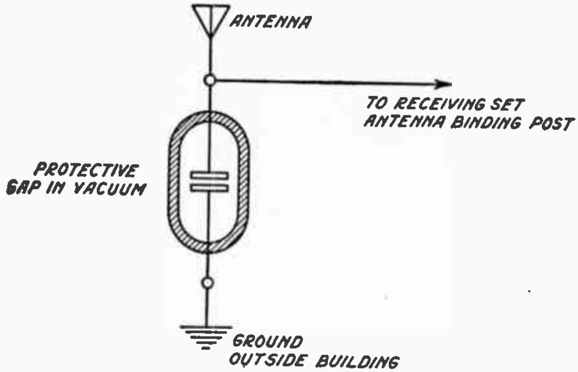
charge through the antenna system, as is evidenced by that unpleasant noise which we call static. Thus, there is a continuous conducting path between a cloud and the earth, resulting in a lightning flash only when extremely high charges are present. When such a discharge takes place, a current of millions of amperes and billions of volts drain the cloud of its charge.

A thunderstorm, then, clears away the charges on the clouds in two ways; first by a continuous stream of charged raindrops and conducting ions; and second, by direct discharges, such as take place between the electrodes of a spark gap. The latter is usually preceded by a collection of charges from nearby clouds until sufficient potential has been collected by some one cloud to break its way directly to the earth through a space of from one and a half to two or more miles.

An electric charge sufficiently strong to break through a space of that distance is of such intensity that its course is influenced very slightly by the relatively small attraction of a piece of antenna wire. Moreover, a grounded antenna is at the same potential as the earth itself.

Since the potential of the antenna is practically the same, the only other assumption that might make it seem that an antenna might be an attraction for a lightning discharge is the fact that the antenna is nearer the cloud than the surface of the earth. The cloud is from 7,000 to 11,000 feet away. The ordinary receiving antenna for broadcasting is seldom more than a hundred feet in the air. A hundred feet more or less travel for a charge of billions of volts is not sufficient to make such a charge change its course as much as twenty feet in order to find such a little path of less resistance. In the few cases known of lightning striking an antenna, it is certain that it would have struck at that very spot if no antenna had been there.

The actual ionized path established by a direct cloud discharge is at the most but a few inches in diameter. Surrounding this ionized path of direct discharge, there is a large accompanying discharge, perhaps several miles in area. This entire area is influenced by the terrific



A VACUUM TYPE OF LIGHTNING ARRESTER

Figure HH: The instruments are connected to the antenna and ground as usual, with the gap shunting the windings. Any electrical surges that gather on the antenna immediately cause a discharge across the gap in the vacuum.

current grounded by the lightning discharge. Sensitive receiving sets are greatly affected by this for several miles around—perhaps anywhere within a radius of scores of miles. It is against this sympathetic discharge that we take our main precautions.

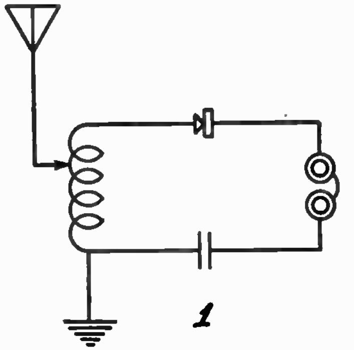
The lightning arrester dissipates such charges with certainty and safety even though the antenna is not grounded, and so forms actual protection, similar to that of the time-honored lightning rod.

The lightning arrester is a safety gap designed with such electrodes that a charge on the antenna of over 500 volts is grounded with the greatest possible facility. Whenever a charge of sufficient voltage is collected on the antenna, a spark discharge takes place across the electrodes of the arrester gap.

Against an actual discharge—that is, lightning striking at a particular place—there is no real protection possible.

Since the actual ionized path of such a direct cloud discharge is but a few inches in diameter the owner of a broadcast receiving set should not expect his particular little antenna with no especial attracting features to be picked out. He would be as much an egotist as an old maid in her little back yard holding out an up-turned thimble, confidently expecting that when but one rain-drop falls from a cloud two miles away, it will so distinguish her as to direct its way to her thimble when it might as easily fall anywhere else within the State.

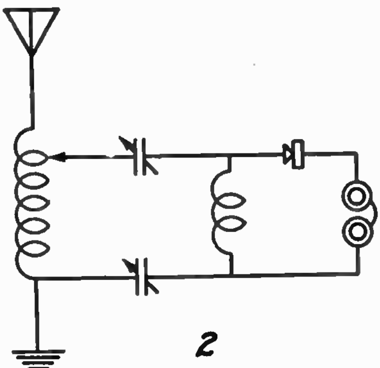
In planning lightning protection, make certain that your antenna is protected by a grounding device as required by the Board of Underwriters. This protects you against damage occasioned by any discharge taking place through the antenna either because of natural leakage or because of indirect cloud discharges and lightning discharges nearby. By having the grounding device properly installed the insurance on the property is protected. A radio set that is properly set up with antenna and with ground connections made in the correct way, affords better protection against lightning than if it were not installed. There is absolutely no justification for



1

DIRECT COUPLING

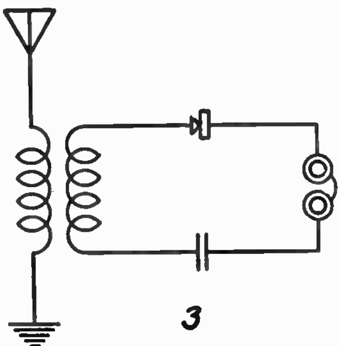
Figure II: The system of tuning employed here is known as "direct coupling" a term coming from the fact that the tuning coil, which may have a number of sliders to take the place of the single one illustrated, is connected by direct metallic path with the aerial proper. While there is a coupling effect between the aerial and the closed circuit (the circuit involving the condenser, detector and 'phones) it is not as pronounced as that occuring between the two coils in diagram 3 on this page.



2

ELECTROSTATIC COUPLINGS

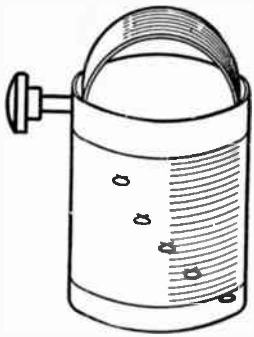
Fig. II: Here a single or multi-slide tuning coil is employed together with two coupling condensers of a variable type. The electrical energy of the aerial system is transferred to the circuit containing the 'phones and detector by the charging and discharging of the condensers.



3

INDUCTIVE COUPLING

Fig. II: Here two independent coils are used, one in the aerial circuit and one in the closed circuit with the 'phones, condenser and detector. The energy in this case is transferred from the aerial circuit to the closed circuit by electro-magnetic induction. Tuning may be affected by changing the degree of coupling between the coils.



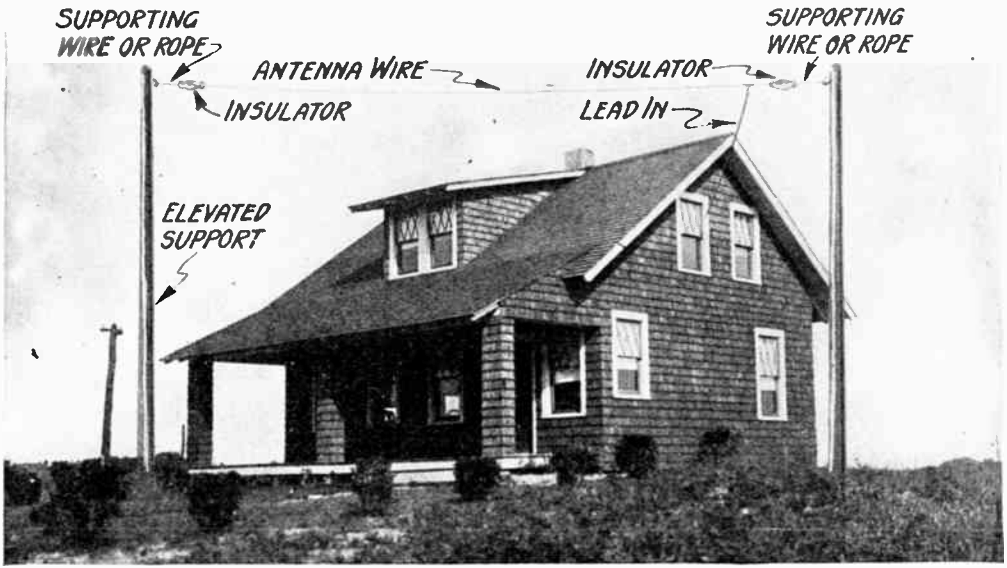
A LOOSE-COUPLER

Fig. JJ. A conventional type of loose coupler. The upper coil is moveable while the large coil (the primary) is usually tapped for purposes of tuning.

the hysterical fear that a radio installation will "draw" lightning—no more justification than in the case of the child's fear that some grinning hobgoblin will jump out from the dark.

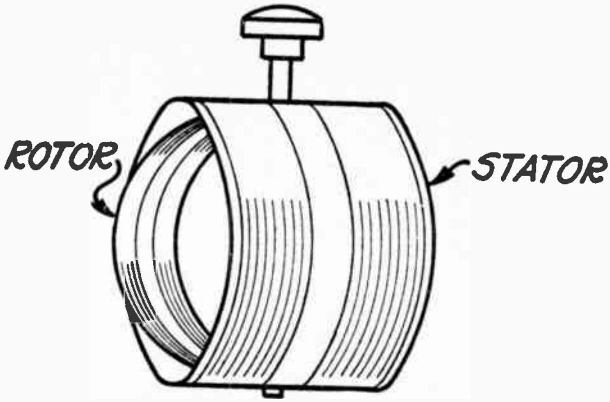
After having digressed, beneficially we hope, into the realm of the aerial proper we shall now return to the subject of tuning. In the accompanying diagrams (Fig. II) we see the three principal methods used in bringing circuits into resonance. The first case was considered previously. It is that of using a single slide tuner directly in connection with the aerial. This is called the *direct coupling* method because the current flows by direct metallic path without being inductively or capacitatively transferred from one circuit to another. In the left-hand diagram, we see the *capacitative coupling* method where the tuning coil is still used but two condensers of the variable type are used to transfer the energy from the aerial circuit to the secondary circuit containing the 'phones and the detecting device. In the third case there is shown the *inductive coupling* method of transferring energy from the primary or aerial circuit to the secondary circuit.

Inductive coupling as illustrated in the third circuit is usually effected by what is known as a loose coupler. The name of the device is more or less indicative of its principle of operation. Two coils loosely coupled, that is placed in "loose" inductive relationship to each other, are mounted so that one coil is movable. The loose coupler usually takes the form depicted (Fig. JJ). A primary winding, which is the winding connected to the aerial and the ground, is placed upon a cardboard or bakelite tube measuring about 3½ inches in diameter. The size of the wire and the size of the tube will, in some measure, depend upon the length of the wave to which it is desired to tune. A second coil, the secondary, which is usually directly connected to the detector, is arranged at the end of the large coil so that it may be turned. From our understanding of



AMATEURS HAVE SENT AND RECEIVED TRANSATLANTIC MESSAGES WITH THIS TYPE OF ANTENNA

Figure KK: As the amateur is limited to transmission on low wavelengths a highly efficient antenna is a prime necessity. This is the best for his purpose.

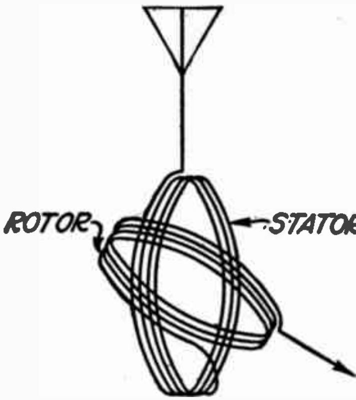


A VARIOMETER

Fig. LL: Two coils are involved in a variometer but, unlike the loose-coupler, they are connected together directly. By turning the coils they are caused to "buck" or aid each other.

inductive effects, it will be seen that by turning the secondary coil the inductive relationship, and therefore the resonance, between the primary and the secondary circuit is altered. When the winding on the secondary of the loose coupler is placed exactly parallel to the winding of the primary, there will be a maximum transfer of energy between the two circuits. When the secondary coil is placed at right angles to the primary there will be a minimum transfer. Here we see the reason why it is not advisable to place aerial wires parallel with power lines.

There is still another method of inductively regulating the transfer of energy from the aerial to the detecting circuit. This is done by an instrument known as a variometer. The variometer is made up of one continuous coil of wire arranged in two sections. The one section is usually mounted on the inside of a wood or composition frame and the second coil is usually mounted upon the outside of a spherical frame revolving within the first coil. Only two terminals are provided with the instrument and here we will see, by means of the illustration and a few words of explanation, how such a device can regulate the flow of energy between two circuits. The stationery and movable portion of the continuous coil in the variometer can be put in inductive harmony or opposition by revolving the movable element. The effect is the same as though two coils were wound in a solenoid form and brought in different positions in regard to each other. When the coils were parallel the effect of the inductance would be practically absent because they would be working to aid each other. However, if the coils were so arranged that the current travelling through them was in opposite directions, the one coil would "buck" the other and there would be a noticeable tendency to choke off the current. Any position between the two extremes would produce a relative amount of, we might say, inductive bucking. The effect is the same as though we caused a stream of water in a pipe to develop a



CONNECTIONS OF VARIOMETER

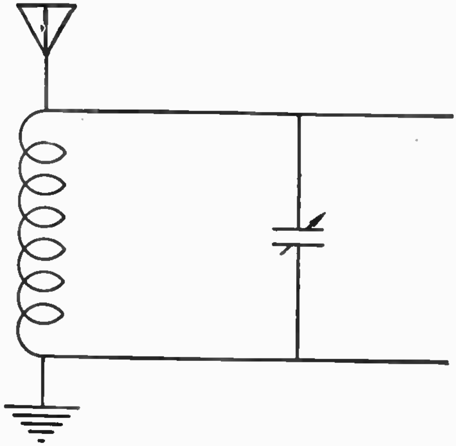
Figure MM: The method of connecting the two coils of a varometer is here shown. It will be noticed that there is a direct metallic connection between the aerial and the remainder of the receiving set. The variometer, however, is not always used in this particular position.

counter pressure. Since the counter pressure could not reach the original pressure (except by the interposition of a valve) some current would always flow. The same is the case with the variometer. Although the coils may be in inductive opposition, some current will always flow.

Variable condensers are widely used in tuning circuits because infinitely small changes in wavelength can be effected owing to the continuously uniform variations in capacity that may be made. It would be most difficult, both from the engineering and practical standpoint, to arrange a coil of wire so that the same effect could be produced inductively instead of capacitatively. For this reason condensers are practically always used in connection with coils. Coils are more or less necessary because they help to produce higher voltages, and, as we shall see later, this is very desirable.

If the student desired to set up a simple tuner involving a mere coil of wire wound around a cardboard tube and a small variable condenser, the apparatus might be connected according to the method in Fig. NN. Here the coil of wire has such a wavelength of its own that when it is used in connection with the aerial and the condenser changes in capacity will give a fairly large wavelength range. This wavelength range, as might be expected, will depend more or less upon the capacity of the condenser for the other elements have fixed values. If the capacity of the condenser is large the maximum wavelength will be large.

While involved in the general subject of tuning, it is desirable to introduce at this point the subject of wave traps. A wave trap is merely a circuit which permits of higher selectivity, that is greater separation between waves of slightly different length. The wave trap cir-

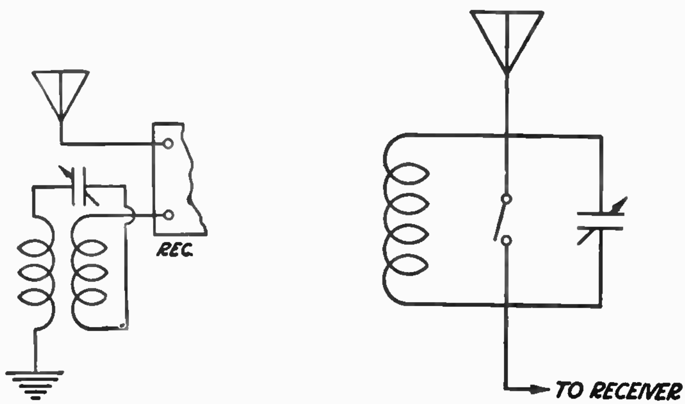


VARIABLE CONDENSER CONNECTIONS

Figure NN: A method of connecting a variable condenser to a single- or double-slide turner to aid sharper tuning.

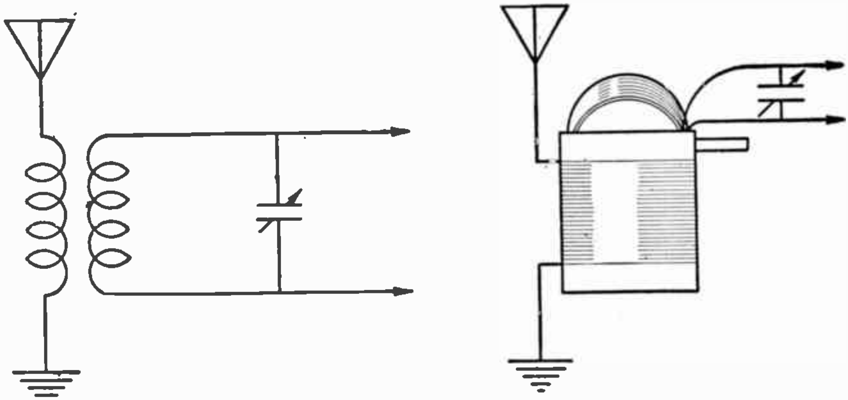
cuit, which consists merely of a small coil of wire (the coil may be of the ordinary honeycomb type) and a small variable condenser is interposed between the aerial proper and the receiver. By turning the condenser, the circuit will respond to the desired wave. Great selectivity is obtained and waves of different length will be effectively prevented from passing. A switch is arranged so that the selector device may be dispensed with by forming a direct connection to the receiver.

A second system for trapping waves



TWO WAVE TRAPS

Figure OO: At the left is shown a two-coil wave trap using a variable condenser. The trap at the right employs only one coil and a variable condenser.



THE CONDENSER AND LOOSE-COUPLER

Figure PP: How the variable condenser is used as a tuning adjunct to the loose-coupler. The connections in both sketches are the same save that one sketch is diagrammatic and the other is in the form of a picture.

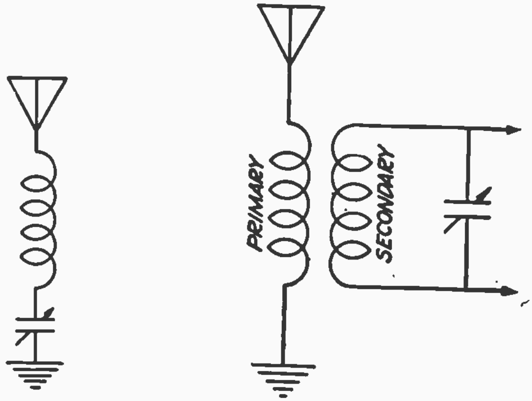
is also shown and here a variable condenser is employed with two coils of wire placed in such positions that their fields oppose each other. One system will be found to work practically as well as the other and perhaps the first one described is the most conveniently assembled.

When variometers or loose couplers are employed in tuning, condensers are usually used in conjunction with them. Otherwise, great selectivity is practically impossible because fine adjustments are not attainable. When a variable condenser is employed with a loose coupler, it is always placed directly across the secondary—shunted across the secondary. Changes in wavelength are brought about by turning the secondary of the loose coupler and by turning the movable plates of the variable condenser. When a variable condenser is used in conjunction with a variometer it is usually shunted across it as in the case of the loose coupler. Circuits like those just described are not highly efficient nor are they extremely selective.

Variable condensers are sometimes used in series with the aerial or ground. In this position they alter the wavelength of the aerial system by placing in series with the aerial capacity another capacity which may be small or large. The reader will recall the principle involved here if he gave proper attention to the explanatory matter in the forerunning portion of this Part.

There are many different ways of tuning aerial circuits but they all involve the simple principles that we have outlined. In some instances more complicated hook-ups are employed, but if the student will study them very carefully he will find that the combination merely involves: (1) loose coupled circuits, (2) directly coupled circuits and (3) circuits involving variable condensers.

Some receiving devices involve a number of independent circuits; circuits that are tuned. Even the simplest sort of a receiver usually involves two independent circuits as illustrated, Fig. QQ. Here we have what is known as the antenna circuit (sometimes called the *open circuit*



THE ANTENNA CIRCUIT

Figure QQ: The antenna or aerial circuit involves the aerial, the tuning instruments connected to the aerial and the ground.

which is technically incorrect) and the closed or secondary circuit. When a signal is tuned to, it is necessary to put the secondary or closed circuit in resonance with the antenna circuit before we can obtain a maximum transfer of energy between the two. That is very easy to understand. We could not hope to get maximum current transference between the two unless they were in electrical harmony; that is, unless one was capable of matching the electrical characteristics of the other. Coming back to our two stretched piano wires, we could not hope to cause one to vibrate at maximum efficiency when the other was plucked unless both the wires were of exactly the same length.

The famous Cockaday four-circuit tuner is a good example of multi-tuned circuits. Here four independent and distinct circuits are employed in a system of tuning which is extremely selective and which produces a very efficient method of broadcast reception.

The Hazeltine Neutrodyne is another receiver which involves more than one independent circuit. In this particular receiver, it is necessary to bring three independent circuits to resonance with variable condensers before the receiver as a whole is in resonance with the incoming waves.

Unfortunately for the radio tinker, the really efficient radio receiver involves from three to six circuits and the tendency in technical development seems to be along complicated rather than simple lines. We say complicated, but, as a matter of fact, no circuit is complicated if it is studied out and analyzed in the light of the explanations given in this course.

The use of three or four independent and adjustable circuits in modern receivers has brought with it a demand for unification in control. It should be quite unnecessary for the radio listener to fuss around tuning several circuits independently when it is possible to mount the condensers controlling these circuits upon one shaft so that they can be turned on their shafts by a single knob.

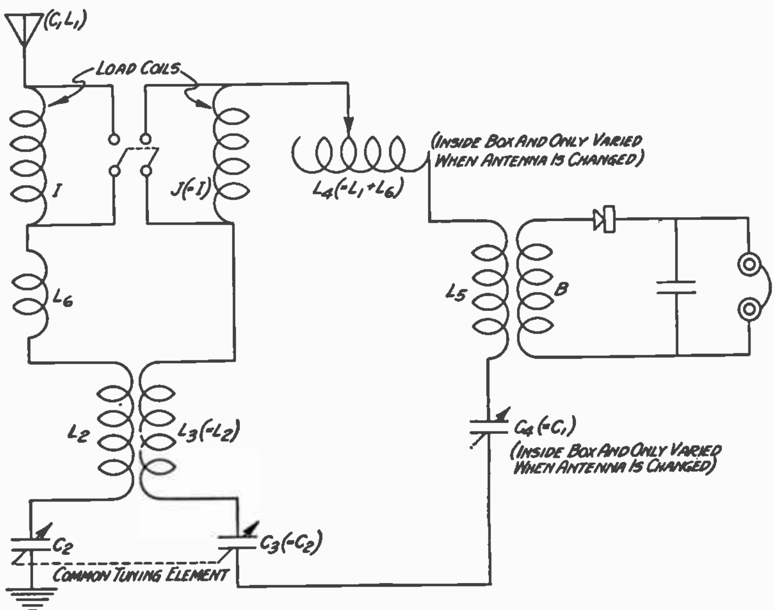
Laurence M. Cockaday has prepared a thorough and at the same time simple discourse on the subject of single control:

"Up to three or four years ago the men and boys who were interested in radio receiving and transmitting apparatus were relatively few in number. Their interest was of quite an experimental and scientific nature.

"But with the advent of popular broadcasting and its development from that time to this, there have been literally millions of people who have been drawn into the radio game by either its recreational appeal or by its educational features.

"The vast majority of those who have been attracted to the field are broadcast listeners with little or no technical training and without much interest in scientific matters. However, these people have a lively interest in receiving apparatus, although they know little about its intricacies. It is, therefore, not extraordinary that the modern trend of receiver design is one of simplification in control.

"The early receivers that employed some of the more complicated and sensitive circuits contained, in some instances, as many as ten to fifteen tuning controls for selecting between signals transmitted on various wavelengths. During the last two years, however, the tuning of the more popular receivers has been reduced to not more than three to five controls. This means that most of the modern sets have no more than that many dials or knobs on the panel.



ONE OF THE FIRST SINGLE-CONTROL SYSTEMS

Figure RR. This wiring diagram demonstrates one of the earlier schemes for tuning two resonant circuits by means of a common capacity tuning element that is adjusted by a single knob.

"An interesting system that indicates great foresight and ingenuity on the part of the inventor, and a significant one, for reducing the number of controls in receivers, was devised some fourteen years ago by John V. L. Hogan, the well-known radio engineer. In his patent Mr. Hogan describes a method for tuning various circuits to resonance by means of a number of associated tuning elements mounted on a single shaft or controlled by a single dial although connected electrically in different circuits.

"The object of this scheme is, briefly, to tune a number of resonant circuits by rotating a single control knob.

"The significance of this method has only recently been apparent.

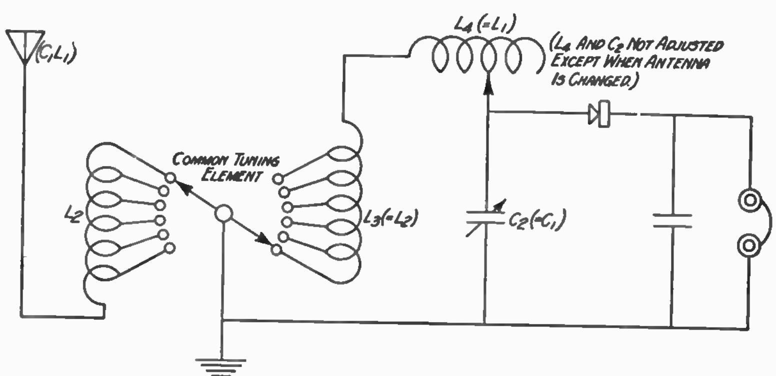
"In Figure RR we find a wiring diagram of the early Hogan single-control receiver that employs two tuned circuits that are controlled by a common tuning element. (See page 151.)

"The common tuning element consists of two variable condensers, C2 and C3, which, of course, must be of equal capacity and must contain the same capacity ratio of maximum to minimum. These two condensers are arranged on the same shaft on which they revolve at exactly the same rate, and as the rate varies, the capacity of each one is always approximately equal to the other. The two inductances L2 and L3 are also of equal fixed values of inductance. The condenser C4, which was contained inside the receiver, was set only once to balance the capacity of the antenna. The coil L4, also a variable instrument that is inside the cabinet, is varied to equal the inductance of the antenna plus the inductance of the coil L6.

"In this early type of single-control receiver, when the two circuits were balanced up as indicated, the two condensers that formed the common tuning element could be rotated by a single knob and still the two circuits would be kept in resonance through the whole wavelength scale. When this condition was established, a practical single-control receiver was evolved.

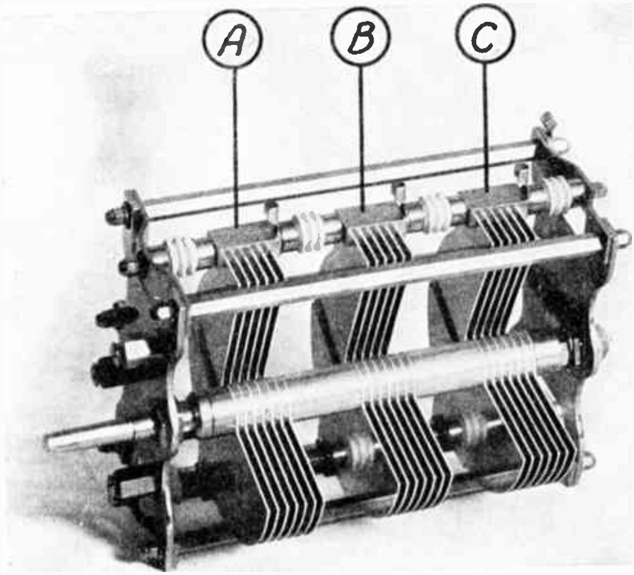
"This specific instance demonstrates the idea of using condensers as a common tuning element.

"The inventor also described and used



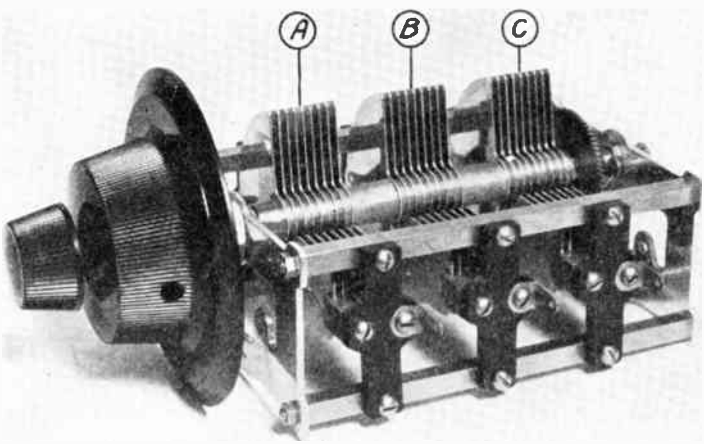
AN EARLY SINGLE-CONTROL METHOD FOR AN INDUCTIVELY-TUNED CIRCUIT

Figure SS. One of the early methods of tuning two resonant circuits by means of a common inductance tuning element that is rotated by a single dial or knob.



A TRIPLE-UNIT CONDENSER

Figure TT. This picture shows a triple-unit condenser. The three units A, B and C may be used for tuning three resonant circuits. This condenser would be suitable for a two-stage tuned radio-frequency receiver.



A TRIPLE-UNIT WITH VERNIER SINGLE-CONTROL

Figure UU. Another make of common tuning element, a triple vernier condenser, is shown here. In this unit, the three sections A, B and C are all controlled by the single knob. The insulation of the unit is composed of six pieces of hard rubber.

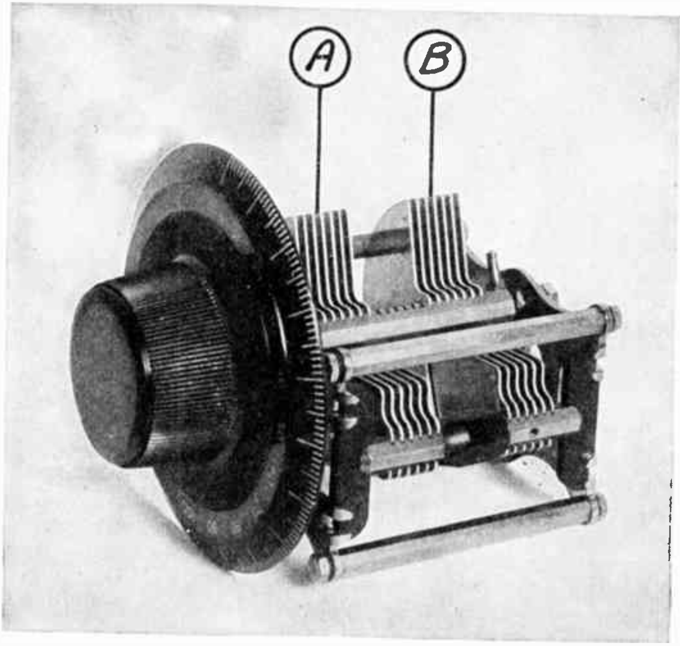
a circuit shown in Figure SS in which he incorporated variable inductances as a means for accomplishing the same results. This receiver is shown diagrammatically in which the inductances in the two tuned circuits are varied in steps of equal amounts in both circuits by a single control knob. These two inductances are shown in the diagram as L2 and L3.

"Additional inductances and capacities L4 and C2 are used inside the cabinet and these are adjusted only when the set is first connected to a new antenna. These two elements are used to compensate for the capacity and inductance of the antenna indicated as C1 and L1. When this initial adjustment has been made, the various wavelengths may be tuned in by adjusting the inductance tuning-element knob.

"Either of these two simple plans for obtaining a single-control receiver may be used with the more complicated and effective receivers, such as used today.

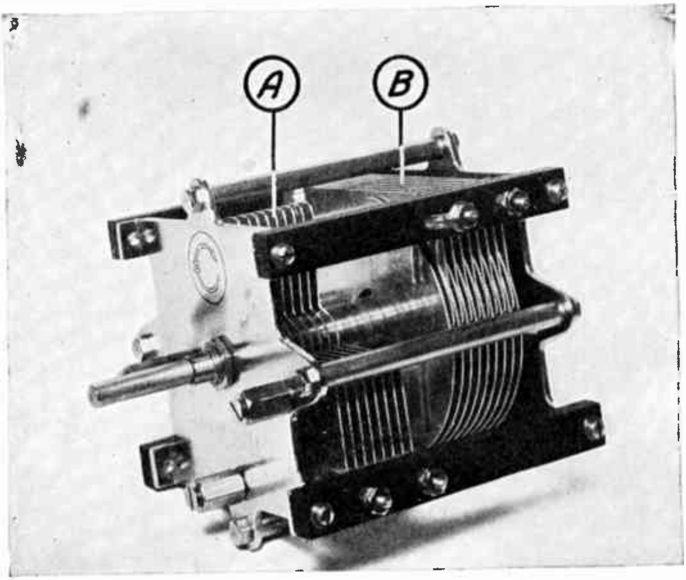
"During the last five years most of the engineering work on receiving sets has been directed toward circuit development, and, during that time, we have had four major types of circuits which have come into general use. These may be enumerated as follows:

1. Regenerative circuit;



A DOUBLE-UNIT FOR SINGLE-CONTROL

Figure VV. This picture shows a double-unit condenser which consists of two units A and B. This unit can be adapted to a single-control, four-circuit tuner or a single-control superheterodyne. It could also be used for tuning a single-stage, radio-frequency receiver.



A LARGE CAPACITY DOUBLE-UNIT

Figure WW. This double-unit is also compose d of two condensers A and B mounted on the same shaft.

2. Transformer-coupled, radio-frequency circuits;
3. Tuned radio-frequency circuits;
4. Superheterodyne circuits.

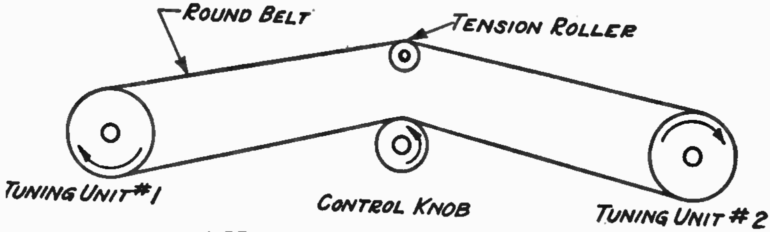
"The development of receivers along these four lines has been merely a refinement of circuit design and circuit stabilization. This work has resulted in some really excellent receivers and in some cases, the ease of control has been greatly improved over the earlier circuits of the same classes. The second class, No. 2, we can neglect, as only one circuit is tuned. However, by the application of the Hogan scheme to the other three of these types or classes of receivers, a receiver will be produced that the least informed novice can tune with ease. Such a receiver will contain only a single knob for adjustment, and it will give better results than the more complicated sets in the hands of the ordinary broadcast listener.

"An application, then, of this scheme will be the most important single factor in the future development of sets; and it will make radio really accessible to the average American.

"The first step in modifying these types of receivers to combine and unify the tuning control, is to select the type of mechanical arrangement to be used. There are three general methods that can be employed:

1. The use of a combined shaft;
2. The use of a gear arrangement;
3. The use of a belt arrangement.

"All three of these methods present specific advantages and problems. In Figures TT, UU, VV, WW, ZZ are shown a number of makes of multiple condensers that embrace the combined shaft



A BELT-OPERATED CONTROL SCHEME

Figure XX. Another method that has been used for the single control of two units. The contro knob rotates the units in synchronism by means of a belt and rollers.

principle. All four of these are of the finest workmanship and construction, and are being used in the newest types of sets that are built by some of the more forward-looking manufacturers.

"The utilization of the second method allows for the use of separate condensers or inductive tuning units of the ordinary type with the familiar 'rack and pinion' coupling between shafts. This scheme is shown diagrammatically in Figure YY. With this arrangement it is extremely important that the train of gears fit snugly and that there be not too much friction.

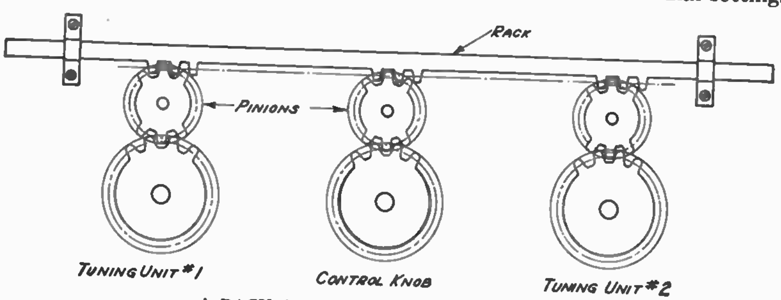
"The third arrangement, which also has its supporters, employs separate condensers or inductive-tuning units which are caused to turn in unison by means of rollers and a belt.

"An idler pulley is usually used to take up slack so that the belt will not slip and thereby keep the units in proper relative position to each other. This method is shown diagrammatically in Figure XX.

"Any of these methods may be employed, but for personal preference and simplicity of explanation we will consider only the first one.

"There are not many regenerative circuits that permit the application of the principle of single-control. The one regenerative receiver that probably stands out as the most suitable for such use is the Four-circuit Tuner.

"In this type of receiver the two circuits that control tuning and regeneration are rotated in unison. Both dials are rotated throughout the wavelength range at the same rate and both should always read the same in dial settings.



A RACK AND PINION CONTROL SYSTEM

Figure YY. A method for controlling two tuning units by means of a rack and pinions. The control knob is indicated as attached to the center gear.

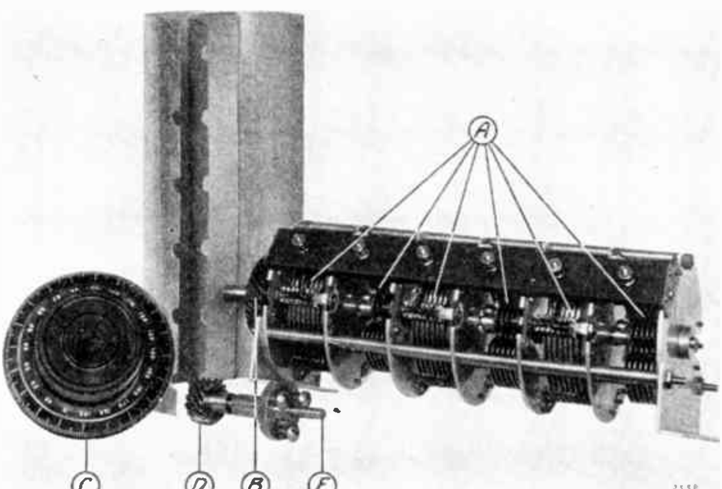
"By using a double-unit condenser combination in place of the usual two condensers, the two circuits (the stabilizer and the secondary) may be adjusted by a single dial. This is shown diagrammatically in Figure B3. C1 would be one section of the condenser and C2 would be the second section. These would both be mounted on a single shaft and rotated in unison.

"The application of the single-control idea to the tuned radio-frequency circuit is almost as simple as its application to the Four-circuit Tuner.

"In Figure A3 are shown the primary and secondary coils which are used to couple two stages of amplification. Connected across their secondaries are variable condensers C1, C2 and C3, in the usual manner, except that these three condensers have a common shaft and a single dial as indicated by the dotted lines and the arrows. This arrangement is for condenser-tuned receivers.

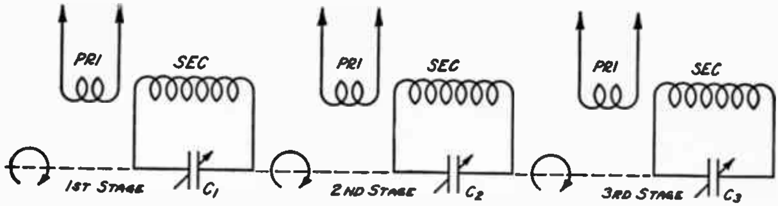
"For inductively-tuned receivers of the tuned radio-frequency type, the general layout or scheme might be as shown in Figure C3. Here the common tuning element is composed of a variable inductive winding. These are shown in the diagram as variometers at L1, L2.

"Stating the method generally, the two tuning elements C1, which controls the loop tuning, and C2, which controls the oscillator tuning (see Figure D3) can be arranged, by choosing the right values of inductance in the circuit, so that they will vary with the wavelength substantially at the same settings. This means that they can be also connected by the same shaft and controlled by a single dial. Any slight variation at the ends of the scale can be adjusted easily by a vernier variometer or other vernier



A SIX-UNIT, SINGLE-CONTROL CONDENSER

Figure ZZ. A complete unit consisting of six condensers A which are all fitted to the same shaft and controlled by a single dial C. The dial is attached to an auxiliary shaft E which operates the condensers through the bevelled gears D aud B. Six resonant circuits may be tuued with this single unit.



HOW THE SINGLE-CONTROL CAN BE APPLIED TO A TUNED RADIO-FREQUENCY CIRCUIT

Figure A3. This diagram shows how the tuning of a two-stage, tuned radio-frequency receiver may be reduced to a single-control. The three condensers, C1, C2 and C3 are mounted on the same shaft and are controlled by a single knob or dial.

device as indicated in the diagram at LV. One engineer has already experienced very fine results from such a combination.

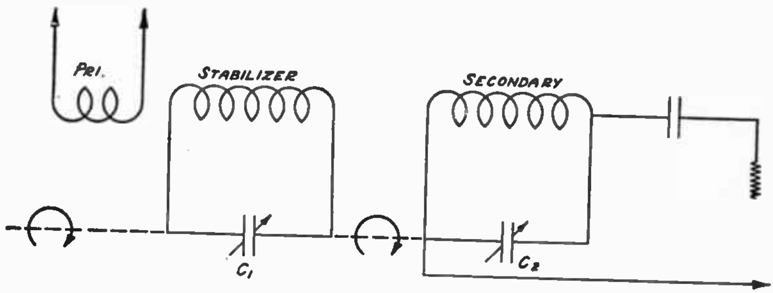
"In summing up, we find that the single-control idea for controlling the more complicated, and therefore the more sensitive and selective circuits, has a number of great advantages and strong points not among the least of which we have found to be:

1. The simplest method of tuning;
2. The calibrated or "logged" dial;
3. The speediest method of tuning;
4. The most accurate method of tuning;
5. Elimination of body capacity;
6. Better looking sets;
7. Sets that the novice will not hold in awe;
8. Much better sales value.

"The simple tuning, including the calibrated feature that tells the user at just what point to set the one dial to bring in the station wanted, is sure to be popular. Besides, a set that a novice can tune as readily as the experienced radio fan is a great development.

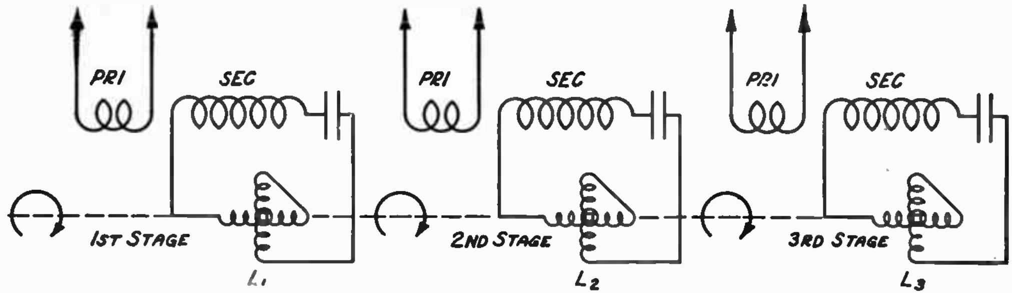
"Finally, sets that do not have so many 'little dials and knobs and gadgets' to turn, to make squeals with, and to collect dust, are sure to be more popular with the women and the children and the man without technical interest.

"In other words, in single-control receivers we will have the first sets that will enjoy an overwhelming popularity with the larger public consisting of men, women and children who want to listen



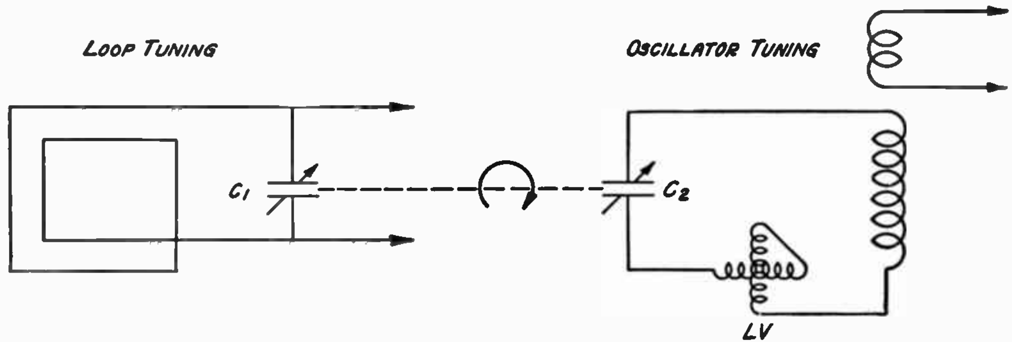
SINGLE-CONTROL ADAPTATION FOR A FOUR-CIRCUIT TUNER

Figure B3. The control method shown in this diagram indicates how two condensers C1 and C2, when mounted on the same shaft and controlled by a single knob, can be employed in a four-circuit tuner.



SINGLE-CONTROL APPLIED TO AN INDUCTIVELY-TUNED RECEIVER

Figure C3: A method whereby a tuned radio-frequency receiver may be tuned by means of three variable inductances, L1, L2 and L3 mounted on the same shaft and controlled by a single dial.



HOW SINGLE-CONTROL MAY BE USED IN THE "SUPER"

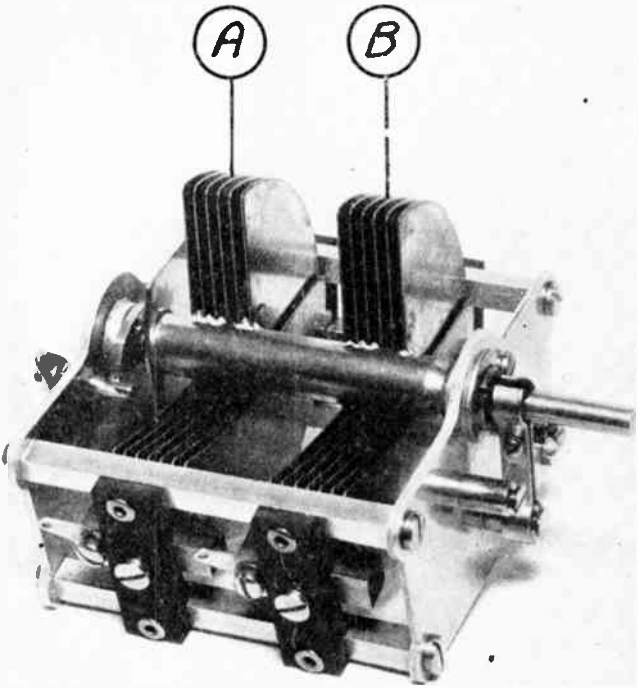
Figure D3: This diagram shows how the loop tuning and the oscillator tuning in a superheterodyne receiver may be simplified. The two condensers C1 and C2 of the proper capacities may be mounted on the same shaft and controlled by a single dial. In this case, however, a small variable inductance unit LV should be used for exact settings on distant signals.

without any fuss and without having to study technical information before they learn the particular tricks of the particular make of receiver they happen to own.

"These are the reasons why the single-control receiver is fast coming into vogue and why it will stay."

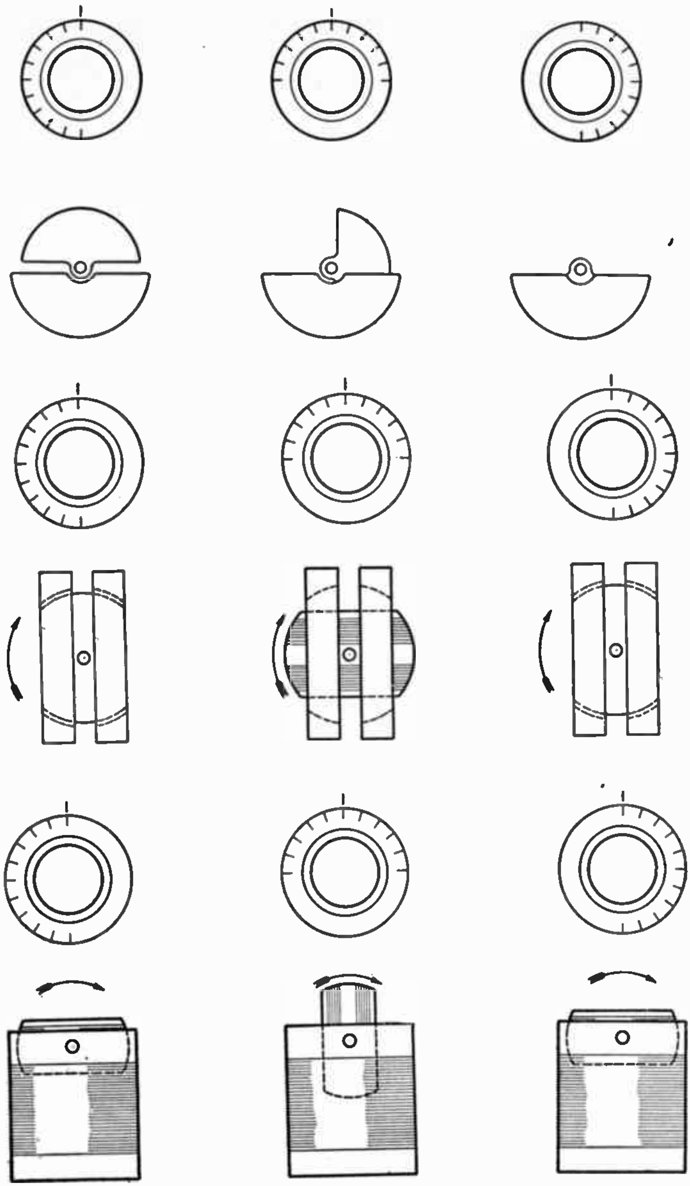
It is of importance that the student should understand the proper use of knobs and dials on radio receivers especially in connection with tuning appliances. The average set owner believes that tuning is a mere matter of turning knobs until some station is accidentally picked up. It is impossible to intelligently tune any kind of a receiver unless the person manipulating the knobs and dials has some understanding of the instruments back of the panel and their position in regard to the dials with which they are connected.

There are two general types of dials in use today; one is calibrated from 0 to



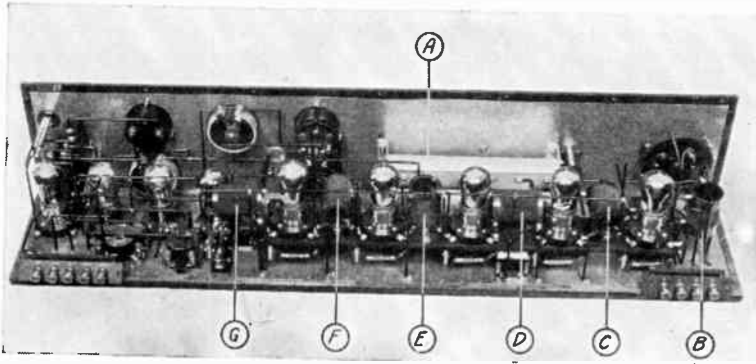
A DOUBLE-UNIT WITH STATORS MOUNTED ON HARD RUBBER STRIPS

Figure E3. The double unit condenser pictured above has two units, A and B. The stator plates are mounted on two strips of hard rubber insulation; both of the rotor sections are mounted on the same shaft. This unit may be used in the same manner as the two units shown in Figures E and F.



THE MEANING OF THE DIAL POSITION

Figure F3: This diagram shows how dials should be employed with the various tuning instruments as a check upon the operation of a receiver. Either 100 degree or 180 degree dials may be used.



A RECEIVER WITH ONE DIAL THAT TUNES SIX CIRCUITS

Figure G3. This picture shows a rear view of a super-pliodyne receiver in which the multiple tuning unit shown in Figure ZZ is used. This unit appears at A, and is enclosed in a metal shield. It tunes simultaneously the six transformers B, C, D, E, F and G, which are connected to as many stages of radio-frequency amplification.

100 and the other, more scientifically perhaps, from 0 to 180 degrees. Then, of course, we also have dials with micrometer or vernier attachments. It is the function of these attachments to turn the shaft of the instrument only a very small distance compared with the distance that the vernier is moved. Most of these combination dials with the vernier have two distinct knobs, one that turns the shaft direct and one that works through a small train of gears to turn it very slowly. Verniers are more or less essential in the case of long distance work and when used with very selective receivers. Oftentimes a movement of 1/100th of an inch is necessary to bring the wave to a point of full resonance. It will be found in general that verniers are practical only when used in connection with variable condensers.

By reference to Fig. F3 we see the position taken by the movable plates of the condenser when the dial is turned half way around. When the movable plates are fully inter-leaved with the stationary plates, the reading on the dial should be 100 in the case of a zero to 100 dial, and 180 in the case of a zero to 180 dial. At the half-way mark (50 or 90) the plates of the condenser should be exactly half way. When a dial is used in this manner it acts as a true index to the angle taken by the plates and figuring from this the operator of a circuit will have a rough idea of the amount of capacitance at every setting.

The proper dial setting for loose coupler secondaries is also illustrated. At zero degrees, the rotor or secondary of the loose coupler should be perfectly horizontal so that there will be a maximum inductive effect between it and the primary. At 50 or 90 degrees the secondary or rotor winding should be at right angles to the primary winding and the inductive effect at this point will be minimized. As the dial is revolved the rotor is brought back to its horizontal position.

Reference should also be made to the little sketches showing the proper use of the dial with the variometer. In a case of this nature, there is a uniform change in inductive relationship between the rotor and stator windings as the knob is turned toward its full number of degrees.

Radio folks—professionals and amateurs alike—have long talked about "dead spots." Experience has shown that there *are* certain stretches of coastal territory and mountainous areas where it is extremely difficult to effect reliable communication in the conventional manner. But always the term "dead spot" is a relative one only; a "dead spot" being due to the partial absorption of the electromagnetic waves.

A well-known example of this phenomena lies in the inability of ship stations in Long Island Sound to establish satisfactory communication with shore stations on the Atlantic side of the Island, even though the Island is, at its widest part, but forty miles across. Coastwise vessels find great difficulty in communicating with New York City in a satisfactory fashion over distances of but fifty or sixty miles when they are close to the Jersey shore.

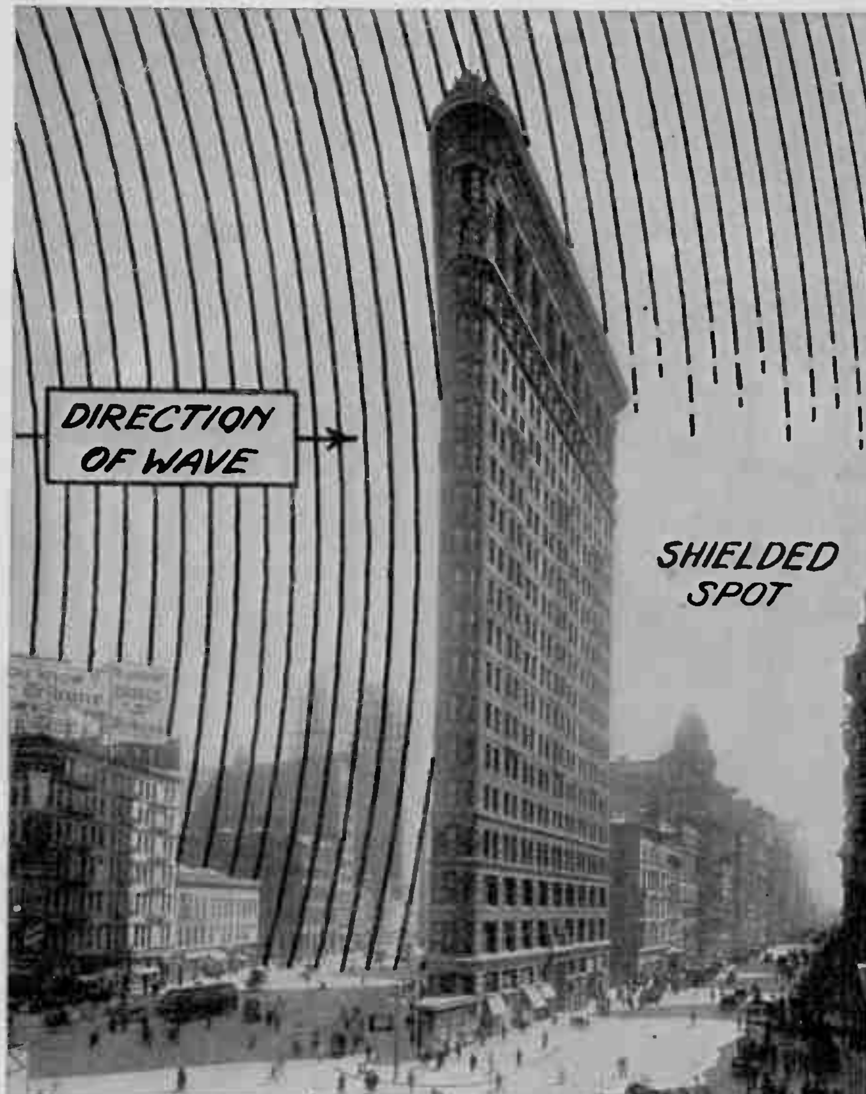
An example of this phenomena which deals with transmission on amateur wavelengths may be cited as follows:

A first class amateur transmitter in New York City finds it possible to communicate directly with a like amateur station in Philadelphia, ninety miles distant, during daylight hours. When darkness falls, the signals of the Philadelphia station become unreadable until late in the evening, and are even then unreliable.

Radiophone listeners, too, report "dead spots" in various localities. In Atlantic City during the summer months it is possible to secure fairly good broadcast programs both from New York and Philadelphia during daylight. At night, however, programs from both points are unreliable. Many points on Long Island, forty to seventy miles distant from the New York City stations, frequently find it impossible to record satisfactory broadcast programs.

During the summer of 1920, an effort was made to take advantage of this phenomena in the choice of sites for stations which were to handle the commercial traffic along the Atlantic coast. During the war the Navy department handled all ship-to-shore traffic, inasmuch as all land radio stations had passed into their hands when war was declared. Subsequent to the Armistice this traffic was handed back to commercial companies. Considerable competition then existed between the older and some newly formed companies as to who should handle the bulk of it. There proved to be a sufficient amount of traffic to make its handling profitable. At least four companies who owned and operated stations within the vicinity of New York were each making frantic efforts to get the better of the other. The most serious difficulty encountered was that of interference between the sending stations.

To be specific, one station at Cape May, New Jersey, two in New York City, one at Babylon, L. I., one at Southampton, L. I., one at New London, Conn., and one on Nantucket Island, frequently tried to establish communication with the same ship at the same time, particularly when that ship would report 200 or more messages ready for transmission. Perhaps one of these stations would receive an acknowledgment from the ship operator whose efforts to get the traffic off were frequently rendered futile because of the interference from the competing stations. Loop aerials and receivers of various types were tried with but little relief.



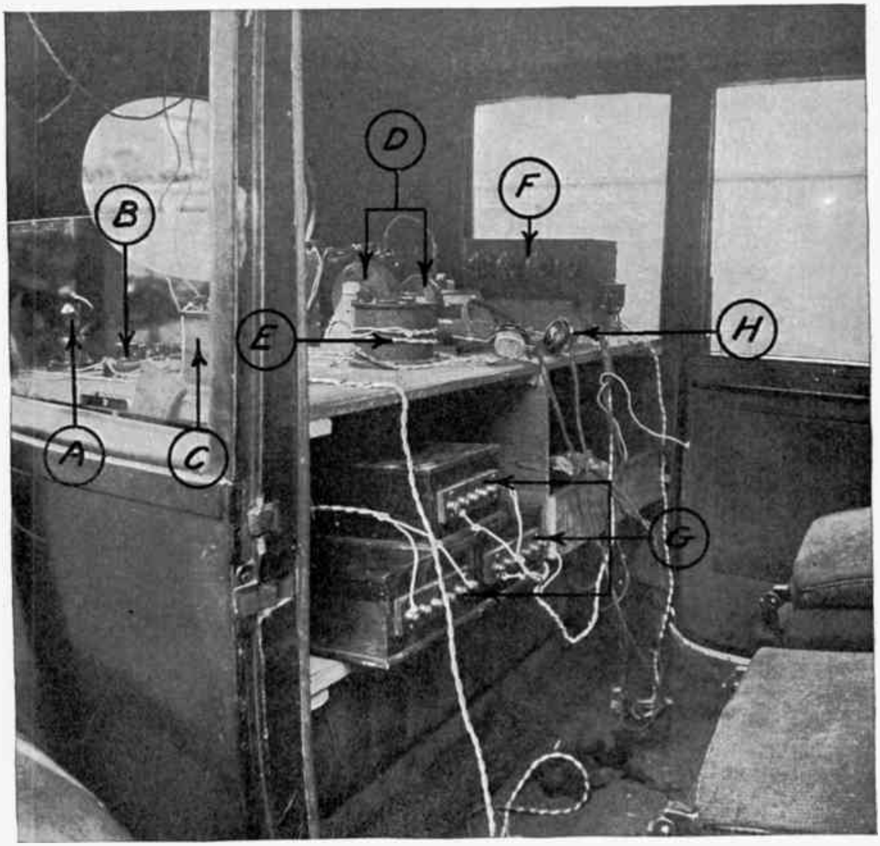
Brown Bros.

HOW "DEAD SPOTS" ARE CREATED

Figure 113: Usually the cause of the trouble is a wall—especially a wall in the form of a building that is largely of metal construction—between your radio receiver and the broadcasting station. Such a structure serves as a shield that deflects the radio waves in much the same way as a ten-foot fence serves as a shield when it intervenes between two men who are conversing. An ordinary crystal or single-tube receiver is usually insufficient to detect the weakened radio waves that do penetrate the shielded areas.

The idea was then hit upon of locating certain points on the North Atlantic coast which would provide comparative freedom from most interfering land stations. The method of locating these "dead spots" proved to be rather ingenious and interesting; to the gratification of those in charge of operations, locations were found where interference from many stations was almost entirely eliminated.

In one of the illustrations which accompany this article (see this page) is shown a super-heterodyne type of receiver mounted in a Ford sedan. The receiver consisted of a three-element vacuum tube detector, a frequency changer, and a four stage-radio-fre-



THE INTERIOR OF THE RADIO SLEUTH

Figure 13: This extremely sensitive receiving apparatus, which was installed in a small sedan, included: A, the vacuum tube used for detection; B, the rheostat for this tube C, the tuning condenser; D, the honeycomb inductances; E, the heterodyne control; F, the radio-frequency amplifier; G, the "B" batteries for the detector, oscillator and amplifier. And, of course, the telephone receivers H.

quency amplifier. The car lighting battery was used for all vacuum tubes. However, separate plate potential batteries were used respectively for the detector, the frequency changer (oscillator) and the radio-frequency amplifier. The circuits of the amplifier were so arranged that the signals could be weakened; that is to say, a certain type of audibility meter was provided. The antenna used consisted of twenty turns of wire on a wooden frame, four feet on a side. The antenna (loop) was so mounted on a rear fender that it could be revolved until pointing toward the transmitting station. Signal strengths obtained with this outfit were equivalent to those which could be obtained on a "T" type antenna, 160 feet high, in conjunction with a single vacuum tube detector and regenerative receiver.

Upon careful study of a topographical map, a point was generally chosen so as to be shielded from the transmitting station by low hills, a rather dense forest, or by a stretch of coast line. Past experience had shown that these usually acted as a shield. At a point near East Moriches, L. I., signals from New York City stations and from New London, Conn., were found to be almost totally inaudible, while signals from the station at Babylon, L. I., were reduced to the point where they would be of no serious trouble. At Smith's Point, some one mile farther toward the Sound, signals from the New York stations, the Babylon station as well as the New London station, were about up to standard. In both positions, signals from out at sea were equally strong. At the Smith's Point location, however, signals from great distances were recorded, as it was possible to read the signals of ships well out at sea and entirely beyond the range of communication of any of the land stations mentioned previously.

As the result of observations in this locality, a receiving station was planned and finally erected. On Cape Cod a point was found near North Truro, Massachusetts, where signals from Boston and Chatham stations were materially reduced. It became necessary at this point, however, to fall back upon large sand dunes for the shielding effect, and an extremely interesting phenomenon was discovered; a movement of the receiver of only a few hundred feet in either direction caused a marked difference in the strength of signals that came from land stations, while practically no change in signal strength was to be observed in the signals that originated at sea.

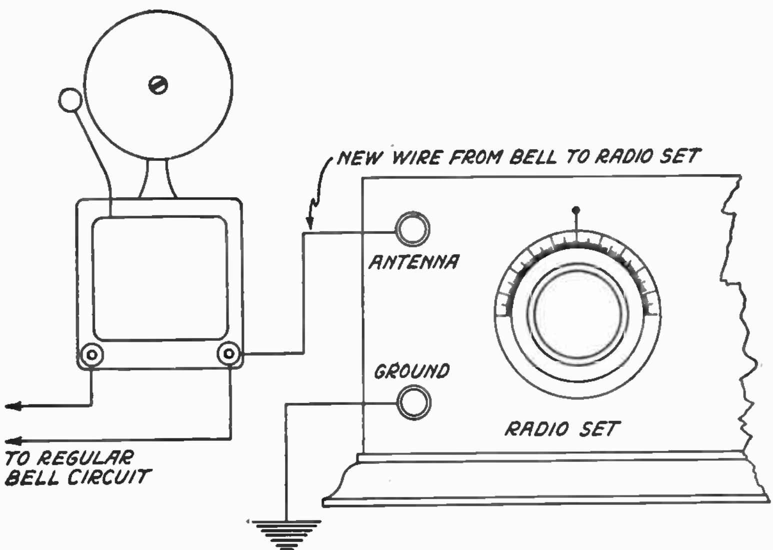
Observations taken near the station at New London, Conn., pointed to considerable shielding of this same sort. While signals from New York City stations came in with considerable strength, signals from Long Island and from stations on Cape Cod and near Boston were weak, whereas signals from all vessels in the Atlantic lines came in with what seemed to be doubled strength. It is certain that the exceptionally good work which the station at New London (WLC) has always done is thus accounted for.

It was desirable to locate a third station on the coast of Maine; for this purpose an extended series of observations were taken between Bar Harbor and Eastport. In addition to natural shields or barriers against radio signals from coastal stations, it became necessary in Maine to look, first of all, for a source of power supply. This existed at but few points along the coast. Observations taken at or near Rockland indicated exceptionally good shielding from all transmitters with the exception of the Naval station at Bar Harbor. Ocean-going vessels in the Atlantic lines could be received at this point with great clearness. The Bar Harbor station, however, was a serious drawback and after many experiments along this part of the coast, a point was found near Harrington, Maine, where shielding from both Bar Harbor and Rockland was ideal. Some weakening of signals from ocean-going vessels was to be noticed, however, due, no doubt, to the absorption taking place while the signals were in transit across Nova Scotia.

It has long been presumed that hills absorbed or deflected radio signals. Frequently mountains cast decided shadows; so do forests in lesser degree. In the case of the forest, absorption plays the greatest part in the weakening of the signal. Where a chain of mountains exist, the shadowing effects may become quite complex. This is also usually true in the larger cities, due to large steel structures, and is particularly noticeable where communication is being attempted upon the shorter wavelengths. The shorter the wavelength the more pronounced the shadowing effect, for the size of objects such as mountains and groups of trees and tall buildings are of the same order as the dimensions of the radio waves. Where the length of the wave is several thousand meters, few mountain ranges are to be found whose dimensions are sufficient to render them other than relatively small objects in the path of the wave.

Large bodies also act as reflectors.

An instance of this is on record. An attempt was being made to receive a sig-



THE WIRING DIAGRAM FOR THE BELL CIRCUIT ANTENNA

Figure J8: When you connect the antenna binding post on your set to the nearest bell, be careful to try both binding posts on the bell and leave the wire permanently connected to the side that brings in the signals with the greatest intensity.

nal from a point directly away from a mountain. The signal from the distant station was considerably weakened by bringing the receiver within approximately one and a half wavelengths of the mountain. It is to be assumed in this case that energy reflected by the mountain back into the receiver, arrived there completely out of time with the oncoming wave. The reflected wave counteracted the incoming wave with the result that signals strength was weakened.

Complete information concerning the effects of various objects upon the transmission of radio energy is not now available. When it is, it should be possible to definitely plot the rise and fall of signal strengths over any particular territory. There is little doubt that the "fading" effects observed by so many broadcast listeners are caused by the reflection of the electric wave from layers of gas many miles above the earth. The assumption is that the energy travels up and through the earth's atmosphere to a layer of ionized gas—that the gas reflects the wave, sending it again earthward—that in its travel the wave has encountered nothing which tends to absorb its energies. Suddenly a vapor cloud or a flaw in the reflecting mirror results in the absorption or loss of the signal. These irregularities occur rapidly at short wavelengths in mountainous or hilly countries —less rapidly over level country and at sea, but, under given conditions, the frequency of the fading intervals is a function of the wavelength.

It sometimes happens that, on account of circumstances over which the radio fan has no control, it is not possible to put up an outdoor antenna which will be suitable for the reception of broadcasting.

Here is one way to overcome this difficulty; it will enable one to receive broadcasting by making use of the ordinary "bell" circuit in the house. In every apartment house there is usually a front door bell and also a buzzer in the kitchen, which is connected for use in the dumb-waiter. This latter circuit makes a good antenna because it is not used as much as the front door bell. As a slight buzz will be heard in the receivers every time the button is pushed, and as the door bell is apt to be rung at almost any time, the dumb-waiter buzzer is the more serviceable of the two.

Using one side of this circuit will not harm either the bell circuit or your receiver. Even when the buzzer or bell is rung, it will have no effect on the set, except that a noise will be heard.

To connect the radio receiver to such an antenna is simple. Loosen up one of the binding posts on the buzzer or bell and connect a wire to it. The other end of this wire should be run down to the antenna binding post on the radio set. In connecting this wire to the buzzer, one must be sure that the wire which was already on the binding post of the buzzer is put back in place, otherwise the buzzer will not ring.

Of course, it is not possible to receive much DX on an antenna of this sort but if circumstances are right, some surprising results may be had. On local broadcasting stations, the signals should be almost as loud as with the outdoor antenna.

END OF SECTION V

SECTION VI

Detection and the Secret of the Vacuum Tube

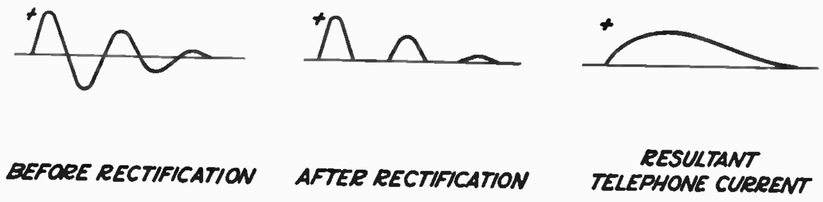
If Nature had made our ears sensitive to the higher vibrations, radio development would have taken a different course and many of the elaborate devices that we now use would be wholly unnecessary. It has often been demonstrated that the average human being is incapable of hearing vibrations with a frequency of over 20,000 per second. This means that we could be in the midst of the most terrifying source of sound waves but that, if these waves were beyond 20,000 cycles a second, we would have no sense of their being present.

This shortcoming of the human ear makes it necessary to employ what is known as a detector in the reception of radio music and code signals. From our previous investigations into the realm of radio, we know that the currents used in radio transmission are of very high frequency. So high indeed that if we permitted them to pass directly through a telephone receiver, we would receive no indication of their presence. The diaphragm of the telephone receiver, having appreciable mass would, in the first place, be unable to respond to the madly fluctuating currents and should the diaphragm respond, the human ear would be insensitive to the air vibrations produced.

Let us see what kind of a current is produced in a receiving set when it is in tune with a radio transmitter of the spark type. Of course, we know that sparks are used only in the transmission of code and not for the carrying of voice or sound. Sparks produce damped waves. That is, wave trains that start out at high amplitude and rapidly diminish to zero. If we were to picture these waves graphically they would look something like the outlines given in Fig. A (right). The wave starts out freshly, reaches a high maximum amplitude and gradually tapers to zero. Although the amplitude *decreases* the student will see that *the wavelength remains the same*; that is the distance between the peaks.

These damped wave trains come very rapidly; so rapidly indeed that a telephone receiver placed in their path would be useless in detecting them. What we need in cases of this nature is some sort of a device that will have the effect of changing the frequency of these extremely agile waves. In other words we wish to bring them from the *inaudible* or supersonic range of vibrations down to the *audible* field where they can be heard and distinguished by the human ear.

It was known for a long time before radio was put into commercial use that certain natural minerals like galena and zincite possessed the properties of *unilateral conductivity*. This term is not so formidable when we are told that uni-



HOW A CRYSTAL TREATS AN OSCILLATING CURRENT

Fig. A. A crystal is a sort of "valve" that permits electric current to flow freely in one direction but cuts off the flow in the opposite direction. This diagram clearly illustrates the action. The current pictured at the left builds up what is known as a "damped wave." Thousands of such "wave trains" go to make up a single dot of the telegraphic code. So rapid do these pulsations come that some means must be employed to make them audible. The crystal detector does this as illustrated on the right. Instead of the pulsations in each wave train affecting the diagram of the 'phones independently, they produce a combined effort which causes all the pulsation iu a single wave train to make but one of the several hundred vibratious in a single dot of the telegraphic code. Thousands of these tiny "noises" would be in a long dash.

lateral conductivity simply means electric *conductivity in one direction.* When current is sent through an ordinary copper wire, the direction makes no difference in the resistance; it is the same either way. However, in the case of a crystal like galena we find a different condition. Galena does not obey Ohm's law in both directions. In one direction the current will obey the laws of Ohm and flow through meeting little resistance. When the current is reversed in its direction, there is immediately placed in its path a hugh block of resistance that practically chokes it off entirely. No one can explain this action although many physicists have attempted to reveal the mysteries that surround it.

Now let us see what would happen if we should interpose a small piece of galena in the path of a rapidly vibrating and highly damped current such as that we considered in Section IV. The impulses travelling in one direction would pass through the galena freely, but the impulses travelling in the opposite direction would be effectively choked off. As a result of this action we would have a series of direct current impulses as shown in Fig. A (left). Since the frequency of vibration would be only cut in half the telephone receiver would still be insensitive to them. However, each group of pulsations act as a unit and they have an accumulative effect upon the diaphragm. The three pulsations shown combine to cause the diaphragm to move once, that is they pull the diaphragm of the telephone receiver down and release it. So rapid are these pulsations that several thousand of these little *wave trains* must exhaust themselves against the diaphragm to cause one tiny dot of the telegraphic code to be made.

A crystal detector is a very simple arrangement. It involves only a small holder which will allow high frequency currents to pass through the active mineral. A number of different minerals are used for crystal detectors but silicon, carborundum, galena and borite are among the most common forms. Galena is one of the most popular because it is the most sensitive. It is usually placed in a small metal container and a tiny wire known as a catwhisker is brought

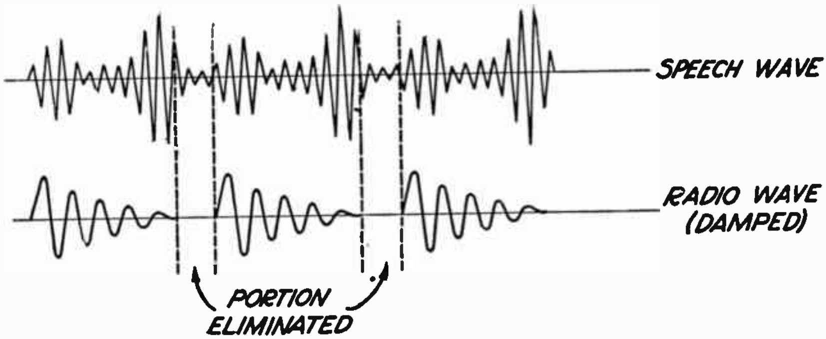


FIGURE B

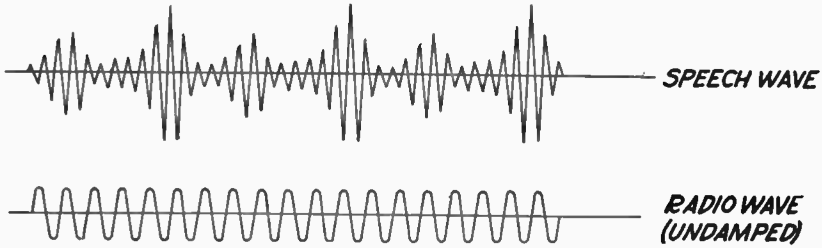
This diagram shows why it is impossible to impress a continuous sound wave upon a series of damped waves. The intervals between the damped waves would be silent and unintelligible sounds would be produced in the distant receiver.

into contact with its surface. This wire leads the high frequency current into the crystal and is also used to find the most sensitive spots. With this type of detector it is necessary to constantly readjust the catwhisker to insure maximum sensitivity. The passage of large amounts of static electricity from the aerial tends to burn the detector point out of adjustment and sudden shocks or jars will be found to disturb its sensitivity.

Strange as it may seem to the student of the art, the simple little crystal, with all of its troubles, is the one perfect reproducer of the sounds transmitted by radio waves. It is a most efficient rectifier. (A rectifier is a device that will produce a pulsating direct current from an alternating current.) Although a most efficient rectifier the crystal is in no sense an amplifier. As a matter of fact, it is a very wasteful rectifier and unless a very sensitive pair of 'phones is used in connection with it, reception is impractical. If the telephones are sensitive, a crystal detector may be used for the reception of broadcast music over a distance of 25 miles. A use has been found for crystal detectors in reflex receivers and a few permanent types have been developed for this purpose. Here the crystal is employed as a detector and the input and output circuits are amplified. The current is amplified before it passes into the crystal and it is amplified after it passes out of the crystal. A very practical form of carborundum detector of the permanent type has been developed for reflex work.

When we bring back to mind the jagged damped waves that we considered at the beginning of this Section, we will understand that such waves could not be employed in the transmission of voice and music. A reference to Figure B will show why this is so. Sound waves produced by the human voice and by musical instruments have a continuity of flow and if such sounds were superimposed upon damped waves part of the sound waves would be entirely eliminated at the receiving end. We would have as a result nothing but a garbled confusion of incoherent sounds.

Spark transmitters of any type cannot be used to carry broadcast music. We must use what is known as a continuous wave. That is a wave that flows continuously without the crude interrup-



THE UNDAMPED WAVE AND THE SOUND WAVE

Fig. C. The undamped radio wave illustrated at the bottom of the drawing is necessary for the transmission of sounds. It will be seen that such waves contains no interruptions unless the current that actuates or excites the transmitter is cut off. When sounds are impressed upon undamped or continuous waves similar to that illustrated, the resulting current in the output circuit of the distant receiver fluctuates according to the intensity of the sound impressed upon the diaphragm of the microphone in the broadcasting station. The wave emitted by the broadcasting station is then said to be "modulated."

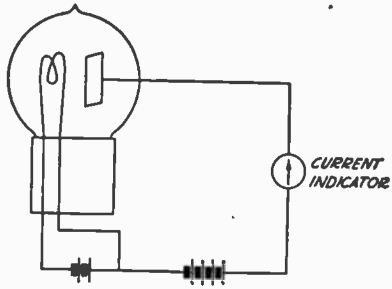
tions produced by the spark system. Reference to Figure C will show how nicely the sound waves can be superimposed upon the undamped waves produced by the huge transmitting vacuum tubes at the broadcasting stations.

The sound modulated waves used in broadcasting are just as elusive as the signals produced by sparks. The vibrations are hopelessly beyond the audible range, but, by the introduction of a crystal detector, this high frequency can be made to produce audible sounds.

We are now ready to take up the subject of the vacuum tube. The development of this instrument by Fleming and DeForest changed the whole aspect of radio. Before DeForest's work, radio was a stumbling, clumsy infant of the technical world. It had very definite limitations and there appeared to be very little room for technical growth and expansion. The vacuum tube, through supplying a more sensitive means of detection changed all of this; made radio the great and glorious thing that it is today.

Our own Thomas A. Edison supplied the spark of genius which finally flowered into the vacuum tube in the hands of Prof. James Fleming, English investigator. In the early 80's, while Edison was investigating the properties of his electric lights, he wandered upon a most unusual condition, a condition that had, until that time, never before presented itself to any scientific mind. The particular experiment involved the simple arrangement in Figure D. A small metal plate was sealed into one of the ordinary carbon filament lamps of that time. Connected between this plate and the filament proper was a sensitive galvanometer in series with the battery. Much to Edison's amazement, he could make current flow across this heated space between the filament and the plate but when the poles of the battery were reversed, no current would flow. Edison thought little of the experiment and was probably too much absorbed in his light experiments to give it more than a passing thought. He had, however, discovered a principle that caused currents to act as they acted when they passed through certain minerals. It was a case of unilateral conductivity or one way conductivity across a heated space.

Prof. James Ambrose Fleming, F.R.



WHAT EDISON DID 45 YEARS AGO

Fig. D. Edison found it possible to make a current flow from the filament to a sealed-in plate of an electric light by connecting the battery and meter as illustrated. It was this remarkable experiment that inspired the modern vacuum tube. This principle is not only used in radio tubes but also in battery chargers of the tube type. The tube in such cases is much larger and constructed so as to conduct heavy currents.

S., took this principle of Edison's and applied it practically in the radio art by developing from it the first two-element vacuum tube. Perhaps it would interest the reader to permit Prof. Fleming himself to outline the development of this history making device:

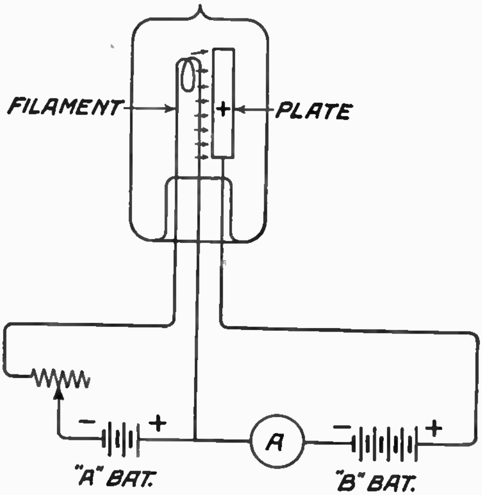
"Forty years ago, early in 1882, after the Edison Electric Light Company of London was formed, I was appointed electrical adviser to the company. I was therefore brought into close touch with the many problems of incandescent lamps and I began to study the physical phenomena with all the scientific means at my disposal. Like everyone else, I noticed that the filaments broke easily at the slightest shock, and when the lamps burned out the glass bulbs became discolored.

"This discoloration of the glass was generally accepted as a matter of course. It seemed too trifling to notice. But in science it is the trifles that count. The little things of today may develop into the great things of tomorrow.

"I wondered why the glass bulb grew dark and I started to investigate the matter. I discovered that in many burned out lamps there was a line of glass that was not discolored in any way. It was as though someone took a smoked glass, drew a finger quickly down it, and left a perfectly clean line behind.

"I found that the lamps with these strange, sharply-defined clean spaces were covered elsewhere with a deposit of carbon or metal, and that the clean line was immediately in the plane of the carbon horseshoe filament and on the side of the loop opposite to the burned-out point of the filament.

"It was obvious to me that the unbroken part of the filament acted as a screen to that particular line of clear glass, and that the discharge from the overheated point on the filament bombarded the remainder of the bulb with molecules of carbon or vaporized metal shot out in straight lines.



HOW THE FLEMING VALVE WORKS

Fig. E. This diagram illustrates the passage of the electrons from the filament to the plate, thus causing a current to flow through the meter deflecting its needle.

"My experiments at the end of 1882 and early in 1883 proved that I was right.

"Edison was at work in his laboratory in 1883 when he noticed that if he fitted a tiny metal plate inside the bulb of an electric lamp and connected it outside the bulb with the positive end of the filament, he obtained a slight current. The phenomenon was called "the Edison effect"; but Edison could not explain it, nor did he use it in any way.

"In October, 1884, Sir William Preece obtained from Edison some of these electric lamps with metal plates sealed inside them, and he turned his attention to the investigation of the phenomena of the Edison effect. He decided the Edison effect was connected with the projection of carbon molecules from the filament in straight lines, thus confirming my original discovery. There Sir William Preece let the matter rest, just as Edison had done. He did not satisfactorily explain the phenomenon nor did he seek to apply it in any way. The Edison effect remained just a peculiar property, a mystery of the incandescent lamp.

"Other work claimed my attention for a long time, but I was certain in my own mind that there was still a great deal to discover about this peculiarity of the incandescent lamp, and directly the opportunity occurred I started to investigate the subject once more. In 1888 I had some special lamps made at the Edison and Swan lamp works. Some were strangely shaped, with long glass tubes springing from the sides; others had tubes shaped like the capital "L." The filaments were of carbon, bent round like a horseshoe, and within the bulbs or in the side tubes metal plates were fixed.

"With these lamps, I conducted many tests of a highly technical nature, which I fully described in various scientific papers to the Royal Society and Physical Society. I was keenly interested, although the average man would have found little in my laboratory to appeal to him. I fully confirmed Sir William Preece's observations that the molecules discharged from the incandescent filament could not pass round a right-angle bend, and double confirmed my original discovery that the molecules traveled in straight lines.

"Then I enclosed the negative leg of the carbon filament in a glass tube, and found that the bombardment of electrified particles was completely stopped. By altering the position of the metal plates, I learned that I could vary the intensity of the bombardment. At last I tried placing a metal cylinder completely around the negative leg of the filament without touching it, and the mirror galvanometer that I was using to detect the currents indicated the strongest current of all. It was plain that the metal cylinder enclosing the negative filament caught all the electrified particles that were shot out from the filament.

"What I discovered led me to experiment with electric arcs in the open air, and I found that the same phenomenon existed. I published the result of these experiments in a paper in 1889, 'On Electrical Discharge Between Electrodes at Different Temperatures in Air and High Vacua."

"Thereafter, whenever the opportunity occurred, I continued my experiments with a view to further discoveries. I need not enter into technical details here, but all my researches indicated that the molecules of my original discovery were composed of particles charged with negative electricity. Since the brilliant discoveries of Sir J. J. Thomson in 1897 we have called them 'electrons.' By surrounding the negative filament with a metal cylinder and

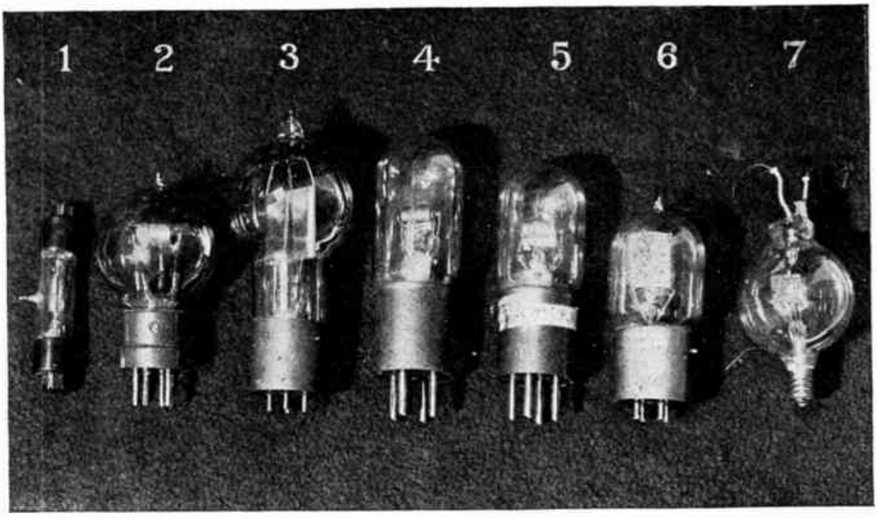


Figure F. AN UNUSUAL COLLECTION OF AMERICAN AND FOREIGN TUBES—
The various forms of vacuum tubes shown above may be identified as follows: 1, the Myers audion (American); 2, amplifier tube used by the French; 3, the De Forest rectifier tube (American); 4 and 5, German tubes made during the war (on account of the scarcity of brass in that country at the time, the bases of these tubes were made of iron); 6, the well-known Moorhead Electron-relay (American); 7, the original De Forest "Audion" (American).

bringing the filament to a high state of incandescence, a current of negative electricity was induced to flow from the filament to the plate, but it could not be induced to flow in the opposite direction from the plate to the filament.

"I have often been asked to explain why the current could flow one way and not the other, and I think a rough analogy is to liken the glowing filament to a battery of guns always firing shells at a certain target. The shells must travel away from the guns. The impulse is behind them, so they must go forward. It is physically impossible for them to travel toward the guns from which they have been fired. In hitting the target the shells burst and expend their energy, just as the electrons give up their energy, or negative electricity, when they hit the cylinder surrounding the filament.

"It is thus easy to understand why the current can flow only one way, that is, from the filament to the cylinder. The electrons are like porters, all hurrying in one direction with a tiny load of negative electricity. As there are no porters traveling in the opposite direction, it is impossible to get any current carried back again.

"In 1899 I was asked to act as electrical adviser to Marconi's Wireless Telegraph Company and to assist in solving the technical problem of equipping the first transatlantic wireless station at Poldhu with electrical apparatus that would send a wireless impulse across the Atlantic. At that time a wireless signal had not been sent much over 100 miles, so it was a big jump to send a signal 2,000 miles.

"We realized that high power would be necessary, and that the old methods of supplying power would be useless. Accordingly, we ordered certain ma-

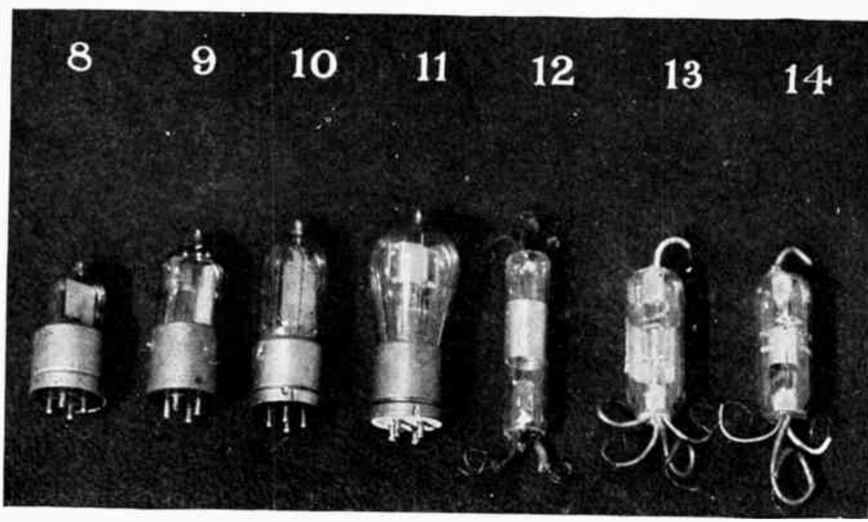


Figure F. INCLUDING SOME OF THE EARLY MODELS USED BY AMATEURS

8 is the De Forest VT-21, a wartime tube (American); 9, the Moorhead amplifier tube (American); 10, the Western Electric VT-1, used by the U. S. Navy and the U. S. Signal Corps during the war (American); 11, the Radiotron, now in common use for detection and amplification (American); 12, the tubular "Audiotron," at one time the amateur's favorite detector (American); 13, an amplifier tube with a second spiral grid that serves as a plate (Japanese); 14, a detector tube, evidently copied after the "Audiotron" (Japanese).

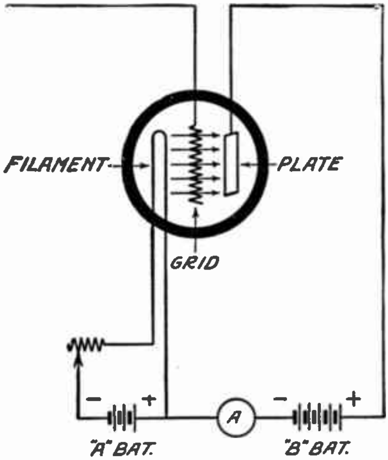


FIGURE G

Diagram of the insulated grid in the vacuum tube. The arrows pointing from the filament to the grid and plate of the tube show the path of the electrons after they are "boiled" out of the filament by heating it electrically.

chinery, which was installed in due course, and in November, 1901, Senatore Marconi, with two assistants, went to St. John's, Newfoundland, to see if it was possible to obtain messages from Poldhu.

"The weather was bad. High winds enveloped them as they stood on Signal Hill trying to induce their kites and balloons to rise in the air. They had barely coaxed one kite to rise when it broke from its moorings and fell into the sea. They tried again until at last the long-looked-for signal was detected. On December 12 they heard three distinct taps signaling the letter "S" and wireless telegraphy across the Atlantic was an accomplished fact, needing only more perfect instruments to make it commercially possible.

"In those early days the coherer was used to detect signals. All wireless students know how it works. The metal filings in the coherer leap together at the touch of an electrical impulse and form a bridge for the current to pass over, and they have to be tapped apart before they can detect another electrical impulse. Senatore Marconi improved on the coherer as a receiver by inventing the magnetic detector. Yet there was room for still further improvement."

The Fleming vacuum tube was infinitely more sensitive in the reception of radio signals than any device that had been used up to that time. After the work of Fleming, DeForest, through a long series of brilliant experiments, added a third element, the grid, to Fleming's valve and brought it from the plane of a sort of scientific makeshift to a marvelous instrument capable of detecting the most insignificant whiffs of electrical energy. The vacuum tube of today is without doubt the most sensitive device in the world.

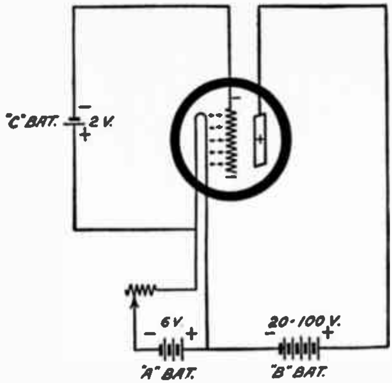


FIGURE H

This diagram illustrates the action of the negative charge on the grid. Since electrons are negatively charged particles, it will be understood that a negative charge on the grid will influence their passages.

If a crystal be connected in an alternating current circuit, only half the impulses will flow through it and the other half of the impulses trying to flow in the other direction will be resisted, or held back. A crystal, then, conducts currents much better in one direction than in the other, and the current that actuates the telephones in a crystal set is that current (which happens to be flowing in the right direction) which the crystal lets through. It will readily be seen that this actuating current is but a part of the received energy, and if all the incoming current could be put to work in some way or other, much louder signals would be produced in the telephones.

We shall now see how the vacuum tube uses all of these received impulses, both positive and negative, and uses them so as to act as a trigger acts in a gun. It takes but a small effort to pull the trigger, although the resultant explosion is many times more powerful than the trigger effort. So the vacuum tube uses the feeble received currents to "trigger off" larger currents supplied by the "B" battery and in this way at the same time amplifying or strengthening the signals. In this case the "B" battery may be likened to the powder in the gun, and the feeble incoming impulses may be likened to the pressure upon the trigger. An incoming impulse pulls the trigger of the vacuum tube, so to speak, and the "B" battery connected in the plate circuit of the tube immediately "shoots" the energy to reproduce the trigger impulse in a much amplified fashion. This is made possible by the rectifying and amplifying qualities of the vacuum tube itself, giving receiving results far superior to those of the crystal detector which possesses only the quality of rectifying.

Edison, while studying the effects of heated filaments of carbon in the old-fashioned electric incandescent lamp, found out that the filament got thinner and thinner as the lamp burned, and that the glass bulb began to get darker

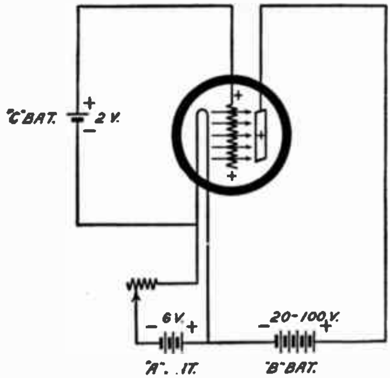


FIGURE I

The action of the positive charge on the grid. Compare this with Fig. H. A positive grid causes an increased electron flow since dislike charges of electricity exert attraction between bodies carrying them.

and darker at the same time. The filament seemed to be disintegrating, and giving off particles which shot across the evacuated space and stuck to the glass. He conceived the idea of placing another electrode or wire in the lamp that would collect these little particles which constantly were being driven away from the filament. Later he found that the extra wire became charged slightly negative every time the lamp was turned on, and finally a battery was connected across between the wire and the filament, with the positive terminal of the battery connected to the wire. Immediately a current was detected flowing in this circuit, and when the lamp was turned off, the current promptly stopped. This action was called the "Edison effect," and we know now that all filaments when heated in a vacuum give off electrons which fly off and away from the filament.

Before we go any further, there are three points to remember which are important if we are to understand the action taking place in the vacuum tube:

First: a vacuum tube will pass current only from the plate to the filament.

Second: the strength of this current is dependent upon the density of the stream of electrons passing from the filament to the plate.

Third: the density of the stream of electrons is dependent upon the temperature of the filament, the kind of material the filament is made of, the distance between the filament and the plate, and the amount of "B" battery potential applied to the plate.

While experimenting with electron streams in flames and hot gases, De Forest found that he could control the strength or density of the stream of electrons by placing a charged wire mesh in the path of the stream. That this is a fact will at once be evident to anyone who knows that "like charges repel, and unlike charges attract." The electrons are negative, and when the mesh is charged negatively the electrons in the stream which are trying to pass through the holes in the mesh are repelled and the stream is reduced and stops, and when the mesh is charged positively, the electrons are strongly attracted and the stream is increased and strengthened.

DeForest then applied this principle to the vacuum valve and interposed his famous "grid" in between the filament and the plate. (See Figure G.) In this diagram the grid is shown disconnected and has no externally applied charge on it. In this state the tube would act about the same as the Fleming valve; that is, there would be a flow of electrons across from the filament to the plate if the filament is heated. This is the same as stating that a current would flow from the plate to the filament (refer to the three points to be remembered, mentioned above). The electrons would pass through the spaces in the grid.

Now suppose we should connect a small battery "C" across from the filament to the grid with the negative terminal connected to the grid and the positive terminal connected to the filament, as shown in Figure H. This would make the grid negative with respect to the filament, or in other words a negative charge of 2 volts will be placed on the grid. Let us study the effect of this charge on the grid in the diagram. The electrons trying to leave the filament, represented by the arrows, are negative. The grid is charged negatively, by the "C" battery. Remembering the fact that "like charges repel and unlike charges attract," we readily see that the electrons are repelled and forced back to the filament; a small number, or none, ever get across to the plate. Hence, in this condition the tube lets little or no current across from the plate to the filament.

What would happen if we suddenly were to reverse the terminals of the "C" battery which is charging the grid? Let us investigate in Figure I. In this case

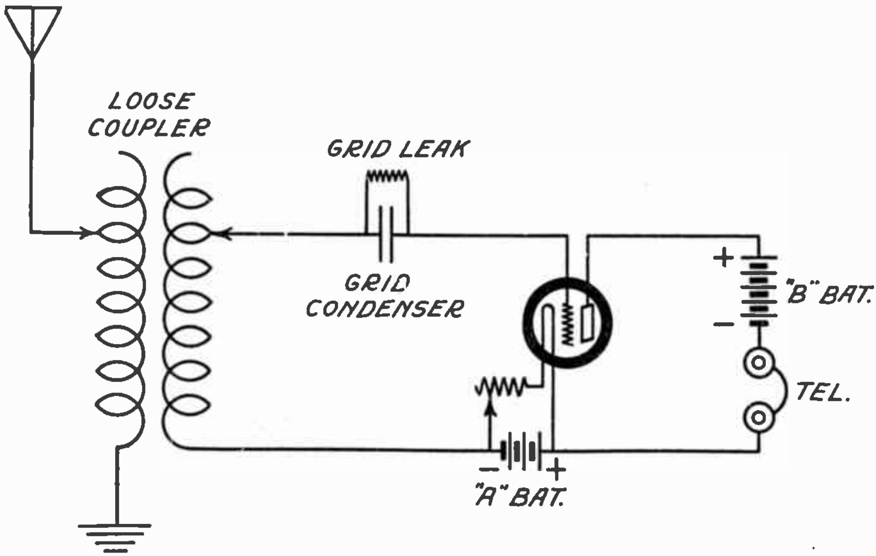


FIGURE J

The diagram above shows the method of connecting a three-electrode vacuum tube to a loose coupler, as a detector.

the grid would have a positive charge of 2 volts, and the negative electrons would be strongly attracted across from the filament to the grid. When they get this far on their journey they begin to feel the greater attraction of the higher positive voltage charge on the plate and they pass through the spaces in the grid in a flying effort to get to the plate, which receives them "with open arms," so to speak. The attraction of the positive charge on the grid draws many times more electrons from the filament than would ordinarily leave it, and thus the density of the stream is increased many times. Another reference to our famous three points will prove that there is at this time a much stronger current flowing from the plate to the filament. The current flowing across from the plate to the filament of course is a direct current, and is known as the "plate current" of the tube. To sum up the action of the tube in a few words, we might say that "the plate current (explosion) of the vacuum tube can be controlled by the voltages (trigger) applied to the grid."

Now we can see the likeness between the action of the vacuum tube and the action taking place in firing a gun.

It takes a very small change in grid voltage to effect large changes in the values of plate current, and it is this plate current that is used to actuate the telephones in a vacuum tube receiving circuit. The feeble received impulses are used to "trigger off" much larger currents supplied by the "B" battery, in this way at the same time amplifying and strengthening the incoming signals. This is the reason why the vacuum tube gives so much stronger signals than the crystal detector, which only rectifies the weak incoming impulses.

In Figure J is shown a conventional circuit with a vacuum tube used as a detector. The loose coupler is used to tune in to the desired wavelength so that the radiated energy may be received and applied to the grid in the form of high frequency impulses. These impulses vary the amount of the direct plate current of the tube so that the same voice waves as spoken into a distant telephone transmitter are reproduced and amplified in the telephones which are connected in series with the plate and "B" batteries. A grid condenser is used to supply the incoming charges to the grid of the tube. The grid leak resistance is used to prevent the negative charges accumulating on the grid in such large quantities that the tube becomes inoperable.

It is interesting to note that this action of the vacuum tube that we have been considering is based entirely upon the tiny electrons that we romanced over in the introduction to the course. When a heavy current passes through a conductor and causes the metal to be heated high above the temperature of its surroundings, millions and millions of tiny electrons are "boiled" out of the wire and jump off into space. If the wire is surrounded by atmosphere at ordinary pressure, these little electrons will not go far before they bump into an atom of one of the gases present in the atmosphere. If this heated wire is placed within the confines of an evacuated space the electrons will "boil" out more freely and they will move with greater speed. Not only this, but the direction they take can be controlled by placing a positively charged plate in the vicinity of the heated filament.

This unilateral conductivity across the heated space between the plate and the filament of the vacuum tube is brought about solely by the movement of large numbers of electrons passing in one direction. They function merely as current carriers. Sometimes it happens that they are boiled out of the filament so rapidly that the positive voltage on the plate is not high enough to cause them to travel at maximum speed. When a condition such as this occurs, the electrons start piling up between the plate and the filament. This results in what is known as a *space charge*. That is, the space between the filament and plate becomes negatively charged through the presence of too many electrons all moving but not moving fast enough. When this space charge is present the vacuum tube will be found to be practically paralyzed for the electrons that leave the filament will be repelled because the space charge is negative and the electrons are negative. It is simply a matter of electrons repelling electrons. There are two remedies for a condition of this nature. One is to cut down the current flowing through the filament so that the filament will not be heated to such a high temperature. This diminishes the supply of electrons. The other remedy is that of applying a higher voltage to the plate so that this electrical "sucking" effect will be increased.

It is evident, even to the layman, that it is desirable to coax out a maximum number of electrons with minimum filament temperature. Bringing down the temperature of a filament means that we can reduce the amount of current used and that we will have as a result a more efficient device.

The great laboratories of the General Electric Company have found ways of increasing electronic emission from filaments and perhaps it would be more beneficial to the student to have Dr. Irving Langmuir, Ph.D., D.S.C., one of the greatest living authorities on the vacuum tube, tell about the amazing method of increasing the supply of electric carriers.

"When metals are heated in high vacuum, electrons, or minute particles of negative electricity, evaporate from their surfaces. If there is another electrode in the evacuated space which is given a positive charge the electrons drift over to this electrode plate or anode so that a current flows between the two electrodes. Dushman has recently derived an equation which should supersede the well-known Richardson equation, giving the relation between the electron current and the temperature of the filament (cathode). The advantage of this new equation is that there is only one constant which we need to know for each different filament material, instead of two constants which were necessary for the Richardson equation.

"The electron emission from a large number of different materials has recently been measured. The thoriated tungsten filament gives a current at a temperature of 1,500° Centigrade absolute, which is about 130,000 times greater than that from ordinary tungsten. Measurements have also been made of filament materials that have even greater emissions.

"In order to make use of the total electron emission that a filament is capable of giving, it is necessary to apply to the plate of the tube a high enough voltage to overcome what is known as the 'space charge' effect. When small amounts of gases are present in the partial vacuum, positive ions are formed in the space between the filament and plate, and these tend to neutralize the negative space charge and allow the current from the filament to pass across the space at much lower plate voltages. In other words, the

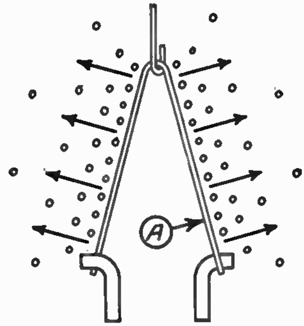


Figure L.—THE ELECTRON DISCHARGE FROM THE ORDINARY FILAMENT

The arrows on this much-simplified drawing show the direction taken by the electrons that are emitted from the heated tungsten filament, A. It is the positively charged plate of the vacuum tube that causes the electrons to be attracted and "pulled" across the vacuous space. The degree to which they respond depends largely upon the voltage of the B battery.

effect of gases is to increase the current-carrying capacity of the tube.

"Such an effect is used in the tungar rectifier. Care must be taken as to just what gas is used for the purpose, for many gases have the effect of poisoning the filament, and cutting down its emission of electrons to a small value.

"If very high voltages are used on the plate, so as to produce intense electric fields, it is possible to *pull* electrons out of the filament. In fact, it is possible to pull electrons even out of cold filaments, that is, filaments at ordinary temperatures. The currents obtained this way from the filament come from very minute areas, but in these areas the current density amounts to more than one hundred million amperes to the square inch.

"The thoriated tungsten filament is a tungsten filament containing one or two percent of thorium, usually in the form of oxide. When such a filament is heated to about 2,500° Centigrade, a little of the thorium oxide is changed into metallic thorium. In the meantime, however, any thorium on the surface of the filament evaporates off, leaving only pure tungsten. If the filament temperature is then lowered to about 1,800° Centigrade, the thorium gradually wanders or diffuses through the filament, and when it reaches the surface (provided that the vacuum is almost perfect) remains there and gradually forms a layer of thorium atoms which never exceeds a single atom in thickness. The thickness of this film is therefore about .00000001 inch, yet this film increases the electron emission of the filament more than one hundred thousand fold. Two of the latest radio tubes which have recently made their appearance and are known as radiotrons UV-201A and UV-199 embody the new principle of the thoriated filament.

"Of course this useful film is very

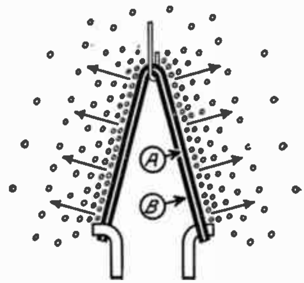


Figure K.—THE ELECTRON DISCHARGE FROM THE THORIATED FILAMENT

Note the greatly increased emission of electrons from the tungsten filament, A, which has been coated with a minute layer of thorium, B. Such treatment of filaments permits the filament current to be cut down without loss of efficiency. That means that less A battery current flowing through the filament will produce the right effect.

sensitive and needs some protection to keep it in good condition. Very slight traces of water vapor or other gases would oxidize this film and destroy it.

"This may be avoided by putting in the bulb some substance that combines with the water before it has a chance to attack the thorium film. One such a substance is metallic magnesium.

"Furthermore, it is necessary to avoid heating the filament to too high a temperature, or the film might evaporate off. It is therefore best to operate such a filament within a rather narrow range of temperature close to 1,700° Centigrade, where the ratio of evaporation is small, and where the temperature is high enough for the thorium gradually to diffuse to the surface and continually repair any damage done by the effect of slight traces of residual gases.

"The thoriated tungsten filament opens up many new fields of scientific investigation. By measuring the electron currents, it is possible to determine accurately exactly how much thorium is present on the surface. An amount of thorium corresponding to only one one-thousandth of the surface covered with a layer one atom deep is easily measurable in this way. It is possible to knock off a thorium film by bombarding it with positive ions, moving at high velocities, and in this way the true nature of the bombardment can also be determined.

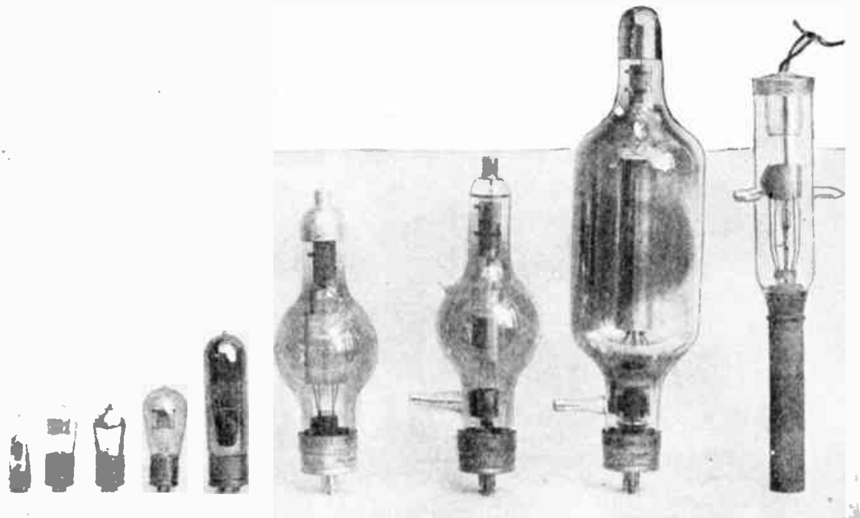
"Most of the applications of high vacuum tubes have depended upon the control of electron currents—as, for example, by the grid in the three electrode tube.

"The action of the grid is due to the charge on the grid that modifies the space charge effect. This is the action that is employed in practically all tubes used today for radio transmission and receiving.

"There are many other methods, however, of controlling electron currents. An important method is that used in the magnetron, where there are only two electrodes in the evacuated space and the control is obtained by means of a magnetic field generated by an external coil of wire. A still simpler form of magnetron suitable particularly to very large power tubes, consists of a very large straight filament in the axis of a cylindrical plate. The magnetic field produced by the current flowing through the filament is enough to prevent electrons flowing between cathode and anode. By heating the filament with alternating current which periodically falls to a low value, a large electron current can be made to flow from the filament to the plate also periodically. This gives a pulsating or oscillating current, which can be used for radio transmission. A 1,000-kilowatt tube of this kind is in process of development; preliminary tests have been in every way satisfactory.

"Another form of tube by which electron currents can be controlled is the dynatron. This depends upon subjecting one of the three electrodes in the tube to electron bombardment in such a way as to cause electrons to be splashed out of it, just as water can be splashed out of a cup by attempting to fill it too rapidly from a faucet. A tube of this kind acts like a real negative resistance, and may be used for producing electrical oscillations with considerable efficiency.

"One of the most important of every day applications of electron discharges from hot cathodes is in the Coolidge X-ray tube, which is now almost universally used as a source of X-rays. These tubes were first made about 1913 and are gradually being improved in many respects. The latest type of tube, suitable for use by dentists, is a small tube weighing only a few ounces, and only about three inches long. Because



General Electric

RECEIVING AND TRANSMITTING TUBES

Figure M. The three tubes at the left are receiving; two of them have the new thoriated filament. The other six are for transmitting; they range from 5 to 20,000 watts output.

of the special features of this tube, the entire X-ray outfit, including the transformer, lead screen and regulating apparatus, weighs only a few pounds and takes up a space of only a small fraction of a cubic foot.

"One great advantage of this new form of tube, besides its convenience, is its absolute safety, even in the hands of inexperienced operators, for there are no high voltages in any part of the apparatus which is accessible."

The beginner in radio is greatly confused in the matter of vacuum tubes because of the large number of types available. Since the expiration of certain key patents, many manufacturers have entered the field of tube production and the market is loaded with all sorts of detectors and amplifiers. While we have no desire to indict the independent manufacturer of tubes, the reader is cautioned to investigate claims very carefully before he invests his money in nondescript articles. Some of the independent tubes will be found to meet all the claims of their manufacturers while others, due to lack of proper equipment, will be practically useless when placed in a circuit. A vacuum tube is more or less like an egg. An egg may look perfectly fresh and the storekeeper may claim that it is fresh, but it will be found very stale when subjected to the olfactory test.

Due to the rapidly changing conditions and to the going and coming of independent tube manufacturers the editors have decided to hold the descriptive matter concerning tubes down to the products of the more staple organizations.

WD-11 and WD-12. The WD-11 and WD-12 tubes are of the dry cell type, that is they are tubes that operate without the use of storage batteries. Their filament current consumption is so small that they may be provided with sufficient current from ordinary dry cells for a long period of time. They are thus economical and beautifully adapted to small receivers where portability or conservation of space must be considered. WD-11 and WD-12 tubes have practically the same electrical characteristics and either type may be used as detectors or as amplifiers. The bases are different, however, for the WD-11 requires either a special socket or an adapter so that it may be inserted in the standard socket.

Used with care, WD-11 tubes should have a life of from 800 to 1000 hours of constant operation. The manufacturer of this tube recommends a B battery of 22½ volts. In some cases, however, it may be advisable to drop this voltage to 18, especially if the reproducing equipment of the receiver emits unnatural noises. It might be said here that too much voltage on a detector tube will cause undue distortion.

The grid condenser used with either WD-11 or WD-12 tubes should have a capacity somewhere in the neighborhood of .00025 mfd. and the grid leak (which is the high resistance used in the grid circuit and which we will consider more fully later on) should be of 2 megohms. When WD-11 or WD-12 tubes are used as amplifiers, a greater plate voltage must be applied. This voltage may be as high as 80, and, although the plates of these tiny tubes will stand as much as 200 volts, it is not practical to go over 90 because of the inability of the average audio frequency transformer to withstand this application of pressure.

When more than one WD-11 or WD-12 tube is used in an amplifying system, an additional 1½ volt cell should be added for each tube. The cells are connected in parallel. A dry battery should give from 70 to 90 hours of operation with tubes of this design. Since the filament requires $1\frac{1}{2}$ volts, in case one tube is used, it is connected directly to the rheostat and the filament. The rheostat in this case has a total resistance of 6 ohms and it will be understood that this resistance is variable by moving the contact over the surface of the wire.

Vacuum tubes are always controlled by rheostats for it is only by regulating the flow of current through the filament that we can increase or diminish the supply of electrons and thereby the amplifying and detecting characteristics of the tube. Rheostats with different resistances are required for the different tubes. More will be said about this later.

UV-200 and C-300. The UV-200 and the C-300 tubes are of the same manufacture and consequently they have practically the same electrical properties. Each of these tubes requires a six-volt storage battery or current from some other six-volt source controlled by a standard six-ohm rheostat. While such a tube may be operated on dry cells connected so as to supply a current of about six volts, such operation will be found very expensive for the filament consumption of these tubes is about one ampere. These tubes are used more as detectors and they have been designed especially for this kind of service. Experience has shown that a B battery having from 15 to 24 volts should be applied to the plate and that a grid condenser somewhere between the capacity of .00025 and .0005 mfd. is best.

UV-201—C301. As in the case of the UV-200 and C-300 tubes, the UV-201 and C-301 are identical in construction and operating characteristics, since they are both made by the same manufacturer but sold through two different channels of distribution. A six-volt storage battery is required for the current supply and this may be regulated by a six-ohm rheostat. These tubes, or rather this tube, should be supplied with a B battery voltage of approximately $22\frac{1}{2}$ volts when used as a detector and with from 45 to 100 when used as an audio-frequency amplifier. Incidentally it will be found that the characteristics of this tube make it more adaptable to audio-frequency amplification than to detection. This tube will also be used with poor success in radio-frequency amplification for it seems that it has been primarily designed to function with highest efficiency in audio-frequency work.

UV-201A—C-301A. As in the cases mentioned previously, the UV-201A and C-301A are one and the same tube sold in different type numbers and under different trademarks. These tubes require six volts of potential, but since they are constructed to consume but $\frac{1}{4}$ amp. at maximum intensity, it is necessary to use a rheostat that will provide from 16 to 30 ohms of resistance. When such specifications are given, the reader is warned not to ignore them and use a lower value. If a six-ohm rheostat should be used for any length of time with such a tube, its life would be greatly reduced and before it finally succumbed, it would act very badly either as a detector or an amplifier.

The tube under discussion requires from 18 to 45 volts as a detector and anywhere from 40 to 125 volts as an audio-frequency amplifier. We have in the UV-201A a most amenable tube, for it may be used very successfully either as a detector and audio-frequency amplifier or a radio-frequency amplifier.

UV-199. The UV-199 is made to operate on two dry cells connected in series. However, practice dictates the sanity of using three cells because of the rapid polarization or dropping of current in the case of a battery of two. It has been found that three cells connected in series will provide sufficient current to operate a UV-199 two hours a day for six months.

Since the filament consumption of these tubes is small (being only .06 of an ampere) it is logical to look to a heavy voltage on the plate to obtain a sufficient supply of electrons for efficient operation. The plate voltage is 80 but the user of the tube may feel safe in advancing well beyond this figure without fear of damaging the tube.

The rheostat used with UV-199 tubes should in the case of one tube be 30 ohms and, in the case of two tubes operating together, one rheostat of 20 ohms will be found sufficient. Three UV-199's in parallel operation can be nicely controlled with a ten ohm rheostat.

At this point the reader should be warned not to operate a vacuum tube (regardless of its type of manufacture) at a higher plate voltage or filament brilliancy than that required for the good reproduction of music. Excessive current in the filament will damage the tube greatly in a short time. This is especially true of the UV-199. Sometimes it can be restored to good operation by lighting the filament for a half hour and leaving the plate voltage off.

The UV-199 may be used either as a detector or amplifier in radio- or audio-frequency systems. While its plate voltage is not critical, about 35 or 40 volts will be found to be the point at which it works best. It is also important to know that when this tube is used as an amplifier the rheostat should be connected in the negative filament lead and that the return lead from the post on the socket marked "grid" should be brought to the negative terminal of the A battery. When the UV-199 is used as an amplifier, from 40 to 80 volts may be used on the plate.

DV-1. The DV-1 tube is of DeForest manufacture and three volts, which may be supplied by two dry cells, is supplied to the filament. As in the case of some of the other dry cell tubes, a 30-ohm rheostat is needed for current regulation. The DV-1 is an excellent detector and a fair audio-frequency amplifier. When used in the former capacity, from 22½ volts to 45 volts will be needed on the plate. As an amplifier, this voltage may be increased from 50 to 85 volts. Experience has shown that the DV-1 is a most excellent radio-frequency amplifier.

DV-2. In the DV-2 we have a tube designed for heavy amplification in audio-frequency circuits. A six-volt source of current (preferably a storage battery) is required by this tube and a six-ohm rheostat is usually employed to regulate the filament current. When employed as an amplifier, a voltage somewhere between 45 and 150 will be found suitable. The reader will be disappointed if this tube is applied to detection.

DV-6A. Here is a six-volt storage battery tube that requires from 22 to 45 volts as a detector and from 45 to 100 volts as an amplifier. It may be used with equal success either as a detector or amplifier.

209-A. This is a tube consuming very little filament current and operating from a six-volt source. It should have a 30-ohm rheostat and a B battery from 90 to 120 volts.

VT-1. The VT-1 is sometimes

called the "J" tube and it is manufactured by the Western Electric Company as a detector and an amplifier. Due to the abundant source of electrons from its filament, a plate voltage of between 12 and 22½ will be found sufficient. This may be increased to 45 when the tube is employed for amplification. It operates from a six-volt storage battery and a rheostat having from 6 to 15 ohms may be used in connection with it. The grid condenser should have a value of .005 mfd. capacity.

VT-2. The VT-2, which is also of Western Electric manufacture, is sometimes called the "E" tube. It is a most excellent audio-frequency amplifier and requires an A battery of 7 volts. However, in practice it is found to work well with a six-volt storage battery and a six-ohm rheostat. B battery potentials may run as high as 350 volts with such a tube.

216-A. In the 216-A we have the master audio-frequency amplifier. It operates from a six-volt storage battery and may be controlled by a 6 to 15 ohm rheostat. The B battery should be of 120 volts although a slightly greater or less voltage may be best. This tube is especially suitable for use in connection with power amplifiers.

There is given on pages 190-191 a table which shows the general characteristics of the various vacuum tubes in general use. Even a perfunctory study of this table will assist the student in choosing vacuum tubes for various purposes.

By using the data given in this chart with our knowledge of Ohm's Law, we may, by a few very simple calculations, determine the exact amount of resistance that should be employed with each tube. Take the figures given in the second and third columns. The second column, it will be noticed, gives the filament terminal voltage and the third column the filament battery voltage. We know that the difference between these two figures represents the voltage drop in the resistance of the rheostat. By following Ohm's Law it will be seen that this is equal to the product of the current flowing through the rheostat or the resistance is equal to the voltage drop in the rheostat divided by the current. Let us take as an example the UV-199 tube. Reference to the table shows that the terminal voltage is three volts and the filament battery 4.5 volts. The difference between these two figures is 1.5 volts which represents the drop in the rheostat. The current flowing through the rheostat as found in column 4 is .06 amperes hence the resistance in the rheostat must be $\frac{1.5}{.06}$ equals 25 ohms. Since every engineer works with a factor of safety it is always wise to employ resistance a little higher than that actually found with figures. A resistance of 30 ohms is best with the UV-199.

When two such tubes are used together the total current flowing through the rheostat is then .12 amperes. We then have $\frac{1.5}{.12}$ which equals 12.5 ohms.

Although small, the grid leak is a most important device. It is part and parcel of the detector vacuum tube itself and it often happens that radio receivers are insensitive and cranky for the want of a more accurately adjusted resistance in the grid circuit. It might perhaps be well to more thoroughly investigate the function of a grid leak.

To become familiar with the function of the grid leak, let us consider Figure N.

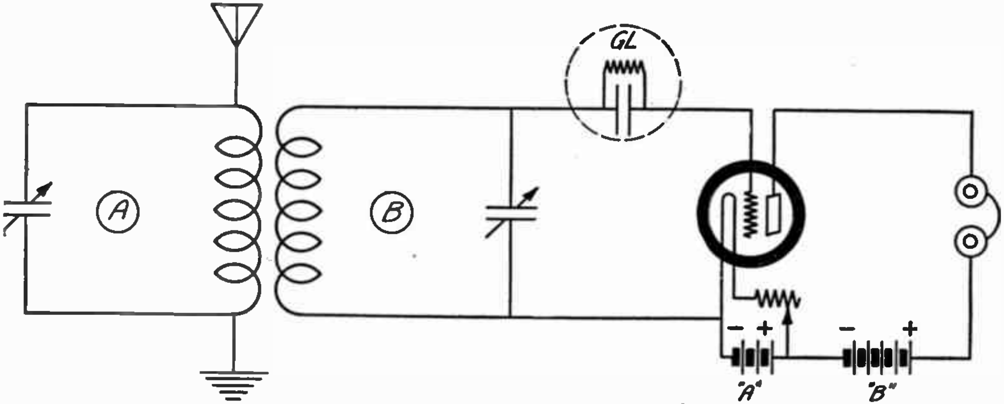
Here we see an ordinary receiving circuit that has connected to the vacuum

VACUUM TUBE DATA

	Filament Terminal Voltage	A Battery Voltage	Fil. Current in Amps.	Resistance of Rheostat	Plate Voltage: Detector	Plate Voltage: Amplifier	C Battery	Amplification Constant	Mutual Conductance Micro-Mhos.	Plate Resistance Ohms
Aerodyne 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	7.25	440	18,000
Ceco Type 201-A	5	6	.25	20-30	22.5-45	90-130	3-9	8	550	14,500
Cunningham C 299	3	4.5	.06	30	20-40	45-90	5	6		
Cunningham C 300	5	6	1	6	15-22.5			7		
Cunningham C 301	5	6	1	4-6	40	45-90	5-6	7		
Cunningham C 301-A	5	6	.25	6-10	40	45-90	5-6	8		
Cunningham C 302	8	10	2.35	4		100-500	3-25	7.5		
Cunningham C-11	1.1	1.5	.25	4-6	22.5-40	45-60	3-5	6.5	400	14,000
Cunningham C-12	1.1	1.5	.25	4-6	22.5-40	45-60	3-5	6.5		14,000
Daven	6	6	.25			90-200	0-4.5	20	500	40,000
De Forest DV-2	5	6	.24-.26	30		90	5-9	6-8.8	550-1100	8,000-11,000
Everest Type 1-A	5	6	.25	20-30	22.5-45	90-135	3-9	9.4	630	15,000
Elektron 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	8.2	550	15,000
Empiretron-Type 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	7.5	640	11,800
Gem 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	10	640	15,500
Hi-Constron Ct-101-A	5	6	.25	20-30		90-180	1-4	18	480	37,500
Magnavox Type A	5	6	.25	20-30		90-135	3-9	6-3	405	15,500
Musselman	3	4.5	.12	20-30	20-45	67.5-100	3-7.5	6.8	380	17,800
Radiotron-UX 112	5	6	.5	6	22.5	45	6-10.5	7.9-8	890-1,670	4,800-8,800
Radiotron-UX 120	3	4.5	.125	20-30		90-157.5	22.5	3.3	500	6,600
Radiotron-UX 210	6-7.5	6-8	1.1-1.25	2-6		90-425	4.5-35	7.5-7.75	775-1550	5,000-9,700
Radiotron 199	3.0	4.5	.06	30	20-40	45-90	5	6	415	15,000
Radiotron UV-200	5	6	1	6	15-22.5			7		
Radiotron UV-201	5	6	1	4-6	40	45-90	5-6	7		

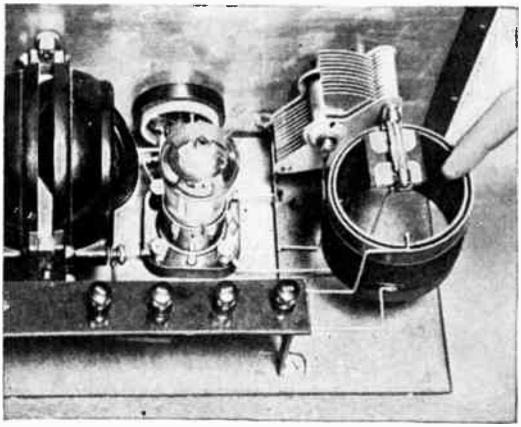
VACUUM TUBE DATA—Continued

	Filament Terminal Voltage	A Battery Voltage	Fil. Current in Amps.	Resistance of Rheostat	Plate Voltage		C Battery	Amplification Constant	Mutual Conductance Micro-Mhos.	Plate Resistance Ohms
					Detector	Amplifier				
Radiotron UV-201-A	5	6	.25	6-10	40	45-90	5-6	8	675	12.000
Radiotron UV-202	8	10	2.35	4		100-500	3-.25	7 5		
Radiotron UV-203	10	12	6.5	4		1000	20-40	15		
Radiotron UV-203-A	10	12	3.25	4-6		1000	20-40	15	3000	5000
Radiotron UV-204	11	12	14.75	4		2000	40-60	22		
Radiotron UV-204-A	11	12	3.85	4-6		2000	40-60	22		
Radiotron UX-199	3.0	4.5	.06	30	20-40	45-90	5	6	415	15,000
Radiotron UX-200	5	6	1	6	15-22.5			7	415	
Radiotron UX-201-A	5	6	.25	6-10	40	45-90	5-6	8	675	
Radiotron UX-12	1.1	1.5	.25	4-6	22.5-40	45-90	3-5	6.5		
Magnatron DC 199	3	4.5	.06	30	45	90	4.5	6.3	382	16,500
Magnatron DC-201-A	5	6	.25	6	45	90	4.5	8.5	850	10.000
RAC 3	4	6	8	4	22.5	45-90	5-10	8		
Sylvania-501-A	5	6	.25	20-30	22.5-45	90-135	3-9	9.2	675	13.400
Super-Tron Type 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	10.7	500	21,400
Tectron 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	9.4	560	16.800
True Blue Type 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	11.8	645	18,300
"Vim" Type 201-A	5	6	.25	20-30	22.5-45	90-135	3-9	6.8	650	10.500
Veby AF 20	5	6	.25	20-30		90-200	0-4.5	20	560	36.000
Westinghouse WD-11	1.1	1.5	.25	4-6	22.5-40	45-60	3-5	6.5	400	14,000
Westinghouse WD-12	1.1	1.5	.25	4-6	22.5-40	45-60	3-5	6.5		
Western Elec. "N"	1.1	1.5	.25	4-6	22.5-40	45-60	3-5	6.5		
Western Electric VT1	2.75	4	1.1	4	22.5-40	45-90	3-5	6		
Western Electric VT2	7	8	1.35	4	45	45-350	3-25	6.5		
Western Electric 216-A	5.5	6	1.10	4	45	45-150	5-13	6		



HOW GRID-LEAKS ARE USED IN A RADIO RECEIVING CIRCUIT

Figure N. This conventional receiver hook-up shows one of the connections for the grid-leak which acts as a throttle upon the flow of electrons from the grid of the vacuum tube.



HOW A GRID-LEAK IS MOUNTED IN A RADIO RECEIVER
Figure O: A grid-leak and a grid-condenser are shown at the right in the picture near the finger.

tube grid a grid leak and a grid condenser. Let us assume that the circuit B is tuned to the same wavelength as the antenna circuit A. Oscillations will then be set up in B and this will be connected to the grid with the vacuum tube by way of the condenser. Therefore, the grid will become alternately positive and negative; and each time the grid becomes positive, the electron current will be decreased. Consequently during each wave train the grid will gain a negative charge.

Now, this negative charge is both good and bad. It is good if we control it and bad if we allow it to reach a point that is too high.

We must remember that the little electrons, which are shot off the glowing filament of the tube are negative in nature and when the grid becomes negative the electrons are forced back to the filament. When negative meets negative repulsion always takes place. Two negatively charged bodies always repel each other. Therefore, we must not allow the grid to become too negative if we wish to operate our radio receiver at its most efficient point.

At the end of each wave train this negative charge should leak off through the condenser or through the glass walls of the tube itself. This should happen before the next wave train comes along, and it is to insure such a result that a high resistance is inserted across the grid condenser. This high resistance is called the grid leak.

The importance of grid leaks grows daily. The day of calling a pencil mark on a piece of cardboard a grid leak is past. Our more sensitive circuits demand a very carefully regulated resistance of constant value and a grid leak of constant value is a mean thing to make.

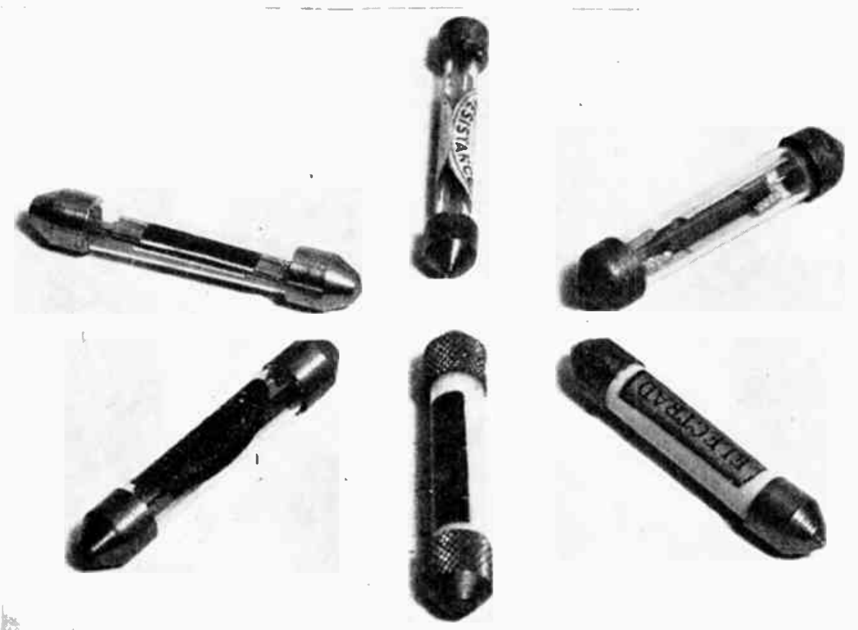
Grid leaks are made by depositing a collodial carbon ink upon a small strip of paper. So difficult has been the task of making these grid leaks with an accurate resistance that only one or two manufacturers have the courage to guarantee that their grid leaks are accurate within 10 per cent. The resistance of grid leaks changes with age, following it appears, as far as physicists know, the same law that holds true for cheese, of which the taste improves with age.

A grid leak made today will have a resistance three months from now somewhere between ¾ and ½ of its original value.

The resistance of grid leaks is measured in megohms. A megohm is a million ohms. 1/10th of a megohm is then 100,000 ohms and ½ of a megohm is 500,000 ohms. The one megohm type is most used, but this is not mentioned as a recommendation.

Too many fans choose their grid leaks on the hit and miss principle. They figure that as long as they have a grid leak in the circuit or an apology for one, their obligation to this particular part of the outfit is fulfilled, yet, the operating efficiency of many an outfit has been ruined through an unhealthy grid leak.

No set rule can be given for the use of grid leaks. Resistances that range all the way from 1/10th to five megohms are used. If we have a pet circuit and want to make sure that we are employing a grid-leak of the proper resistance, there is only one thing to do and that is to cut and try. But one cannot cut and try, if one only has a single grid leak. If we buy three grid leaks, one with a resistance of ½ megohm, one of one megohm and one of 1½ megohms, there



HOW GRID-LEAKS ARE CONSTRUCTED

Figure P: Grid-leaks are usually made of a strip of insulating material that has been impregnated with some substance containing a carbon or graphite base and hermetically sealed in a glass tube. This construction insures a constant value of resistance that, under other conditions, would be subject to change by atmospheric effects.

is a possibility that we may arrange these in a combination of just the necessary resistance. When these resistances are connected in series as illustrated in Figure R, we add them to determine the total resistance. Thus the following formula would hold true:

$$R = R1 + R2 + R3$$

When we connect in series, we always add the resistance. Now, if we were to obtain a lower resistance, we connect the grid leaks in parallel for which arrangement the following formula holds true:

$$1/R = 1/R1 - L/R2 - 1/R3$$

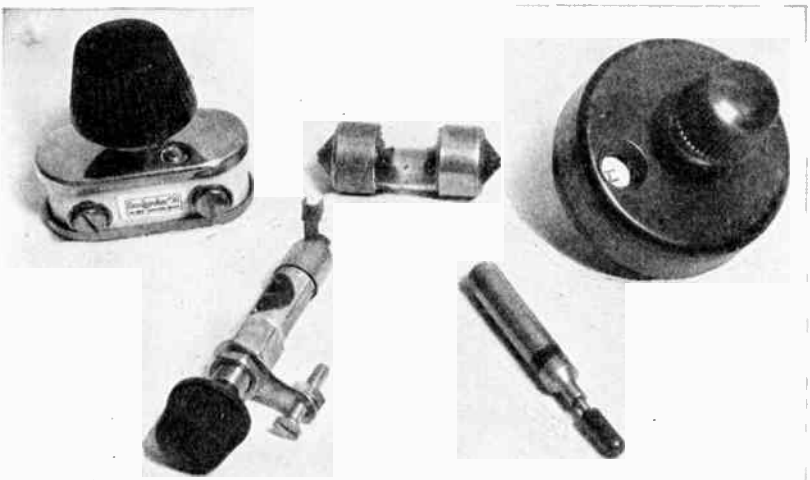
We see it is possible to juggle the three little grid leaks around so that we can obtain rather a wide range of resistances.

What is the most perfect form of grid leak?

There is such a thing, yet some of us would probably guess all nigh before we should hit upon it.

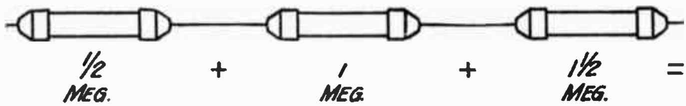
Who would imagine that a perfect grid leak is a two-element vacuum tube?

When the filament of a two-element tube is cold and no current is passing through it, the resistance of the space between the filament and the plate is infinite. If current is allowed to pass through the filament, the resistance of this space can be changed all the way from infinity to a few thousand ohms. Therefore, a two-element vacuum tube with a battery and rheostat is the most dependable form of variable grid leak, and the best way of using this variable grid leak is shown in Figure S. Of course the average bug will not care to go to this trouble, but for the real radio



VARIABLE GRID-LEAKS OF STANDARD TYPES

Figure Q: Some types of variable grid-leaks are built so that pressure upon a substance varies its conductivity or so that a plunger passes through a loosely-packed, highly resistant substance. In another type a contact slides over a surface that is completely impregnated with a substance like graphite. There is besides a unique grid-leak that contains a highly resistant liquid which makes contact on a large or small area of metal terminals as the grid leak is turned in its contact springs.



HOW TO FIGURE COMBINED RESISTANCES IN SERIES

Figure R: Grid-leaks connected in series as shown in the diagram have a resistance that is equal to the sum of their individual resistances.

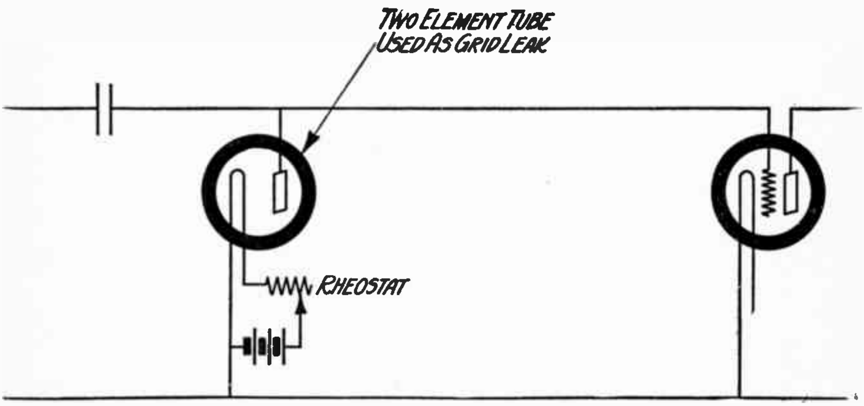
"crank," nothing can be thought of that will surpass this arrangement for bringing results.

Who would think that a grid leak would cause circuit noises? But a poor grid leak will do exactly that. Grid leaks, aside from being non-inductive and non-capacitative should also be non-microphonic. When tiny carbon particles are brought together they are bound to be microphonic unless they are properly treated. The least movement of these particles due to mechanical disturbance or to temperature effects will alter the resistance of the grid leak and we will get a registration in the 'phones. For this reason grid leaks must be made of the very best materials and thoroughly protected from moisture and other disturbing effects. If we build our own pencil-line grid leaks, it will be wise to soak them in paraffine after the connections are made.

Right here it is well to give a word of warning about the connections. Small clamps of copper are best to use, since much of the trouble in grid leaks results from poor contact with the ink surface.

This is an appreciation of the lowly grid leak. Let us remember that it is quite an important thing after all and that it demands the respect of the set owner just as much as its more aristocratic brothers and sisters, the condensers, coils, vacuum tubes and headphones.

There is a practical side to the use of vacuum tubes which the student will



A SUBSTITUTE FOR A GRID-LEAK

Figure S: How a two-element tube, preferably one of the old Fleming valves, may be connected in a receiving circuit to perform the function of a variable grid-leak.

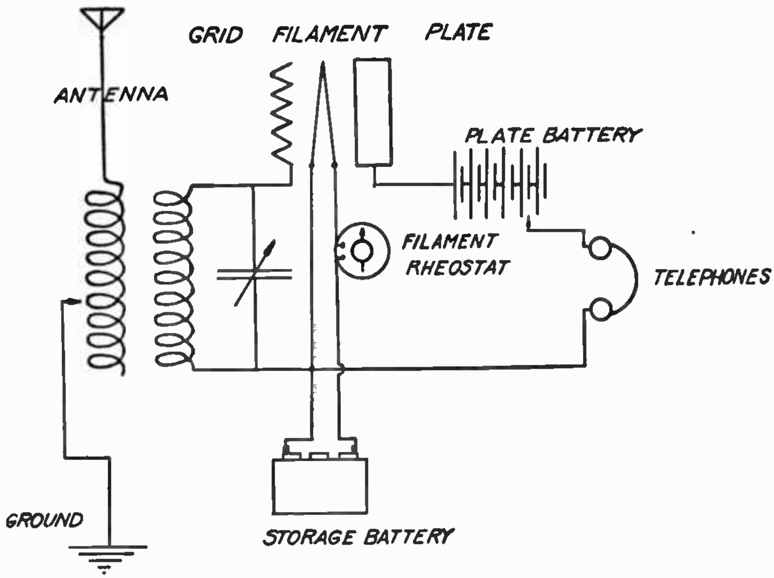


FIGURE T

A vacuum tube used as a detector is shown in this diagram. To simplify the explanation of the functioning of the circuits, the grid condenser, which is used in most cases, has been omitted.

have to master before he can employ this device intelligently. For instance, we have what is known as "hard" and "soft" tubes in radio and each has certain definite properties that may be taken advantage of in radio reception. William C. Ballard, Jr., an associate of Prof. Vladimir Karapetoff of Cornell University, has prepared an authoritative treatise on hard and soft tubes from which the alert reader may glean many points of value.

"The term 'soft' as applied to a vacuum tube is something of a puzzler to most people, as there is nothing about any kind of a vacuum tube that would suggest such a name. The name, however, has been handed down from 'X-ray' terminology and indicates a tube through which a discharge can be easily produced and whose rays have but feeble penetrative power. When these tubes are investigated it is found that they do not have a very high vacuum and contain appreciable traces of some gas or gases. If the traces of gas are removed from the X-ray tube either by absorption or pumping, the tube becomes 'hard' and requires a much higher voltage for its operation as a consequence. The rays sent off by a hard tube have much greater penetrative power and are frequently spoken of as 'hard' rays."

In order to understand just why a trace of gas makes a tube a good detector we will have to consider briefly what goes on in the detector circuit.

Figure T shows a common connection used for detector tubes. The radio signal sets up an alternating current in the antenna circuit almost exactly similar to the kind of alternating current we use for electric lights and power, but one which changes its direction about ten thousand times as rapidly as the kind we use for such purposes. An alternating current is one that flows for a while in one direction, stops, and flows for the same time in the opposite direction; then it reverses and flows in the original direction again, and so on indefinitely. The alternating currents with which we have to deal in radio reverse their direction of flow very rapidly. For instance, if we are receiving a 300-meter wave the current never flows in any given direction for over one-half of one millionth of a second. The usual way by which the rapidity in which a current builds up and dies down is measured in cycles per second. When the current has built up in one direction, reduced to zero, built up in the other direction, reduced to zero and comes back to its original starting point, we say that it has gone through one cycle. Applying this form of measurement to the 300-meter wave mentioned above, it requires one millionth of a second to complete a cycle. Hence the frequency is recorded as one million cycles per second.

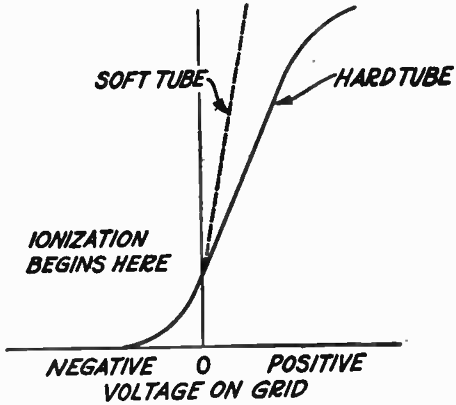
If we were able to put a current of this character through the windings of a telephone receiver there would be little or no effect produced. While the current is flowing in one direction it tries to pull the diaphragm or vibrating metal plate toward the magnet, and when the current has reversed the opposite force will be exerted on the diaphragm. But for the 300-meter wave these opposing pulls will only last for one-half of one millionth of a second apiece, and before the first pull has any chance to move the diaphragm, the second pull acts on the diaphragm and neutralizes the effect of the first pull. Since the push and pull are equally strong there will be no appreciable motion of the diaphragm.

But we can make these currents actuate a telephone receiver if we can make the pulls stronger than the pushes or vice versa. Under these conditions the effect of one pull cannot be exactly balanced out by the next push, and after several strong pulls and weak pushes the diaphragm will begin to move. As the diaphragm moves it pushes a little air along in front of it and thus produces a sound wave.

From the way in which the process has been described the reader may think that the diaphragm is moving slowly, but actually it moves so rapidly that your eye cannot begin to follow it. But, as rapidly as it is moving, its motion is slow compared to the lightning-like changes of the radio current, and we may have several hundred pushes and pulls before there is any appreciable motion of the diaphragm.

One way to make the pulls stronger than the pushes would be to entirely eliminate the pushes, or more strictly speaking, the electric currents that produce the pushes. This is just what happens when we use a crystal detector. The crystal has the property of letting currents pass through easily in one direction and of shutting them out almost entirely in the opposite direction.

The vacuum tube accomplishes this result not by shutting off all current in one direction but by making the pushes and pulls of unequal force. Referring to Figure T again, the radio waves set up currents in the antenna circuit and their effect is in turn transmitted over onto the grid of the detector tube. The alternating currents in the antenna circuit produce alternating voltages on the



THE DIFFERENCE BETWEEN A HARD AND SOFT TUBE
Fig. U: This shows how both soft and hard tubes act with various voltages on the grids.

grid, which may be considered in the light of electric pushes and pulls following each other rapidly. The telephone receivers shown in Fig. T are not connected directly in the grid circuit but are placed in a second circuit known as the "plate circuit" on account of the fact that in order to complete the circuit, current has to flow between the filament and the plate.

The peculiar action of the vacuum tube lies in the control which the grid has upon the current flowing in the plate circuit. The grid acts as a sort of screen through which the plate current has to pass in its passage from the filament to the plate and the amount of current that gets through the screening grid depends upon the voltage applied to the grid at that particular instant. If the grid is positively charged, by connecting the positive side of a battery to it and the negative side to the filament, the plate current will increase to a value higher than the value which would flow when the grid is connected directly to the filament by a piece of wire. When the connections to the battery are reversed so that the negative pole is connected to the grid and the positive pole is connected to the filament, the plate current will drop to a still lower value.

The simplest way in which to express a complex relation such as exists between plate current and grid voltage is in the form of a "curve." To show the relation between the plate current and the grid voltage we rule a number of equi-distant parallel lines, both vertical and horizontal, and assume that distances measured in a horizontal direction to the right represent positive grid voltages, horizontal distances measured to the left represent negative grid voltages, vertical distances measured upward represent positive plate currents and vertical distances measured downward represent negative plate currents. The heavy horizontal and vertical lines represent the lines from which we start the measurements. In order to find out just what current will flow when the grid is one volt negative we look for the first vertical line to the left of the heavy vertical line and follow this line up until it crosses the curve. The distance that we had to travel along the first left-hand line to reach the curve will give us the value of the plate current under the specified condition of one volt negative on the grid, and this length can be most easily found by projecting it over by eye on the heavy vertical line where the scale of units of the plate current is shown. In the case shown the plate current is 2. (See Fig. V, page 201).

If we investigate the value of plate current when the grid voltage is one volt positive we will have to follow the first right-hand line up until it intersects with the curve and the corresponding value of plate current in this case is 8. Similarly, when the grid voltage is zero the plate current has a value of 4.5.

For the sake of simplicity, let us suppose that the value of the grid voltage induced from the radio signal varies between one volt positive and one volt negative, the plate current will increase up to 8 when the grid is positive, drop back to 4.5 when the grid voltage is zero and drop still further to 2 when the grid is one volt negative. The plate current passes through the telephones and when the plate current is increased beyond its normal value the pull on the diaphragm will be increased, *producing a "pull" on the diaphragm*. When the grid is negative the plate current will drop below its normal value, and by cutting down the pull below normal give the diaphragm a push in effect. On account of the shape of the curve, the pull will be stronger than the corresponding push so that the diaphragm will finally move after several cycles have acted upon it, and thus send out a sound wave. If the curve has been a straight oblique line, the value of the push and the pull would have been more nearly identical and a lesser effect would have been produced upon the telephone diaphragm. On the other hand, if the curve has been very much more curved or had a sharp break in it, the difference between push and pull would have been much more marked and the pull on the diaphragm would have been even more pronounced with a consequently stronger signal.

The curve shown in Figure V was drawn for a hard tube. The high vacuum and the absence of all gas gives a smooth curve and one which usually does not have any very sharp bends in it. Where slight traces of gas are left in the tube the curve is more likely to resemble that shown in Figure U. From an inspection of this curve it can readily be seen that there will be a large difference between the corresponding pushes and pulls and a correspondingly strong signal in the telephones. The reason for this sudden break in the curve is due to the effects of "ionization by collision."

As the electrons sent off by the filament in a soft tube are drawn over to the plate they collide with some of the gas particles or molecules still left inside the tube. Up to a certain electron speed nothing happens, but when the electron is moving rapidly enough it will break up any gas molecule with which it comes into contact. The gas molecule is composed of a small particle of gas to which are attached small particles of electricity. When the gas molecule is broken up, some of the electricity is set free and moves over with the other electrons to the plate, thus increasing the plate current. This value of speed necessary to break up the gas molecule is quite well defined and the plate current takes a sudden jump just as soon as it is reached. When this ionization action is very intense it causes a blue glow inside the tube. The best adjustment for detector action is very much below the blue glow point and can be best determined by listening in the telephone while gradually increasing the plate voltage and filament current. When a certain point has been reached a hissing and frying sound will be heard in the telephones; this indicates that the first stage of ionization has been reached. Now turn the plate voltage or filament current down until the hissing has just disappeared and the tube should operate at its best point.

There is one difficulty in the operation of soft tubes; they are liable to change their degree of "softness." The metal parts inside the tube have the property of absorbing and giving up gas, depending on what happens to be going on inside the tube. In general, heating either the electrodes inside the tube or the glass walls of the tube will set gas free in the tube. On the other hand, operating a tube at or near the glow point has a tendency to absorb some of the free gas and make the tube harder. Tubes usually grow harder in use rather than softer, so that it is sometimes possible to bring them back to their original sensitive condition by carefully heating the glass bulb. The heating of the bulb has the tendency of loosening up some of the gas particles that have become stuck on the sides of the bulb, thus reducing the vacuum to the proper sensitive point.

There is a comparatively simple test which almost any experimenter can make to determine the degree of vacuum inside a soft tube. This test requires a

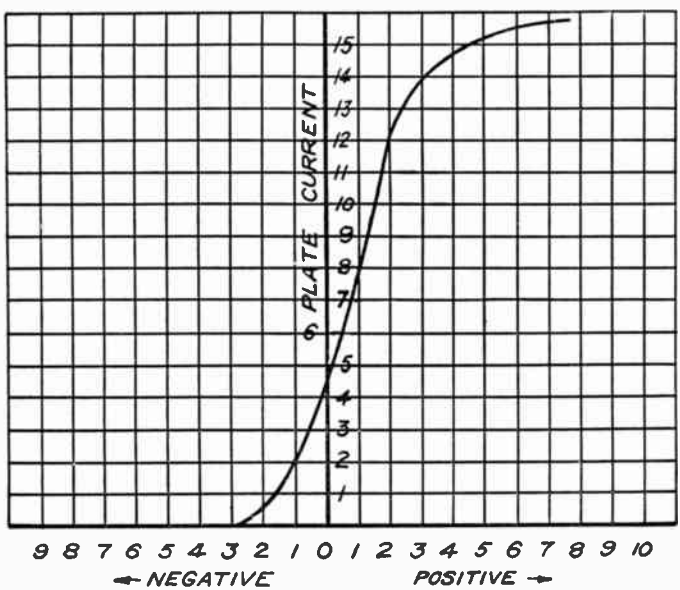


FIGURE V

The relation of grid voltage to plate current in a hard tube is shown by what is known as the "characteristic curve."

small spark coil which can give about a one-quarter inch spark. Connect one of the high tension terminals to the battery (if not already so connected) and set the coil into operation. Next, grasp the tube in the hand, taking hold of the glass bulb, and take care that no part of the hand comes nearer than an inch to the metallic base. Touch any of the terminals to the high tension lead of the spark coil and carefully examine the tube for any signs of glow inside it. No glow at all indicates that the tube is either very hard or else that it is full of air. A pale greenish glow which seems to stick on the inside surface of the glass bulb indicates about the right amount of gas for good detector action. It may operate all right when the bulb fills with a palé greenish-blue glow, but if the glow is purple or confined to a small area directly around the plate and filament the probabilities are that there is too much gas inside the tube to give satisfactory detector action because of excessive ionization.

Soft tubes, while undoubtedly more sensitive as detectors, are not particularly reliable and for this reason many experimenters are using hard tubes as detectors and making up the difference in signal by using more amplification. This is particularly true with a regenerative receiver, where the detector circuit losses are eliminated by the feedback action of this circuit."

As vacuum tubes grow older they become "fagged out" and, although they may appear the same from the outside and though the filaments may light as cheerfully as ever, the reproduction given by them will be "thin" and scratchy. The bringing about of this condition may be accelerated by abusing the tubes when they are in use. A tube may be abused by burning its filament at too great a temperature or by placing a too high voltage upon the plate. The current passing through the filament and the voltage upon the plate should be only the amount necessary for good reproduction at a fair and not excessive volume. When a radio set is blasting away so that it annoys everybody within the block, it can be taken that its operator knows little about radio or that he cares nothing about the economical operation of his radio set.

While it is true that excessive filament current and plate voltage will hasten the end of a tube's good performance, this must not be taken to mean that a tube will not reach this stage eventually even though it is carefully used. If a set is used nightly, tubes will probably begin to show signs of depreciation in from six to eight months. The volume of the set will drop and the reproduction will have a scratchy, nasal tone. When a condition of this nature is reached, it simply means that the filament of the tube has given up practically all of its free electrons near the surface and that the few electrons left are not sufficient to cause enough current to flow between the filament and the grid. Therefore the reproduction will be "thin" and unsatisfactory.

There is a way of reactivating tubes so that the older ones may be brought back to a state approximating their original condition. The process simply explained is that of sending an extra high current through the filament for a short period of time. This treatment heats the filament to an excessive temperature and many of the electrons that were safely below the surface are "boiled" or forced out into the outer layers.

The current used for this reactivation is usually alternating current be-

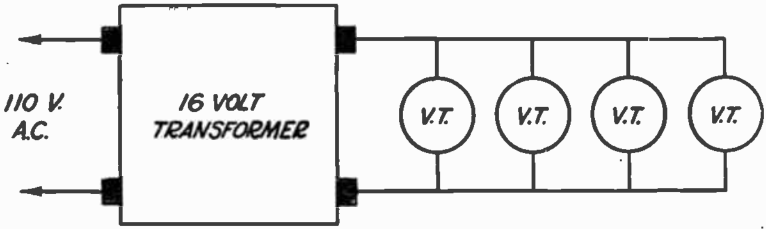


FIGURE W: CONNECTIONS FOR TUBE REACTIVATOR

The simple connections for a vacuum tube reactivator. The transformer used is a voltage reducing type which overloads the filaments of the vacuum tubes in the secondary circuit for a brief period.

cause it is found to have more effect than direct current. Perhaps this is because of its throbbing or pulsating nature, each pulsation coming as a distinct shock. For 201A or 301A tubes 16 volts of alternating current is necessary to bring about recuperation. This should be applied for only 30 seconds. If it is applied longer than this, the filament will be unable to withstand the terrific punishment and will perhaps succumb. After this treatment, the filament may be connected to an 8-volt source of current (which may be direct current) and it may be left here for ten minutes. This latter treatment seasons the tube and it will then be found to have regained a large part of its original perfection.

In event the more serious readers wish to try their hand at reactivating a group of tubes they may follow the diagram given. As many as ten tubes may be treated at one time.

The 16-volt treatment for reactivating indisposed vacuum tubes is by no means standard. Some of the manufacturers of reactivating devices have designed their equipment to develop a voltage higher than 16. Nor is the time limit mentioned in connection with the treatment standard. Some engineers believe that short treatment at high voltage is the solution while others feel, and perhaps rightly so, that a lower voltage should be used with a longer time limit.

The objection to the higher voltage (say 20 volts) is that it requires a fairly robust filament to withstand this high pressure for the full time limit. A real old tube may often be killed by the cure. In any event, however, the purchaser of a tube reactivator should follow out the directions of the builder.

All tube reactivators do not have transformers. Some manufacturers have taken advantage of the drop across resistances and have provided the proper voltage by this means.

In the following pages the student will find listed photographs and the general characteristics of practically all the standard vacuum tubes. These have been alphabetically arranged so that they will be conveniently available for ready reference. If the reader is looking for a tube with special characteristics for use for a specified purpose he will, no doubt, find it by glancing through the data. For instance, if he is looking for a tube for use with a resistance coupled amplifier he will require one with a high plate resistance. The list shows that the Daven and the Hi-Constron are ideal for this purpose.

Aerodyne 201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current amps.; .25
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C-battery; 3-9 volts
Amplification constant; 7.25
Mutual conductance; 440
Plate resistance; 18,000
Standard socket.

Cunningham C-299

Filament terminal voltage; 3
A-battery voltage; 4.5
Filament current; .06 amp.
Resistance of rheostat; 30 ohms.
Detector plate voltage; 20-40
Amplifier plate voltage; 45-90
C-battery; 5 volts
Amplification constant; 6
Mutual conductance; 415
Plate resistance; 15,000
Special socket, 199 type

Cunningham C-300

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; 1 amp.
Resistance of rheostat; 6 ohms.
Detector plate voltage; 15-22.5
Not intended for use as amplifier
No C-battery
Amplification constant; 7
Standard socket

Cunningham C-301

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; 1 amp.
Resistance of rheostat; 4-6 ohms.
Detector plate voltage; 40
Amplifier plate voltage; 45-90
C-battery; 5-6 volts
Amplification constant; 7
Mutual conductance; 675
Plate resistance; 12,000
Standard socket

Cunningham C-301A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; .25 amp.
Resistance of rheostat; 6-10 ohms.
Detector plate voltage; 40
Amplifier plate voltage; 45-90
C-battery; 5-6 volts
Amplification constant; 8
Mutual conductance; 675
Plate resistance; 12,000
Standard socket

Ceco 201-A

Filament terminal voltage; 5
A-battery; 6 volts
Filament current amps. .25
Rheostat resistance; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-130
C-battery; 3-9 volts
Amplification constant; 8
Mutual conductance; 550
Plate resistance; 14,500
Standard socket

De Forest DV-2

Filament terminal voltage; 5
A-battery voltage; 6
Filament current amps.; .24-26
Resistance of rheostat; 30 ohms
Amplifier plate voltage; 90
Not intended for detection
C-battery; 5-9 volts
Amplification constant; 6-8.8
Mutual conductance; 1100-550
Plate resistance; 8000-11,000
Standard socket

Daven

Filament terminal voltage; 6
A-battery voltage; 6
Filament current amps.; .25
No rheostat needed
Not intended for detector
Amplifier plate voltage; 90-200
C-battery; 0-4.5 volts
Amplification constant; 20
Mutual conductance; 500
Plate resistance; 40,000
Standard socket

Everest 1A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current amps.; .25
Resistance rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C-battery voltage; 3-9
Amplification constant; 9.4
Mutual conductance; 630
Plate resistance; 15,000
Standard socket

Empiretron 201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; .25 amps.
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C battery; 3-9 volts
Amplification constant; 7.5
Mutual conductance; 640
Plate resistance; 11,800
Standard socket

Elektron 201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; .25 amp.
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C-battery; 3-9 volts
Amplification constant; 8.2
Mutual conductance; 550
Plate resistance; 15,000
Standard socket

Gem 201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; .25 amp.
Resistance of rheostat; 20-30 ohms.
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C-battery; 3-9 volts
Amplification constant; 10
Mutual conductance; 640
Plate resistance; 15,500
Standard socket

Hi-Constron CT-101A

Filament terminal voltage; 5
A-battery; 6 volts
Filament current; .25 amp.
Resistance of rheostat; 20-30 ohms
Not intended for detector
Amplifier plate voltage; 90-180
C-battery; 1-4 volts
Amplification constant; 18
Mutual conductance; 480
Plate resistance; 37,500
Standard socket

Magnavox Type A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; .25 amps.
Resistance of rheostat; 20-30 ohms
Amplifier plate voltage; 90-135
Not intended for use as detector
C-battery; 3-9 volts
Amplification constant; 6.3
Mutual conductance; 405
Plate resistance; 15,500
Standard socket

Musselman Tube

Filament terminal voltage; 3
A-battery voltage; 4.5
Filament current; .12 amps.
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 20-45
Amplifier plate voltage; 67.5-100
C-battery; 3-7.5 volts
Amplification constant; 6.8
Plate resistance; 17,800
Mutual conductance; 380
Standard socket

Radiotron WK-12

Filament terminal voltage; 1.1
A-battery voltage; 1.5
Filament current amps.; .25
Resistance of rheostat; 4-6 ohms
Detector plate voltage; 22.5-40
Amplifier plate voltage; 45-90
C-battery voltage; 3-5
Amplification constant
Special socket

Radiotron UX-200

Filament terminal voltage; 5
A-battery voltage; 6
Filament current amps.; 1
Resistance of rheostat 15-22.5
Not intended for amplifier
Amplification constant; 7
Mutual conductance; 415
Special socket

Radiotron UX-199

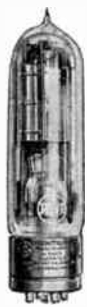
Filament terminal voltage; 3.0
A-battery voltage; 4.5
Filament current amps.; .06
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 20-40
Amplifier plate voltage; 45-90
Amplification constant; 6
C-battery; 5 volts
Special socket

Radiotron UX-201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current amps.; .25
Resistance of rheostat; 6-10 ohms
Detector plate voltage; 40
Amplifier plate voltage; 45-90
C-battery voltage; 5-6
Amplification constant; 8
Mutual conductance; 675
Plate resistance; 12,000
Special socket

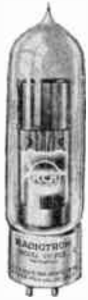
Radiotron UV204

Filament terminal voltage; 11
A-battery voltage; 12
Filament current amps; 14.75
Resistance of rheostat; 4 ohms
Not intended for detection
Amplifier plate voltage; 2000
C-battery; 40-60 volts
Amplification constant; 22
Special socket



Radiotron UV203A

Filament terminal voltage; 10
A-battery voltage; 12
Filament current; 3.25 amps.
Resistance of rheostat; 4-6 ohms.
Not intended for detection
Amplifier plate voltage; 1000
C-battery; 20-40 volts
Amplification constant; 15
Mutual conductance; 3000
Plate resistance; 5000
Special socket



Radiotron UV203

Filament terminal voltage; 10
A-battery voltage; 12
Filament current; 6.5 amps.
Resistance of rheostat; 4 ohms.
Not intended for detection
Amplifier plate voltage; 1000
C-battery; 20-40 volts
Amplification constant; 15
Special socket

Radiotron UV202

Filament terminal voltage; 8
A-battery voltage, 10
Filament current; 2.35 amps.
Resistance of rheostat; 4 ohms
Amplifier plate voltage; 100 to 500
Not intended for detector
C-battery; 3-3.25 volts
Amplification constant; 7.5
Socket, special

Radiotron UV201A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; .25 amp.
Resistance of rheostat; 6-10 ohms.
Detector plate voltage; 40
Amplifier plate voltage; 45-90
C-battery; 5-6 volts
Amplification constant; 8
Mutual conductance; 675
Plate resistance; 12,000
Standard socket. Bakelite base

Radiotron UV201

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; 1 amp.
Resistance of rheostat; 4-6 ohms.
Detector plate voltage; 40
Amplifier plate voltage; 45-90
C-battery; 5-6 volts
Amplification constant; 7
Standard socket

Radiotron UV200

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; 1 amp.
Resistance of rheostat; 6 ohms.
Detector plate voltage; 15-22.5
Not intended for amplification
Amplification constant; 7
Standard socket. Bakelite base

Radiotron 199

Filament terminal voltage; 3
A-battery voltage; 4.5
Filament current; .06 amp.
Resistance of rheostat; 30 ohms.
Detector plate voltage; 20-40 volts
Amplifier plate voltage; 45-90 volts
C-battery; 5 volts
Amplification constant; 6
Mutual conductance; 415
Plate resistance; 15,000
Bakelite base. Special 199 socket

Radiotron UX210

Filament terminal voltage; 6-7.5
A-battery voltage; 6-8
Filament current; 1.1-1.25 amps.
Resistance of rheostat; 2-6 ohms.
Not intended for detection
Plate voltage; 90-425
C-battery; 4.5-35 volts
Amplification constant; 7.5-7.75
Mutual conductance; 775-1550
Plate resistance; 5000-9700
Standard socket. Bakelite base

Radiotron UX120

Filament terminal voltage; 3
A-battery; 4.5 volts
Filament current .125 amps.
Resistance of rheostat; 20-30 ohms.
Not intended for detection
Amplifier plate voltage; 90-157.5
C-battery; 22.5 volts
Amplification constant; 3.3
Mutual conductance; 500
Plate resistance; 6600
Bakelite base. Special UX120 socket

Radiotron UX112

Filament terminal voltage; 5
6-volt A battery
Filament current; .5 amp.
6-ohm rheostat
Detector plate voltage; 22.5
Amplifier plate voltage; 45
C-battery voltage; 6-10.5
Amplification constant; 7.9-8
Mutual conductance; 890-1670
Plate resistance; 4800-8800 ohms.
Bakelite base. Standard socket

Radiotron UX-213

Rectifier tube
Two plates
Full wave
Filament terminal voltage; 5
Filament current; 2 amps.
Max. A.C. input 220 volts per plate or 440 volts total
D.C. load 65 milliamperes

Radiotron UX-216-B

Half wave rectifier
Filament terminal voltage; 7.5
Filament current; 1.25 amps.
Max. A.C. input; 550 volts
Max. D.C. load; 65 milliamperes

Radiotron UX 874

Voltage regulator tube
Rated voltage of 90
Starting voltage 125
Max. D.C. current; 50 milliamperes

Sylvania 501-A

Filament terminal voltage; 5
A-battery; 6 volts
Filament current amps.; .25
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplification voltage; 90-135
C-battery; 3-9 volts
Amplification constant; 9.2
Mutual conductance; 675
Plate resistance; 13,400
Standard socket

Supertron 201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current amps.; .25
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C-battery; 3-9 volts
Amplification constant; 10.7
Mutual conductance; 500
Plate resistance; 21,400
Standard socket

Tectron 201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current; .25 amp.
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C-battery; 3-9 volts
Amplification constant, 9.4
Mutual conductance; 560
Plate resistance; 16,800
Standard socket

True Blue 201-A

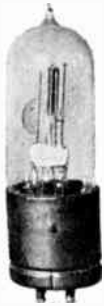
Filament terminal voltage; 5
A-battery; 6 volts
Filament current amps.; .25
Resistance rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-130
C-battery; 3-9 volts
Amplification constant; 11.8
Mutual conductance; 645
Plate resistance; 18,300
Standard socket

Veby AF-20

Filament terminal voltage; 5
A-battery; 6 volts
Filament current amps.; .25
Resistance rheostat; 20-30 ohms
Not intended for detector
Amplifier plate voltage; 90-200
C-battery; 0-4.5 volts
Amplification constant; 20
Mutual conductance; 560
Plate resistance; 36,000
Standard socket

Vim 201-A

Filament terminal voltage; 5
A-battery voltage; 6
Filament current amps.; .25
Resistance of rheostat; 20-30 ohms
Detector plate voltage; 22.5-45
Amplifier plate voltage; 90-135
C-battery; 3-9 volts
Amplification constant; 6.8
Mutual conductance; 650
Plate resistance; 10,500
Standard socket



Westinghouse WD12

Filament terminal voltage; 1.1
A-battery voltage; 1.5
Filament current amps.; .25
Resistance of rheostat; 4-6 ohms.
Detector plate voltage; 22.5-40
Amplifier plate voltage; 45-60
C-battery; 3-5 volts
Amplification constant; 6.5
Special socket

Westinghouse WD11

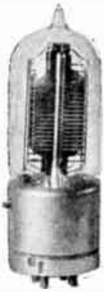
Filament terminal voltage; 1.1
A-battery voltage; 1.5
Filament current; .25 amps.
Resistance of rheostat; 4-6 ohms.
Detector plate voltage; 22.5-40
Amplifier plate voltage; 45-60
C-battery; 3-5 volts
Amplification constant; 6.5
Mutual conductance; 400
Plate resistance; 14,000
Special socket

Western Electric 216A

Filament terminal voltage; 5.5
A-battery voltage; 6
Filament current amps; 1.10
Resistance of rheostat; 4 ohms
Detector plate voltage; 45
Amplifier plate voltage; 45-150
C-battery; 5-13 volts
Amplification constant; 6
Standard socket

Western Electric VT2

Filament terminal voltage; 7
A-battery voltage; 8
Filament current amps; 1.35
Resistance rheostat; 4 ohms
Detector plate voltage; 45
Amplifier plate voltage; 45-350
C-battery; 3-25 volts
Amplification constant; 6.5
Standard socket

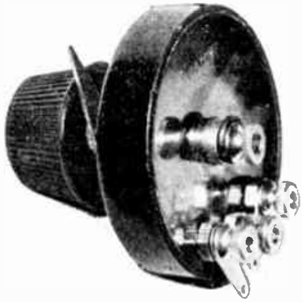


Western Electric VT1

Filament terminal voltage; 2.75
A-battery voltage; 4
Filament current amps; 1.1
Resistance of rheostat; 4 ohms.
Detector plate voltage; 22.5-40
Amplifying plate voltage; 45-90
Amplification constant; 6
C-battery; 3-5 volts
Standard socket

Western Electric "N" tube

Filament terminal voltage; 1.1
A-battery voltage; 1.5
Filament current; 2.5 amp.
Resistance rheostat; 4-6 ohms.
Detector plate voltage; 22.5-40
Amplifying plate voltage; 45-60
C-battery: 3-5 volts
Amplification constant; 6.5
Special socket

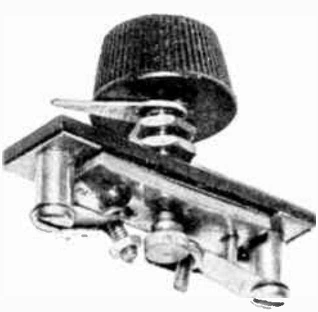


Central Radio Laboratories

Material; moulded bakelite
Mounting; arranged for panel
Resistance element; coated paper
Resistance range; ¼ to 5 megohms
Size; 2¼ inches in diameter
Four binding posts
Provided with knob

Allen-Bradley

Material; moulded porcelain
Mounting; arranged for panel or base
Resistance element; carbon discs
Resistance range; 1/10 to 10 megohms
Size; 1⅞ x ¾ in.
Provided with two binding screws
Metal top and bottom
Moulded knob



Central Radio Laboratories

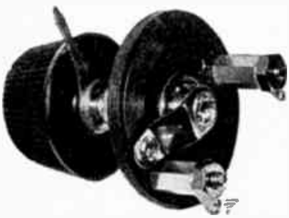
Material; strip bakelite
Mounting; arranged for panel
Resistance element; carbon impregnated cloth
Resistance range; ¼ to 5 megohms
Size; 2¾ x ¾ in.
Two binding screws
Provided with insulated knob

Fil-Ko-Resistor

Material; moulded bakelite
Mounting; arranged for panel
Resistance element; high resistance carbon
Resistance range; ¼ to 5 megohms
Size; two inches in diameter

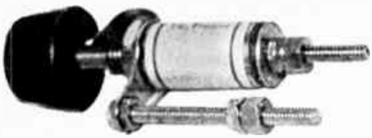
Strand

Material; moulded bakelite
Mounting; arranged for base mounting
Resistance element; carbon coating
Resistance range; ¼ to 5 megohms
Size; 1 3/8 diameter
Moulded knob
Two binding posts



Walnart Electric

Material; panel bakelite
Mounting; arranged for panel
Resistance element; carbon coated surface
Resistance range; ¼ to 5 megohms
Size; 1½ inches diameter
Moulded knob
Two binding nuts



Electrad Variohm

Material; pressed metal
Mounting; arranged for panel
Resistance element; paper discs impregnated with carbon
Resistance range; ¼ to 5 megohms
Moulded knob
Arranged to accommodate fixed condenser

Pudlin Variable Leak

Material; glass tube
Mounting; arranged for clips
Resistance element; carbon paste
Resistance range; ¼ to 5 megohms
Size; 1¾ inches long

Durham Variable

Material; glass tube
Mounting; arranged for clips
Resistance element; carbon paste
Resistance range; ¼ to 5 megohms
Size; 1¾ inches long

FIXED GRID LEAKS

Crescent Lavit Unit

Material; Lavite tube
Mounting; for base board
Resistance; trade secret
Resistance; 48,000 ohms.

Bradley Fixed Leak

Material; moulded insulation
Resistance element; carbon impregnated
Resistance; at 100 volts; made in units ranging from 1/10th to 5 megohms
Made to fit standard mounting

Daven Leakandenser

Material; bakelite bobbin
Resistance element; carbon-coated paper
Resistance at 100 volts; made in sizes ranging from 1/10th to 5 megohms
Contains proper fixed condenser
Mounting; standard clips

Durham Fixed Grid Leak

Material; glass tube
Resistance element; metalized filament
Resistance at 100 volts; made in resistances from 1/10th to 5 megohms

Dubilier Fixed Grid Leak

Material; glass tube
Resistance element; metalized filament
Resistance at 100 volts; made in resistances ranging from 1/10th to 5 megohms

Electrad Fixed Grid Leak

Material; moulded insulation
Resistance element; carbon-coated paper
Resistance at 100 volts; made in resistances ranging from 1/10th to 5 megohms

Freshman Fixed Grid Leak

Material; glass tube
Resistance element; carbon-coated paper
Resistance range; made in sizes ranging from 1/10th megohm to 5 megohms

Muter Fixed Grid Leak

Material; glass tube
Resistance element; carbon coated paper
Resistance at 100 volts; made in resistances ranging from 1/10th to 5 megohms

Pudlin Fixed Grid Leak

Material; glass tube
Resistance element; carbon coated paper
Resistance at 100 volts; made in various resistances ranging from 1/10th to 5 megohms