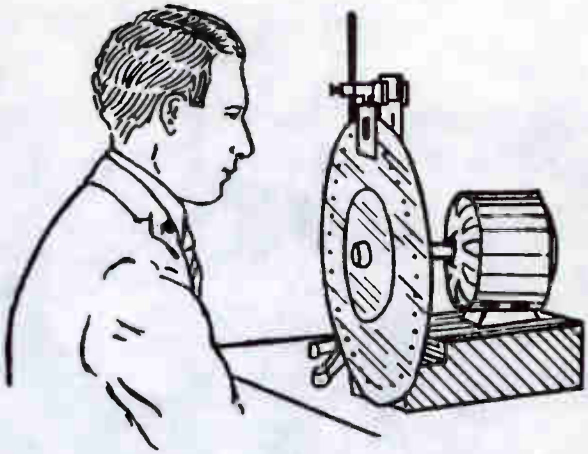

EXPERIMENTAL TELEVISION

How to Make
A Complete Home Television
Transmitter and Receiver
1932

A. Frederick Collins

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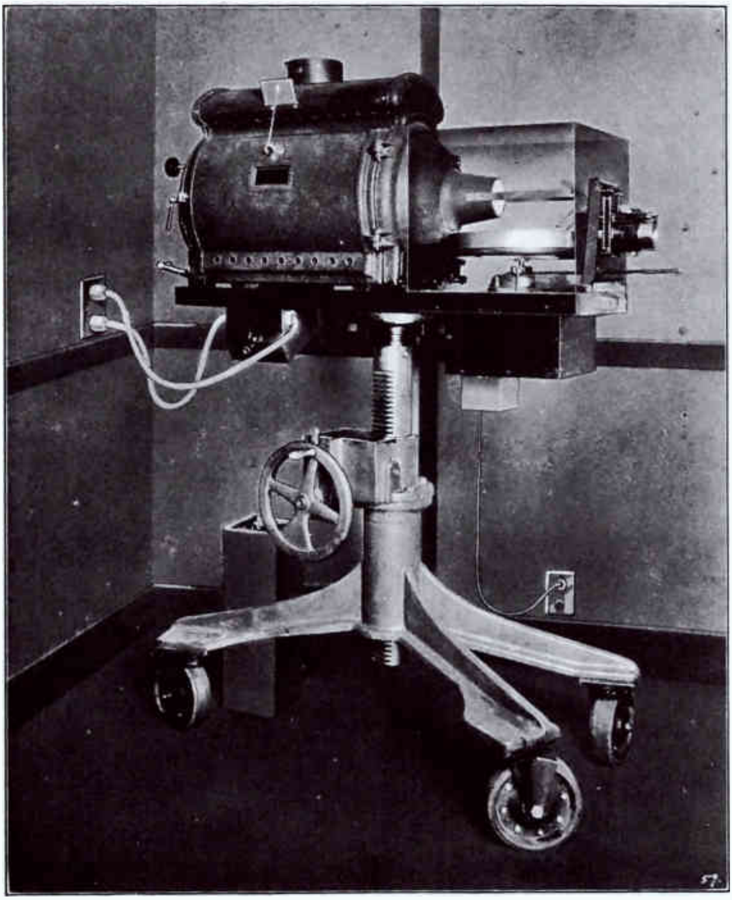

TELEVISION SCANNING EQUIPMENT
DESIGNED BY HOLLIS S. BAIRD

EXPERIMENTAL TELEVISION

A SERIES OF SIMPLE EXPERIMENTS
WITH TELEVISION APPARATUS
ALSO
HOW TO MAKE A COMPLETE HOME TELEVISION
TRANSMITTER AND TELEVISION RECEIVER

BY
A. FREDERICK COLLINS, F.R.A.S.
INVENTOR OF THE WIRELESS TELEPHONE, 1899
HISTORIAN OF WIRELESS, 1901–1910

*With One Hundred and Eighty-five Text
Illustrations and Diagrams
by the Author*

EXPERIMENTAL TELEVISION

A. Frederick Collins

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1991

TO

HOLLIS S. BAIRD

America's Television Genius

WARNING

Remember that the materials and methods described here are from another era. Workers were less safety conscious then, and some methods may be downright dangerous. Be careful! Use good solid judgement in your work, and think ahead. Lindsay Publications Inc. has not tested these methods and materials and does not endorse them. Our job is merely to pass along to you information from another era. Safety is your responsibility.

A WORD TO YOU

A SAYING that came into play a few years ago and which is still often heard is, "Television is just around the corner." Now, as a matter of fact, *television is really here*, and this is especially so as far as the amateur experimenter is concerned.

As a token of the truth of this statement, I submit that there are at the present time at least 35 licensed telecasting stations in the United States, of which about 12 are already active, and 10 or 12 in other countries. These stations send out television programs nightly while thousands of *lookers-in* view the reproduced images that come to them on the transcendental wings of short electric waves.

Nearly all these stations also broadcast the voices of the artists who are being televised, and this adds mightily to the pleasure of those who are looking-in at the images. These *sight* programs, as they are called, are usually sent out on a shorter wave length than the *sound* programs which accompany them, and, it follows, they are telecasted and broadcasted by independent transmitters. An exception to the above rule is the station W2XAB, of New York, which sends *sight* on *107* meters, and whose cooperative station W2XE sends *sound* on *49* meters.

To give you an idea, in the remote event that you do not already know, of the sight and sound programs that are telecasted and broadcasted from the dual stations, here is a typical program which I have taken from *The New York Times:*

TELEVISION PROGRAMS

TODAY

W2XAB—New York

Sight on 107 meters.	Sound on W2XE, 49 meters.

2:00 to 6:00—Experimental program.
8:00—Sue Read, songs.
8:15—Sports parleys.
8:30—Harold Boggess, songs.
8:45—Juvenile artists.
9:00—Mystery sketch.
9:15—Ruth Kerner and Gladys Kahn, songs.
9:30—Don Sal and Franky Brown, songs.
9:45—Elliot Jaffee, tenor.

The transmission of sight and sound programs requires apparatus that must be very accurately designed and made, and its operation must be in the hands of technicians who are highly skilled in the art, but with this you do not need to concern yourself. To belong to the ever-increasing army of *lookers-in* as well as *listeners-in*, you must, of course, have a television receiver as well as a radio receiver, and it has been my pleasure to tell you how to make one with which you can get the desired results.

Now, while *television is here*, I would not have you believe that the received images are perfect; nay, they are not even good, but it is this very fact that gives the television experimenter a thrill, for, like wireless telegraphy and telephony of yore, he has a practically unlimited field in which to exercise his inventive ability.

This being the way of it, I have written this book chiefly for the amateur experimenter and based it on the *scanning-disk* *method*—the only one that is in actual use at the present time for sending and receiving television images. Moreover, the experiments are put down in sequence so that, even if you are the veriest tyro in this new and fascinating art, you can follow them along step by step and acquire quite a wide and useful knowledge of the subject in the easiest and pleasantest way imaginable.

The scanning disk, though, is not the only method by which television is, at least, theoretically possible, the chief contender at the present moment being the *cathode-ray oscillograph tube.* As this seems to be a potential successor of the scanning disk method, I have written in a whole chapter of experiments with it, which you will find most interesting and instructive.

The disk is a purely mechanical means of scanning, and therefore it possesses inertia, while the cathode ray tube is an electrical means, and, consequently, it is inertialess. This being true, it is easy to see that the latter possesses marked advantages over the former in its operation and should give clearer images with an increased scope of them. Difficulties of major importance, however, are encountered when it is applied to the actual reception of telecasted images, but these may be overcome at any time.

Telecasting as it is practised to-day is on about the same level as broadcasting was up to 1920, when the crystal-detector receiver was the best to be had, but with this difference, that, whereas the scanning disk gives a more or less blurred image, the crystal set gave a clear tone, and, whereas with the former method any distance can be bridged, with the latter the distance was limited to something like 100 miles.

Then, when the vacuum tube came into use, it solved the problem of broadcasting by providing a simple and efficient way to send out the sound programs and, at the same time, to detect and amplify them at the receiving end. From this you will gather that what is really needed now is some scheme for scanning that is simple and efficient, has no moving parts, and will give clear and large images.

The engineering staffs of the great electrical concerns have thus far failed to produce such an apparatus, and it is my private opinion publicly expressed that when it does come—and come it must—it will be the result of the genius of some independent experimenter who possesses an inventive mind which approximates the Edison caliber.

A. Frederick Collins

Crescent Court
195 Claremont Avenue
New York City

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EXPERIMENTAL TELEVISION

CHAPTER I

EXPERIMENTS WITH LIGHT

Television is the new art of "seeing by electricity", and the word has been coined from the Greek root *tele*, which means "far off", and the Latin word *videre* which means "to see." Now television is based on three fundamental factors, and these are (1) light, (2) electricity, and (3) chemistry, and when you combine these in a certain ingenious way, it is possible for a person at the receiving instrument to see the image of an object at the transmitting instrument over long distances. The connection between the two instruments may be either a wire circuit, as in the ordinary telephone, or without wires, as in the wireless telephone, or *radio*, as it is now called.

What Light Is.—What we call "light" is ordinarily thought of as something that is itself luminous and which we can see, or which enables us to see the things that are around and about us. So far, all well and good, but this glittering generalization is not the half of it, indeed it is only a fourth of it; for light consists of four distinct parts, or phases, and, named, these are (1) the vibrations of electrons of atoms, which set up (2) waves, which travel through the ether, (3) the eye, which receives the waves and forms the image, and (4) the visual center of the brain, where the image is converted into the sensations of form, shade and color.

How Light Vibrations Are Set Up.—To understand how the electrons are made to vibrate and how these vibrations set up waves in the ether, let us begin with matter in its mass form, or a *body*, as it is called. Now a body of any kind is made up of (1) molecules; these, in turn, are made up of (2) atoms, and, finally, these are made up of (3) protons and electrons.

A *molecule* consists of two or more atoms, and it is the smallest part of an element or a compound that can retain the identity of that substance. An *atom* is the smallest part of an element that can exist as matter, either alone or in combination with like particles of the same or a different kind of an element. An *atom* consists of a central core, or nucleus, of one or more positive charges of electricity, or *protons*, and outside of this is one or more negative charges of electricity, or *electrons*, and these revolve around the latter in an orbit as pictured in Fig. 1, just as the planets revolve around the sun.[1]

Now when (1) a substance is sufficiently heated, or (2) it is subjected to chemical action, or (3) an electric arc is formed, the electrons of the atoms of which it is formed are set into rapid vibration, and this is the real source of light. Here are some experiments that you can make which will demonstrate how light vibrations are set up.

(1) Heat a piece of iron rod until (*a*) it takes on a dull red color in a dark room. You will know then that the

[1] This is the Bohr theory of the atom. You will find it fully described in many college text-books.

electrons of the atoms it is formed of are vibrating just rapidly enough to produce light waves. (*b*) Heat the rod to a higher temperature and you will see it as a *cherry red color*. This means that the electrons are vibrating still

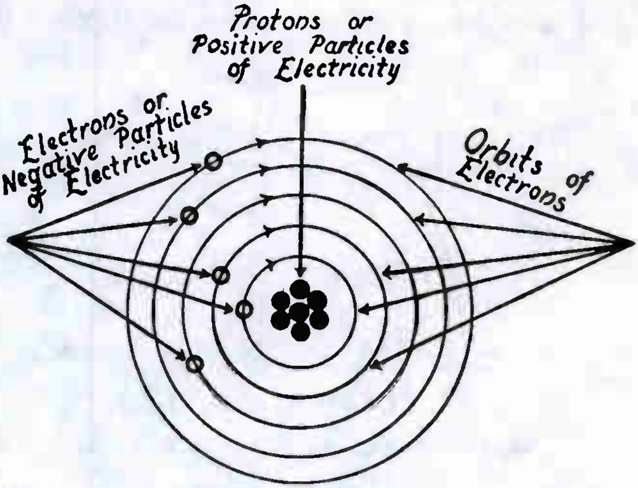


FIG. 1—Diagram of an Atom Built up of Electrons and Protons.

more rapidly and, hence, sending out shorter light waves. Lastly, (*c*) heat it until it is *incandescent*, that is, *white hot*, then you will see it as a dazzling white body. This indicates that the electrons are vibrating as rapidly as it is possible to make them, and that it is sending out light waves of every length.

(2) To make a light by chemical action, you need only to heat a substance to its *kindling temperature*, when it will combine with the oxygen of the air and burst into flame. (*a*) When you strike a match, the friction provides the neces-

sary heat to ignite it, and chemical action sets the electrons into rapid vibration and so makes it burn, when it will set up light waves. (*b*) Another way to set the electrons into vibration sufficiently rapid to send out light waves is to put a piece of red phosphorus about the size of a pea into an individual china butter dish and put a few drops of iodine

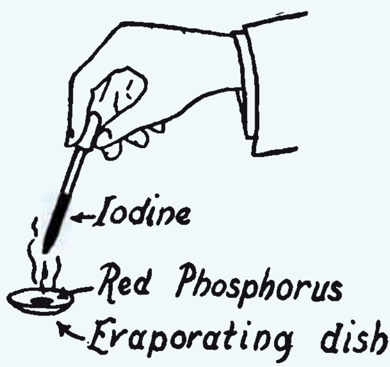


FIG. 2—Making a Light by Chemical Reaction.

on it with a medicine dropper, as shown in Fig. 2. In the resulting reaction, both heat and light waves will be set up.

(3) To make an electric arc light, connect two carbon rods about ¼ inch in diameter with a battery that gives 40 volts or more, then push them together until their ends touch, when the circuit will be closed. This done, draw the carbons a little apart, when an electric arc will be formed between them, as shown in Fig. 3. The current flowing across the air gap between the carbons produces a very high temperature, and the result is that the electrons of the atoms of carbon are set into exceedingly rapid vibration, which causes them to send out the short waves that

produce violet light, as well as the longer ones that produce the other colors. The arc light develops the brightest artificial light that has yet been devised, and is used for illuminating objects whose images are to be transmitted by television.

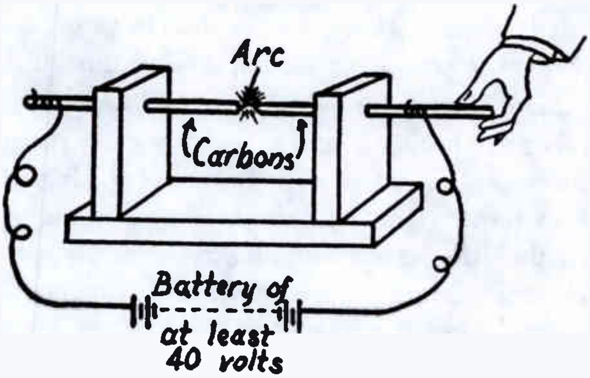


FIG. 3—Making a Light with Electricity.

How Light Waves Are Set Up.—Knowing now how the vibrations are produced which set up and send out light waves, you should next get an idea of what the ether is and how the waves are formed in it and travel through it.

What the Ether Is.—The *ether* is formed of positive and negative electricity, that is to say, of *protons* and *electrons*. In the ether the entities are not bound together as they are in the atom, but they are more or less free and form a continuous *medium*, as it is called, in very much the same way that the atoms of oxygen and nitrogen which are separate from each other form the substance we know as the atmosphere.

A medium that will fulfil the conditions required of it so that it will transmit light waves, must be incompressible as far as these waves are concerned, and yet so thin that material bodies can pass through it freely, just as water is incompressible and yet thin enough to allow a fish to swim freely in it. Of course, the ether has no actual density, because it is space without matter, but in the transmission of light waves it acts as an incompressible medium.

What Light Waves Are—(1) When one or more electrons of the ether are brought into sufficiently close proximity to one or more protons, an *atom* is formed; (2) when the ether is made to rotate rapidly in circles, *magnetism* is produced; (3) when the ether is *sheared*, as Sir Oliver Lodge phrased it, an electric current is produced, and, finally, (4) when some external force is applied to the atom, as, for example, when it is heated or subjected to chemical action, or energized by an electric current that will make the electrons of it vibrate at enormously high frequencies through a small distance, they will impart their energy to the ether and set up light waves in it in very much the same way that the energy of the vibrating prongs of a tuning-fork will impart their energy to the air and set up sound waves in it.

These light waves, which are really ether waves, just as sound waves are really vibrations in a material medium, are formed of alternate electric and magnetic whirls that are linked together, the energy of the one changing progressively into the energy of the other so that in this way they keep on moving through the ether indefinitely. Since these ether waves, or light waves, are electric and magnetic forms of energy, they are called *electro-magnetic waves*, and they travel through space at the rate of about 186,500 miles a second.

You can make the following experiments which will give you an idea of how light waves are formed by the vibrations of electrons and how the waves travel out from their source. (1) Take a flexible rope about 10 feet long and lay it on the floor, now grip one end of it with your hand and give it a little horizontal jerk, when a wave will start from the end you are holding and travel over to the

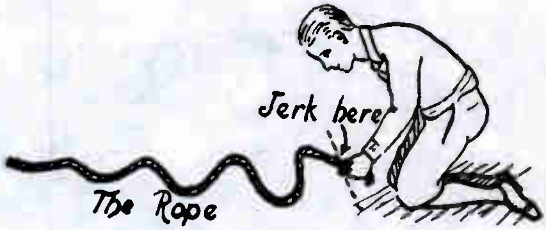


FIG. 4—Free Waves in a Rope.

other and free end as shown in Fig. 4. This is a purely *mechanical wave*, but it shows that while the wave travels progressively out from the source of energy, the material that it is formed of does not move longitudinally. It represents, in a crude way, a single ray of light.

(2) Having made the above experiment, throw a little stone into a pool of still water, and circular waves will be formed by the impact of it, as shown in Fig. 5, and these will move outward toward the shore. The reason that the waves are formed and travel outward is that the impact of the stone forces the molecules of the water down below their normal level, with the result that those which immediately surround them are displaced and forced up above their

normal level. The force of gravity now comes into play, so that these descend and throw up another series of molecules. In this way a number of concentric waves are formed. Each part of the wave, as it travels outward in a *straight line*, may be considered to represent a ray of light.

(3) While the waves of the rope travel out from the source of vibration in a single line and the waves of water travel out from their source of vibration in concentric circles, the waves of air, or sound waves, travel out from

FIG. 5—Circular Waves in Water.

their source of vibration in concentric spheres. In this respect the latter resemble light waves, in that they are radiated in every direction.

To test the truth of these statements, you need only to suspend a small bell in the center of a room and tie a string to it so that you can ring it from a distance. Stand at different points around the bell, keeping your good ear at about the same level with it; then sit on the floor under it, and, finally, stand on a step-ladder above it. After you have listened from each one of the different positions, see Fig. 6, you will have noted that in each case the auditory area of your brain produced the sensation of sound, or, as we say in more simple but less exact language, you *hear the sound.*

(4) Finally, fix a lighted candle, or an electric lamp that is energized, in the center of the room. Now stand at different points around the source of light with your eye about on a level with it; this done, sit down on the floor under it, and,

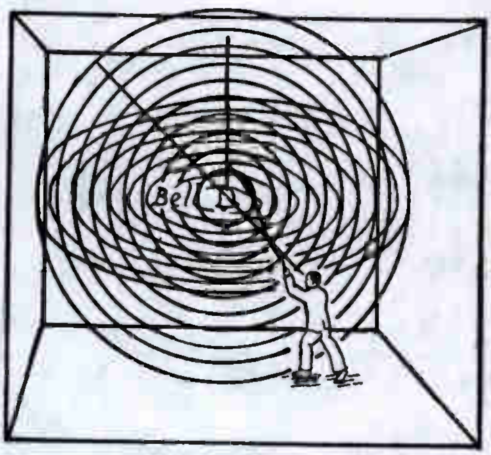


FIG. 6—Spherical Sound Waves in Air.

lastly, stand on a step-ladder above it. The waves set up by its vibrating electrons will reach your eye in whatever position you take. This shows that the waves have a spherical form, as pictured in Fig. 7.

Luminous and Non-Luminous Bodies.—When the electrons of the atoms of a body are set into vibration they, in turn, set up and send out light waves, so that the body becomes a source of light. It is then called a *luminous body.* If the light waves from a luminous body fall upon a body that does not give out light waves, or a *non-luminous body,* as it is termed, the latter reflects the waves and becomes visible. It is then known as an *illuminated body.*

Transparent and Opaque Bodies.—There are some kinds of bodies, as for example, glass, through which light waves will pass quite freely. These are called *transparent bodies.*

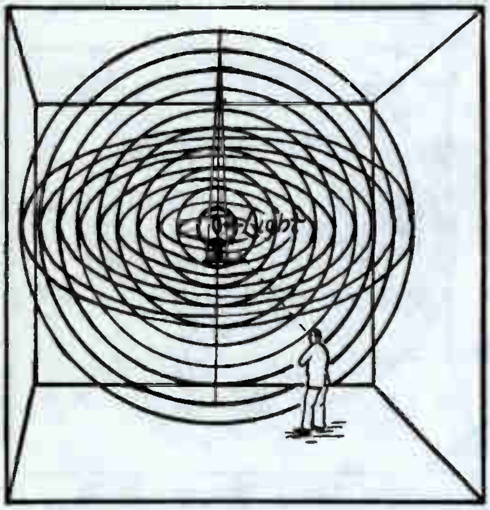


FIG. 7—Spherical Light Waves in Ether.

Oppositely disposed, there are some kinds of bodies through which light waves will not pass and these are called *opaque bodies.* In between these two extremes are certain bodies through which some of the waves that strike them will pass while some will be reflected or absorbed. These are called *translucent bodies.*

Light Waves Are Invisible.—A train of light waves that follow a straight line is called a *ray.* When a number of these rays are parallel and closely grouped they form a *beam* of light. You can't see light waves, and unless a ray, or beam, strikes directly into your eye, by which I mean that unless you look right at the source of the light waves, they will not produce the sensation of light, or, in other words, you can't see them.

To prove this paradoxical statement (1) let the sunlight pass through a small hole in the door of a dark room. Now if there is no dust in the room you will not be able to see

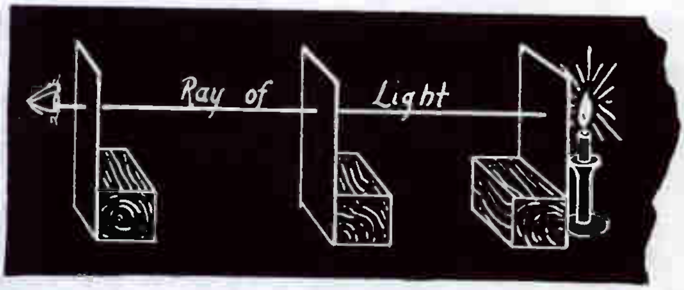


FIG. 8—Light Rays Travel in Straight Lines.

the beam of light, for, as has previously been stated, light waves are themselves invisible. (2) To see the path of the beam, however, is easy enough, for it is merely necessary to raise the dust in the room by sweeping the floor or beating a rug, and then the light waves will strike the particles of dust and these will reflect the rays directly into the eye.

Light Rays Travel in Straight Lines.—Rays of light always travel out from their origin or source of reflection in straight lines if the transparent medium, *i.e.*, the air, water, glass, etc., through which they are passing has the same density throughout, or is *homogenous*. But when a train of light waves, or ray, strikes a surface and is reflected, or passes from one medium to another of different density, it will be bent out of its original course, as you will soon see.

But what I want to demonstrate now is that a ray of light travels in a straight line, and here is an experiment to prove it. Take three pieces of cardboard, say 5 by 7 inches on the sides, and make a little hole in the middle of each one about 3 inches from one of the ends. This done, secure each of the cards to a wooden block so that all of the holes will be at the same height. Now set them in a straight line, as shown in Fig. 8, and then place a lighted candle or an electric light back of the hole of the last card, and look through the hole of the first one.

As long as the holes are in a straight line with each other, you will be able to see the illuminated area, but if you move any one of the cards, the holes will be thrown out of alignment and you will no longer be able to see the light, because the rays will be cut off.

How Light Rays Form an Image.—It is the fact that light rays travel in straight lines which makes it possible for them to form an image on a screen after passing through a small hole. It is by virtue of this same fact that the image they form will be an inverted one. The following simple experiment shows clearly how and why this inversion takes place.

Take two sheets of cardboard 10 by 12 inches and make a sharp pin-hole in the center of one of them, leaving the other one as it is. Now set a candle about 6 or 8 inches in front of the card with the pin-hole in it, and the cardboard screen about a foot back of it, as shown in Fig. 9. This done, darken the room and you will see the inverted image of the candle on it.

The cause of this phenomenon is that the rays are sent out in every direction by every part of the candle flame and the rays from the point *A* will pass through the hole and strike the screen at *A′*. In the same way the rays from *B* will pass through the hole and strike at *B′*. The same action holds good for all parts of the candle, the rays that are reflected from the candle proper following the same law, and the net result is that a complete inverted image of the candle and its flame is formed on the screen.

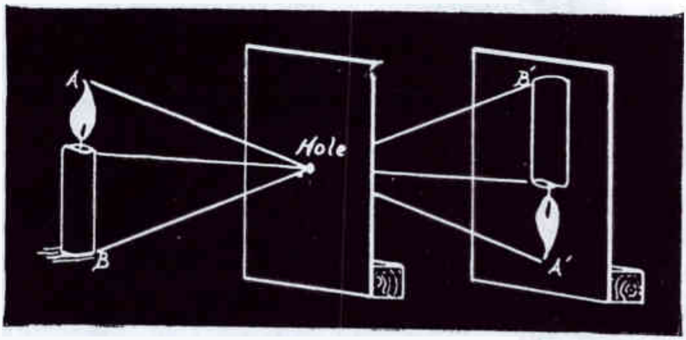


Fig. 9—How Light Rays Form an Image.

The Intensity of Light Rays.—As you have seen, light waves are sent out in every direction from their source and the *intensity*, that is the strength, of each ray which is travelling out along a given line is the same as that of the others which are travelling out along other lines, hence the amount of surface that they can illuminate depends on the distance from the source.

Thus at twice the distance, see Fig. 10, the rays are spread out over four times the surface, so that their illuminating power is only ¼ as great at *B* as it is at *A*; at *C*, which is four times the distance, it is $\frac{1}{16}$ the power that it is at *A* and so on. The intensity of light that is received from a luminous source is, it follows, inversely proportional to the square of the distance from its source. This is termed the *law of inverse squares*.

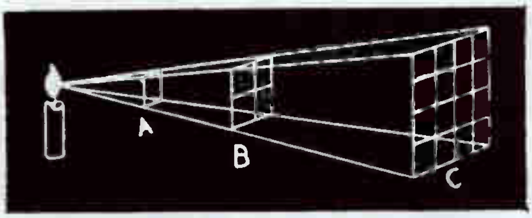


FIG. 10—How Light Rays Decrease as the Distance Increases.

How Shadows Are Formed.—A *shadow* is formed when an opaque body is interposed between a source of light waves and a surface on which the latter fall. A shadow, then, is simply the *absence of light* within a certain defined area from which the rays are cut off by a body.

Of course there are different kinds of shadows, but we shall confine the experiments in this text to those produced by a small source of light, because these are the only ones that are concerned with television

(*a*) Hold a ruler vertically between the wall and an ordinary fish-tail gas burner so that the edge of the flame is toward the wall. Note that the shadow is sharply defined, and that the entire shadow is equally dark. (*b*) Now turn the flame so that the broad side faces the wall, and observe that the darker center of the shadow is bordered by an area of less intense shade. (*c*) Suspend a marble or a billiard ball by a thread,[1] then cast its shadow on the wall by the use of a candle flame or other small source of light. The shadow will be sharp, circular, and equally dark over its entire area.

The Reflection of Light.—Next to the source of light that illuminates the object which is to be projected through space by the television transmitter, the *reflection* of light waves is of the greatest importance. So let us find out exactly how

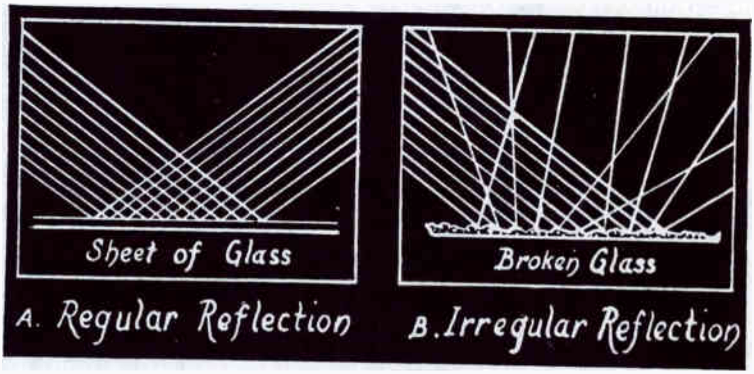


Fig. 11—The Reflection of Light Rays.

the reflection of light is accomplished. Ordinarily all of the objects we see are non-luminous. They are illuminated by the rays from one or more luminous bodies whose light waves are reflected from their surfaces into our eyes.

When a light wave comes into contact with the surfaces of most bodies, it bounces back, just as a rubber ball bounces back from a surface against which it strikes, and it always moves away in a direction that is angularly opposite to that

[1] A drop of sealing-wax will serve to fasten the thread.

in which it was initially moving, the rule being that the angle of reflection equals the angle of incidence and is on the opposite side of the perpendicular. Now the reflection of light waves may take place under one of two different conditions, namely (1) regularly and (2) irregularly.

When reflection takes place *regularly*, the waves are turned back from a smooth surface and the reflected rays are all parallel to each other, just as are the incident rays which strike the surface, as shown at *A* in Fig. 11. But when reflection takes place from a rough surface, the reflected rays are projected in various directions as pictured at *B*. To demonstrate these two modes of reflection, make the following experiments. (1) Let the rays from a source of light fall on the smooth surface of a mirror or a sheet of metal. They will be reflected in parallel rays, as for example when a good little boy throws the sun's rays into the eyes of a bold, bad policeman across the street.

(2) Take a pane of window glass and break it up into a lot of little pieces, then spread a layer of it on a board. When the rays of the sun fall on it, they will be reflected in numerous directions. However light rays may be reflected, the angle of the reflected ray is always equal to the angle of the incident ray, as the ray from the source of light is called.

The Refraction of Light.—The *refraction of light* also plays an important part in television, for it has to do with the formation of images by lenses. By *refraction* is meant the bending of a ray of light out of its normal path. This is usually the result of its passage at an angle from one transparent substance to another.

The following experiment will easily show how a ray of light is bent when it passes from the air into water. Put a teaspoon in a glass of water and observe that the handle is

FIG. 12—The Refraction of Light Rays.

apparently broken off at the point where it enters the liquid, as shown in Fig. 12. The reason that a ray of light is bent out of its *normal* path when it passes obliquely from

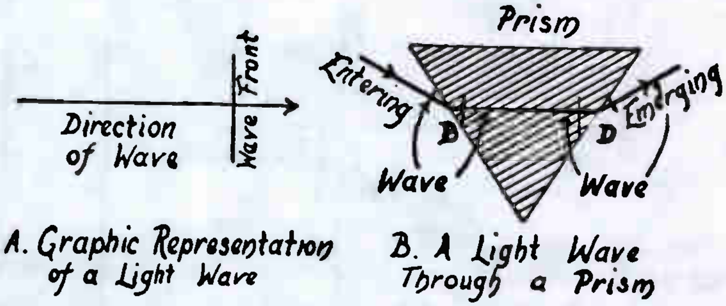


FIG. 13—How a Prism Refracts a Ray of Light.

one substance to another is because (1) the velocity of light waves is less in glass than in air, and (2) the wave fronts are at right angles to the direction in which the ray is traveling as shown at *A* in Fig. 13.

When a ray of light passes through a prism, as at *B*, and each wave reaches the side of the prism, the upper end of the wave will strike the surface and enter the glass first. This end of the wave is then retarded by the denser glass and it will move more slowly in the ether of the latter than it does in the ether of the air, so that by the time the lower part of the wave enters the glass, the wave is straightened up and the path of the ray is bent.

The ray then passes through the prism in a straight line to the other side of it. Here the lower part of the wave

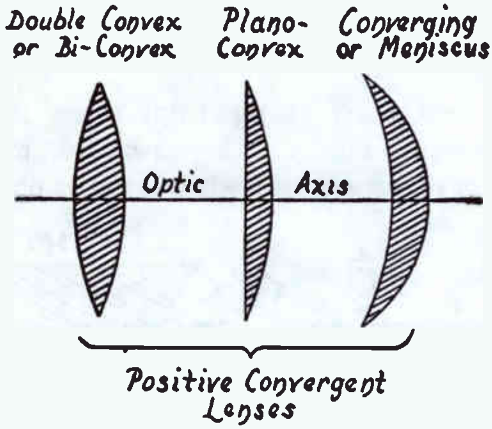


FIG. 14—Kinds of Convex Lenses.

passes out into the air first, and moves forward at a higher speed than the upper part of it, which is still in the glass, and so the path of the ray is again bent. When the entire wave has emerged from the glass, it once more travels in a straight line.

The Shapes of Lenses.—The two chief kinds of lenses are (1) convex lenses and (2) concave lenses. A *convex lens* is one that is thicker at its center than it is at its edge, while a *concave lens* is thinner at its center than it is at its edge. As the convex lens is the only kind that is used in television, I shall describe its various shapes and exclude the concave lens. The three shapes that a convex lens may have are (1) the double convex lens, (2) the plano-convex lens and (3) the concavo-convex lens, all of which are shown in Fig. 14.

Refraction Through a Lens.—The form of a *double convex* lens is determined by the intersection of two curved surfaces which are parts of spheres. The two points which represent

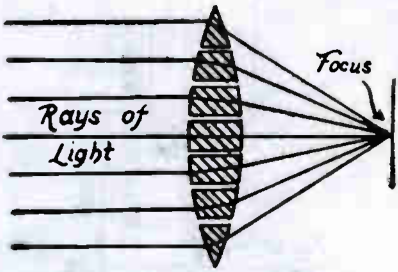


FIG. 15—How a Lens Refracts Light Rays.

the centers of these spheres are called the *centers of curvature*, and when a line is drawn through them it forms what is called the *principal axis* of the lens. The point midway between the curved surfaces and on the principal axis is called the *optical center* of the lens. If a ray of light passes through the lens along its principal axis or through its optical center, it will not be refracted.

The easiest way to understand how a convex lens acts on a beam of light passing through it is to think of it as being built up of separate parts, each one of which is a prism, so that these are not in contact, as shown in Fig. 15.

When a ray of light falls on any one of these prisms, it is refracted toward the thicker part, and the result is that all of the rays, on emerging from the lens, will converge toward a point which is called the *principal focus.*

To Find the Focus of a Lens.—To find the *focal length* of a convex lens, that is, the distance from the center of the lens to the point where all of the rays meet, the simplest way is to let the rays of the sun pass through it and fall on

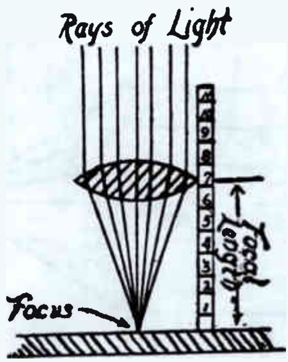


FIG. 16—How to Find the Focus of a Lens.

a screen, then measure the distance at which the lens converges the rays to a small point on the screen, as shown in Fig. 16.

What Colors Are.—Up to the present time *television in natural colors* has not figured in commercial equipment, but it is actually possible to transmit images of subjects in colors and, hence, you should know something about the way that colors are formed. Sunlight is made up of light waves of various lengths and when these are separated by a prism they produce the seven colors of the spectrum. The wave lengths and the color sensations that they set up are as follows:

COLORS AND THEIR WAVE LENGTHS

The Colors	*Wave Lengths in 10 Millionths of an Inch*
Red	133
Orange	120
Yellow	113½
Green	105½
Blue	98
Indigo	92½
Violet	83½

Now when all of these wave lengths fall on any surface that will reflect all of them into your eyes, they produce, in the visual center of the brain, the sensation of *white*. Thus it is that when waves of sunlight and certain kinds of artificial light fall on what we call *white* paper, it looks *white* to us When they fall on what we call *red* paper all of the other wave lengths that produce the other colors are absorbed, but the waves whose length produces *red* are reflected; and so it is with all of the other colors. Finally, what we call *black* is merely the absence of all of the wave lengths that produce the above colors.

To demonstrate that sunlight is made up of wave lengths which produce the aforesaid colors, (1) cut a slit in a business card, 1/32 inch wide and an inch long. Now hold the card back of a prism and see to it that the slit in it is parallel with the edges of the latter; next let the rays of the sun shine through the slit, then look down through the side of the prism so that the rays coming through the slit will pass through the prism and be refracted into your eye, as pictured in Fig. 17. You will then see the seven colors of the spectrum.

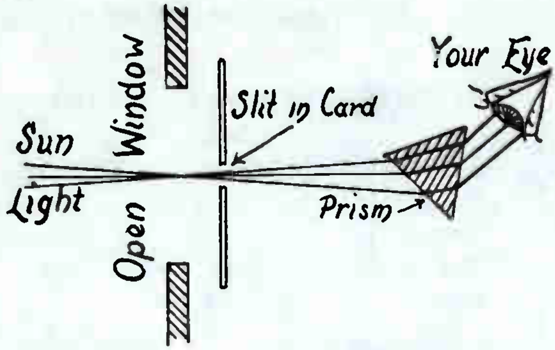


FIG. 17—How to See the Spectrum.

(2) Cover a south window with paper heavy enough to keep the rays of the sun from passing through it and into the room and cut a hole about two inches square in the

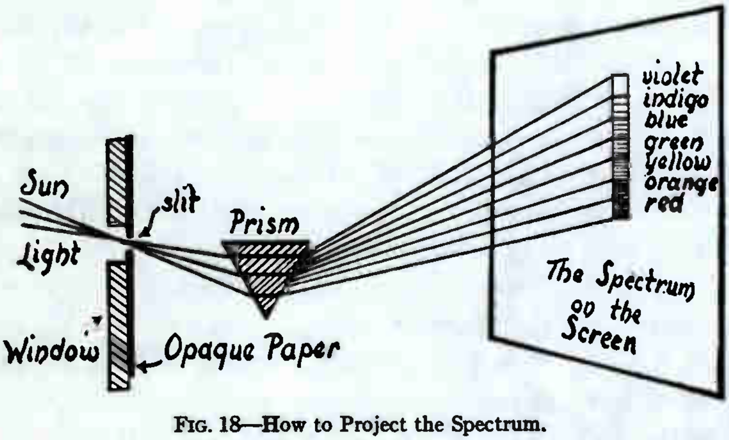


FIG. 18—How to Project the Spectrum.

lower part of the paper. Paste the card that you used in the first experiment over the hole, with the slit in a horizontal position and then hang up the prism or otherwise support it, with its edges parallel with the slit, as shown in Fig. 18

This done, get a large sheet of cardboard and tack it on the side of the wall opposite the slit in the window. To make the experiment, you must adjust the position of the prism until the rays that pass through the slit will fall on it and will be separated, so that the colors of the spectrum will be projected in a band on the cardboard screen, as is also shown in Fig. 18.

CHAPTER II

EXPERIMENTS WITH VISION

We get the word *vision* from the Latin verb *videre*, which means *to see*, and we use it to indicate that sense or faculty by which the brain becomes conscious of light and color effects. The primary organ of vision is the eye, and this is so made that an image of the object that you are looking at is formed on its screen, or *retina*, as it is called, at the rear of it. The shape, shade, and color of the object are then carried by electric currents along the optic nerve, which is formed of millions of nerves, to the cerebral center of visual sensation, which is in the occipital region of the brain.

The Eye a Television Apparatus.—You may or may not know it, but your eye is a complete and very perfect television apparatus, forming, as it does, an image of an object at some distance away from it, and this may be very considerable, provided, of course, that nothing intervenes to cut off the light rays. This being true, it is well, then, to find out just how your eye is made and how it works.

How the Eye Is Made.—It will be enough to say for the present purpose that it consists of a nearly spherical mass, (see Fig. 19), *the eyeball*, which is held in the *orbit*, or cavity of the skull, and made movable by six muscles, of which four are known as the *rectus* muscles and two as the *oblique* muscles. As shown in Fig. 20, the eyeball is covered with

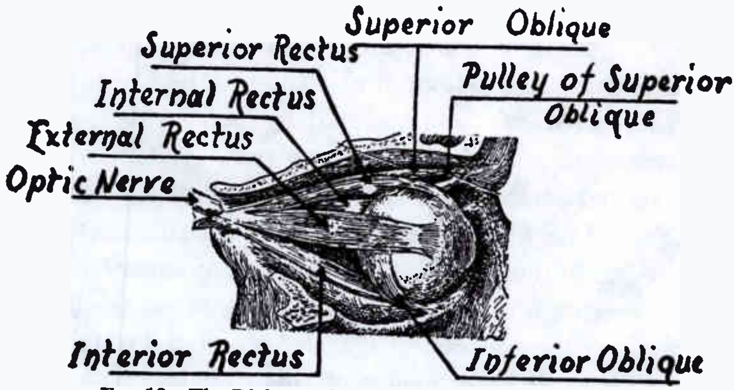


FIG. 19—The Right Eyeball, Showing its Various muscles. (*A Side View of It.*)

(1) a tough, fibrous membrane called the *sclerotic*, and that part of it through which the light passes into the lens is

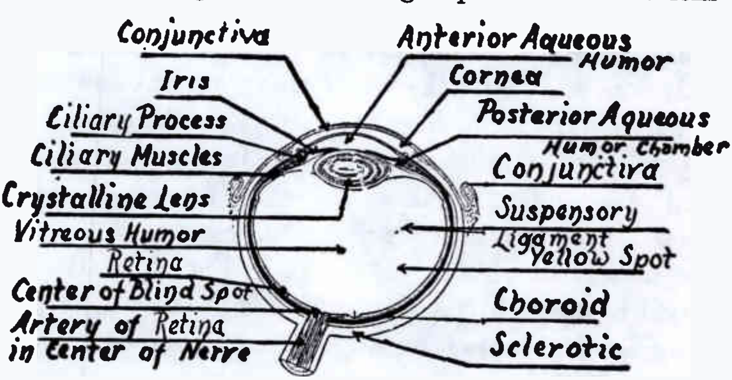


FIG. 20—A Horizontal Cross-Section of the Human Eyeball. (*Looking Down on It.*)

known as the *cornea*. Inside of the eyeball is (2) the *iris*, a diaphragm controlled by the muscles, the opening in which is called the *pupil*. This is automatically made larger or smaller to regulate the amount of light passing through (3) the *crystalline lens*. (4) The *choroid* is a vascular[1] mass that contains large pigmented cells, and this lies between the sclerotic and (5) the *retina*; the latter is a highly sensitive membrane which, when stimulated by light waves, results in the sensation of vision. The two parts of the eye that interest us particularly are (*a*) the crystalline lens and (*b*) the retina. The former consists of an elastic transparent substance built up of rod-like cells. It is a *biconvex lens*, that is, it is convex on both sides, and it is hung immediately back of the pupil by the *suspensory ligament*, which is a tough band of elastic tissue; it is by means of this that its convexity is changed so that the focus for different distances can be adjusted. This operation is called *accommodation*.

The retina is the sensitive membrane on which the lens projects the image of the external object. As a matter of fact, the retina is the actual instrument of vision, being directly connected with the visual center of the brain by the optic nerve. The retina lines the rear wall of the eyeball, and that portion of it which performs the function of vision is formed of a supporting tissue on which are several layers composed of various nervous elements.

The *sensory layer*, which is shown in Fig. 21, is the first one[2] which we shall consider, and this is built up of *rods and cones*. The former consist of minute hair-like projections, and scattered among them are shorter conical bodies. Both the rods and cones are microscopic in size and examina-

[1] Through these *vascular cells* flows the pigment that gives the eyes their color.
[2] In front of it are the pigment granules.

tion of these with a high-power microscope shows that they, in turn, consist of an exceedingly large number of hexagonal cells,[1] each of which is joined to one or more nerve filaments. Finally, these are connected with the optic nerve that leads to the brain.

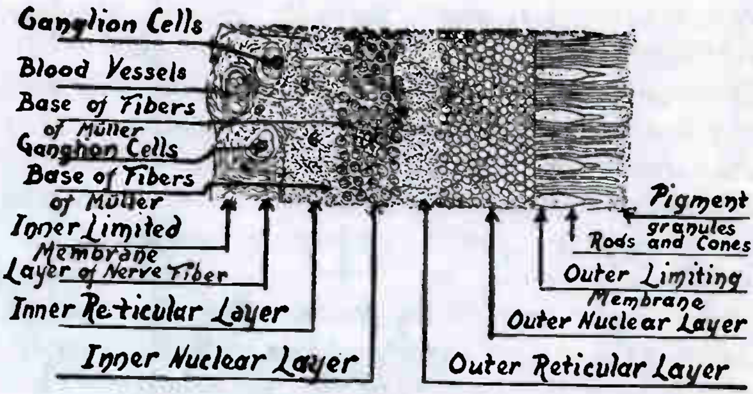


FIG. 21—Cross-Section of the Retina of the Human Eye.

Through these cells there flows a continuous stream of a chemical compound that is sensitive to light and which is known as *rhodopsin*, or *visual purple*, as it is commonly called. A very interesting thing about the retina is that all of the early attempts to make a television apparatus, and not a few of the later ones, were based on the principle of the hexagonal cells, though in the beginning physiologists did not know of their existence.

How Your Eye Works.—The way that your eye functions is like this: When you look at either a luminous or non-luminous body, the light waves which are sent out from the

[1] In the human eye these run into the millions.

former, or are reflected by the latter in a line with the crystalline lens of your eye, pass through and are focussed on the retina, and form an image of it just as the lens of a camera projects an image of a body, or subject, on the ground-glass screen.

When the light waves strike the rhodopsin, or visual purple that flows through the hexagonal cells, the intensity of the waves varies the resistance, or, let us say, its reciprocal, which is the conductance, of the visual purple. This, in turn, varies the intensity of the impulses, which are probably electric currents, that flow through the nerve filaments to the visual center of the brain, where the sensation of light and color is impressed.

Some Experiments With Vision.—*The Eye and the Camera.*—You can get a very good idea of the way your eye functions by using a folding camera. You cannot use a box camera because it has a *fixed focus* and an *adjustable diaphragm*, while a folding camera has a *variable focus* and a *variable diaphragm*, and in this respect it is very like the eye.

(1) The word *accommodation* is used to mean the automatic adjustment of the eye so that the crystalline lens will focus the image sharply upon the retina. In the eye of man and the higher animals, accommodation is chiefly effected by varying the curvature of the lens, and this, as previously pointed out, is accomplished by the suspensory ligament.

Now take the camera and move the lens forth and back, until the image of the object is sharp on the ground glass screen. Since the curvature of the glass lens of the camera cannot be changed as nature changes the convexity of the crystalline lens of the eye, it becomes necessary to resort to the mechanical expedient of moving the lens closer to or farther from the ground-glass screen, and this operation is called *focusing*.

(2) The *pupil* of the eye, which is really an opening, or *aperture*, in the center of the iris, contracts and expands automatically as the exigencies of the case require. When the light is too strong, it contracts and cuts off some of the rays; when the light is feeble, it expands and lets all of the available rays pass through to the crystalline lens.

The iris *diaphragm* shutter in your camera works on the

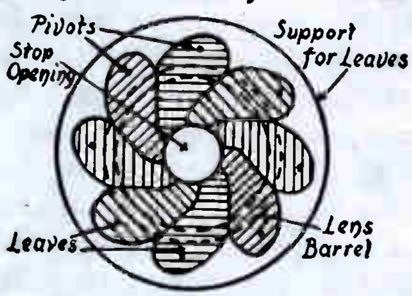


FIG. 22—An Iris Diaphragm Shutter.

same principle as the iris of your eye, in that the aperture can be continuously made smaller or larger, but it differs from that of the eye in that the result is obtained by manual control. The diaphragm is formed of a number of curved leaves cut out of thin sheet metal, and each leaf overlaps the adjacent one, which is pivoted to a support, as shown in Fig. 22.

These leaves all work simultaneously, and, by moving a lever, they can be made to slide to the circumference of the support, like the leaves of a fan, and this gives the lens its largest opening. When the lever is moved the other way, the leaves will close, and you can make the opening any desired size. The iris diaphragm shutter is made on the same principle, and the leaves are so assembled that they may serve the purpose of both the stop and the shutter.

(3) The photographic dry-plate or film represents the retina of the eye, in that it is formed of a light sensitive substance, and, when a ray of light strikes the sensitive silver compound on the plate, a chemical change is produced, just as is the case when light strikes the visual purple of the retina The difference between the retina and a sensitized plate or film is that the instant the rays of light have acted on the visual purple of the eye, a fresh sensitive surface is presented to the succeeding light rays, but when the rays of light act on a plate or film, the chemical change is more or less permanent.

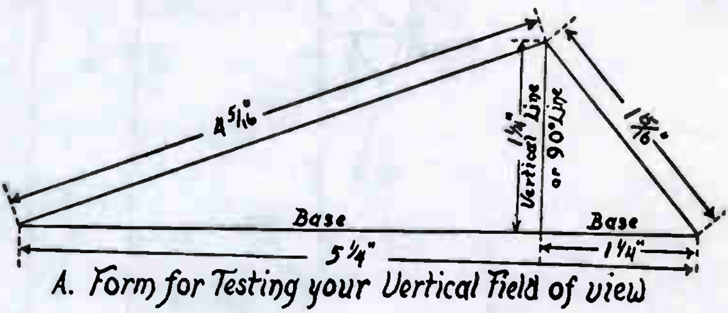
The final difference between the retina and a plate or film is that when a ray of light strikes the visual purple of the eye the chemical change varies its electrical resistivity and the current is carried to the visual center of the brain, while no other action takes place in the silver compound after the light has once struck it.

An Experiment With the Field of View.—What is called the *field of view* is the space in front of your eyes, in which you can see an object, by moving the eyeballs up and down and from side to side by means of its extrinsic muscles,[1] without turning your head. The field of view that is covered by each eye is about 50 degrees upward and 70 degrees downward, making 120 degrees in a vertical plane, and 60 degrees in-

[1] That is those muscles which are outside of the eyeball and are fixed to it and another part back of it.

ward and 90 degrees outward, making 150 degrees in the horizontal plane. The field of view of both eyes is, therefore, in the neighborhood of 120 degrees vertically and 180 degrees horizontally.

(1) You can easily test the vertical field of view as follows: Cut a strip of cardboard 1 ½ inches wide and 5¼ inches long, and draw a vertical line across it 1¼ inches from one end. This done, draw a line from each corner of the base line to the top of the vertical line. This produces acute angles

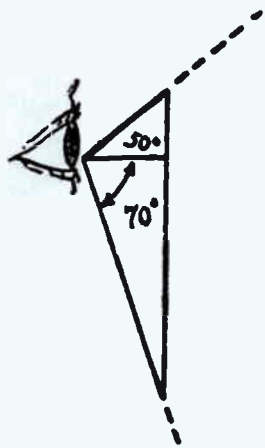


A. FIG. 23—Testing Your Field of View.

at one end of it and right angles at the other end, as shown at *A* in Fig. 23.

To make the test, hold the cardboard angle in a vertical plane with the apex of the angle close to the exact center of the pupil of your eye and the base line exactly straight up and down. The vertical line (90-degree line) will be even with the optic axis of your eye, as pictured at *B*. Now sight along the 50-degree line by looking upward and then along the 70-degree line by looking downward, when you will see that these are the extreme upper and lower limits of the vertical field of view.

(2) Having made the above experiment, you can test out the horizontal field of view as follows: cut out a strip of cardboard 1 11/16 inches by 5 1/4 inches and then draw a vertical line across it 2 7/16 inches from one end. The next step is to draw a line from one corner of the base line to the top of the vertical line. Then there will be a right-angled

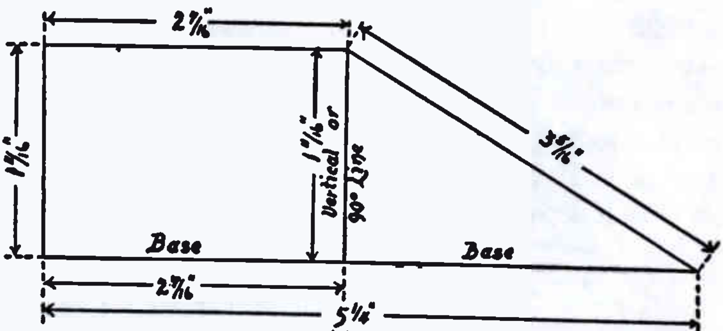


B. Testing your Vertical Field of View

B. FIG. 23—Testing Your Field of View.

triangle on the one side and a rectangle on the other side of the vertical line, as shown at *A* in Fig. 24.

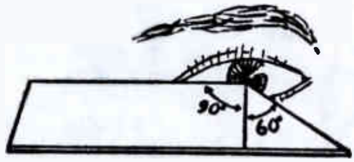
To make the experiment, hold the cardboard in a horizontal plane, with the apex of it close to the center of either eye, and have the base line exactly horizontal, when the vertical line (90-degree line) will be in alignment with the optic axis of the eye as pictured at *B*. The 60-degree line will rest on your nose, and it is this organ which prevents you from seeing at a wider angle in this direction. Finally, by sighting along the horizontal 90-degree line, you will see that this marks the extreme limit of your horizontal field of view.



B. Form For Testing Your Horizontal Field of View

A. FIG. 24—Testing Your Field of View.

How Distance Limits Vision.—Another factor that limits vision is *distance*, and this is true even when there is no



B. Testing your Horizontal Field of View

B. FIG. 24—Testing Your Field of View.

obstruction, such as dust, smoke, water vapor, etc., between the eye and the object. Now make the following simple experiments.

(1) Stand this book up so that one of its printed pages is on a level with your eye, then step back to a distance of 10 feet

from it, and note that the letters of each word and the words of each line run together, and that instead of being able to separate the characters and individual words you will see a solid black line.

The reason for this is that the rays of light that reach your eye from each letter move along in a straight line, and when the rays from the letters that are close together meet on the retina of your eye, the angle they form is so small that you cannot separate them, so they appear to run together.

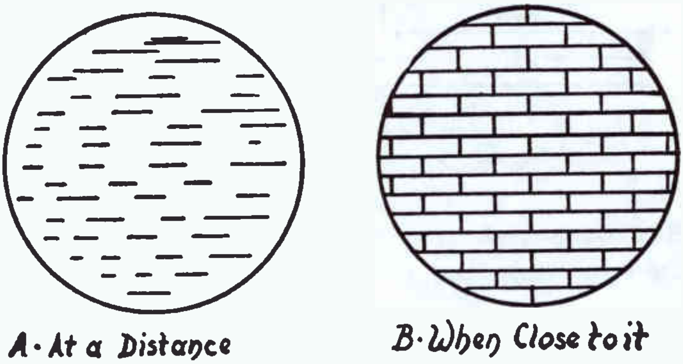


FIG. 25—How Distance Affects Vision.

Now step a little closer to the book and observe that the apparently continuous line is broken up into black spots, and as you move up close enough that the rays of light coming from the letters form an angle of an appreciable size, your eye will then be able to resolve the black spots into distinct letters. The limit of vision, then, is not determined by distance alone, but depends on the amount of separation relative to the distance.

(2) Another experiment that shows how distance affects vision is to look at the wall of a building, see Fig. 25, from a

sufficient distance that you cannot tell whether it is made of white brick or concrete. In approaching the building, you will be able to see broken lines of mortar if the walls are of brick, and on moving a little closer to it you eventually see each brick sharply defined.

Scotopic, or Night Vision.—We get the word *scotopic* from the Greek word *skotos* which means *darkness*, and *scotopic vision*, *twilight vision*, or *night vision*, as it is variously called, means the ability, or adaptability, of the eye to see in the dark. The eye thus possesses two ranges of visual power, and these are known as (1) the *light-adapted state*, or *daylight state*, which refers to the ability of the eye to see when it has become accustomed to a fairly high intensity of light, and (2) the *dark-adapted state*, or *twilight* or *night state*, when it has the ability to see after it has become accustomed to a very feeble light.

(1) To test the scotopic vision, you need only to go from a brightly lighted room into a very dimly lighted room, where you will not be able to see anything until your eyes have become accustomed to the darkened condition.

An experiment that most of us have unconsciously made many times consists of entering a darkened theatre, where it is almost impossible to see which seats are occupied. After five or ten minutes scotopic vision will begin to function and it is then possible to see things in the auditorium quite clearly. The reason you can see in the dark-adapted state is because the iris of the eye slowly opens until the pupil is widely expanded and so lets in the greatest possible amount of light.

Since the television image is not very bright, the darker the room is, the better you can see the details on the screen.

Another interesting experiment may be made out of doors on a clear moonless night. After your eyes have become adapted to scotopic vision, pick out a feeble star such as, for example, *Alcor*, which is a companion star to *Mizar*, the next star to the end one in the handle of the *Big Dipper*, see Fig. 26. Look at Alcor for a minute or so steadily and then turn your eyes a little to one side of it. It will then seem a trifle brighter than it did before. With a little practice you

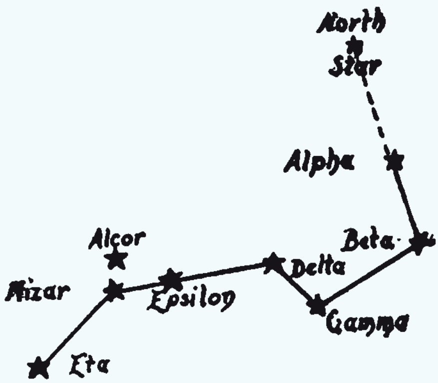


FIG. 26—A Test for Scotopic, or Night Vision.

will be able to see a star by *indirect vision* that will completely disappear when you look directly at it.

How the Eye Responds to Motion.—When you are looking at a scene in which everything is motionless, your eyes will take it all in without attention to detail, unless you concentrate upon some particular feature of it, but the instant something in it begins to move about, your eye is fixed upon that point and you see it with greater exactness than those parts that are stationary. This stimulus is known in physiological optics as the *visual perception to motion.*

As an illustration you can read the printed page of a newspaper in a leisurely and complacent fashion until a fly alights on it, (see Fig. 27) and begins to groom itself or runs around on it. Then the details of the printed page fade away, however interesting you may have found the text, and the fly claims greater attention. When the insect flits away,

Fig. 27—The Response of Your Eye to Motion.

then, and not until then, can you pick up the sense of the printed matter.

At the race track, the details of the scene are indefinite except when your attention is directed to some particular object or part of the scene. But the moment the horses are brought out, your eyes are concentrated upon them, for here is motion, and this makes the strongest appeal to vision.

The Persistence of Vision.—The term *persistence of vision*, or, as it is called in physiological optics, the *duration of visual* *sensation*, means that when an image is formed on the retina of the eye it does not disappear the instant the light is cut off, but persists, due to the fact that the response to the stimulus continues for the fraction of a second.

As an illustration of how the persistence of the image affects your vision, take the case of a rapidly revolving spoked wheel: when you look at it the spokes apparently *run* together, that is to say, they no longer appear to be separate and distinct but to have become an integral part of the whole. Moving pictures are based on this phenomenon, and television makes use of it to a large degree.

With moving pictures, the slowest rate at which the successive frames[1] of a film can be run through the projecting machine in order to make the images formed on the retina of the eye appear continuous is about 1/16 of a second, or 16 frames per second. At this speed your eye will not be able to take cognizance of the time interval that elapses between any two adjacent frames, and you see the integrated picture, the movements of which are blended together in smooth progression.

Higher speeds, up to 24 frames per second, can be used before you are conscious of any variation imposed upon the persistence of vision. The image of an object that is formed on the retina of the eye persists from 1/30 to 1/50 of a second. The speed of the film through the projector is determined by (1) the length of time the image persists on the retina and (2) the speed with which the action of the scene takes place.

Without the persistence of vision, moving pictures as they are now made and projected would fail in their purpose.

[1] Each individual picture on a moving picture film is called a *frame*.

The same is equally true of television pictures. The following experiments clearly show just how the persistence of vision acts.

(1) Spin a half-dollar on its edge on a table, and you will be able to see both sides of it at the same time, as shown in Fig. 28. The figure on the *heads* side will run into and merge with the figure on the *tails* side of the coin, hence you will not be able to discern the contour of either one. It was Sir John Herschel who first pointed out, about one

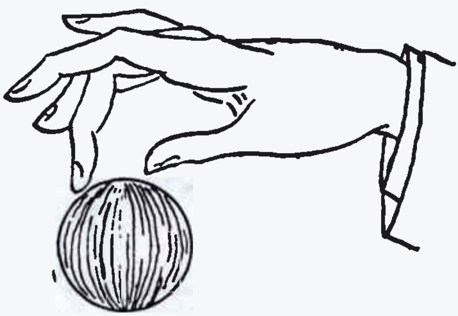


FIG. 28—How to See Both Sides of a Coin at the Same Time.

hundred years ago, that this effect was caused by the persistence of vision.

(2) The next experiment illustrates exactly the phenomenon of the persistence of vision as it is utilized in the reception of television pictures. Get a stick about two feet long, light one end of it and then whirl it rapidly around in the dark. It will appear to be a continuous ring of light, as shown at *A* in Fig. 29. The explanation of this apparently continuous ring of light is the key, not only to the reception of television images by the eye, but also to a whole series of illusions that are based on the persistence of vision.

To understand the cause of the phenomenon, just consider that an instantaneous flash of light enters your eye; the action it produces on the retina would last about one-eighth of a second, and one would apparently see the light for a fraction of a second after it had really vanished.

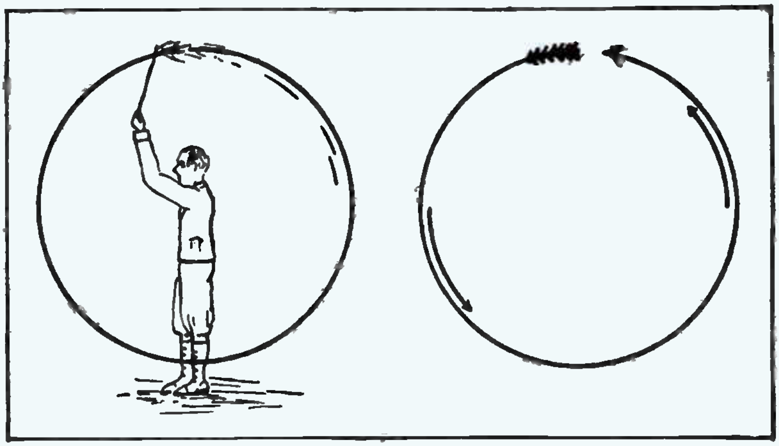


FIG. 29—How the Persistence of Vision Acts.

This being true, when you whirl the lighted stick around, it makes a complete circle starting from the top and returning to the same point. This it does in less time than it takes the impression of light on the retina to die out. And so it is with the impressions that are produced by the light at every succeeding instant of the movement of the stick, and, as all of the impressions run together, the ring of light appears to be not only continuous but also consistently bright.

CHAPTER III

EXPERIMENTS WITH THE SCANNING DISK

The ancient Romans used the word *scandere* to mean *to climb*, and this, of course, implied a *step by step* movement. From this root we get the word *scan*, and we use it to mean a close point-to-point examination of a thing. In television the word *scanning* means that the *field of view*, as that part of the scene or object which is to be televised[1] is termed, is broken up into a large number of *picture elements*, that is little parts which go to make up the picture. This important operation is generally accomplished with a *scanning disk*,[2] that is, a disk in which a series of holes has been cut in the form of a spiral, and which is rotated at high speed.

The Invention of the Scanning Disk.—The new art of television had its beginnings in Germany away back in 1884, when Paul Nipkow, an experimentalist, invented the spiral scanning disk, a picture of which is shown in Fig. 30. That this simple disk is employed in practically every system at the present time—nearly 50 years later—shows that it possesses a high degree of merit, for hundreds of experts working under the most favorable conditions have not thus far been able to provide a device that is as good. It has,

[1] The word *televise* means the process of scanning an object, a subject or a scene.
[2] The English call it an *exploring disk*.

however, many obvious faults, and this is one of the chief reasons why practical television has been so long on its way and is just now coming into its own.

Besides the inherent faults of the scanning disk, Nipkow lacked two essential devices in order to make a workable television system. These were (1) a sufficiently sensitive

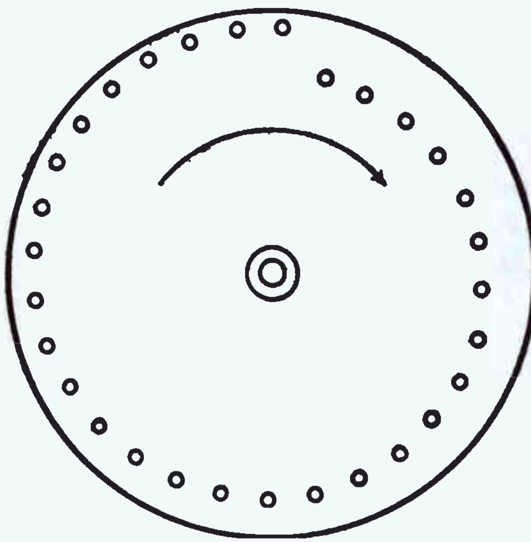


Fig. 30—The Nipkow Scanning Disk.

photo-electric cell and (2) an amplifier for increasing the strength of the transmitting and receiving currents. For the first he used a *selenium cell*, which, when a light falls on it, decreases its resistance and so allows a larger current of electricity to flow through it[1]. Now while this seems to provide the essential principle, the trouble with it in practice is that its response, or what is equally vital, its recovery to

[1] The increase in the current flowing through it is proportional to the intensity of the light that falls on it.

its normal state of resistance, is altogether too slow to take care of the exceedingly large number of impulses of light produced by the scanning disk.

As for the second device, *i.e.*, the *amplifier*, it was wholly unknown to Nipkow and his successors for the next 25 years or more, for it was yet to be invented. It is only within recent years that we have had both the amplifier and a photo-electric cell that will respond rapidly enough to be practical.

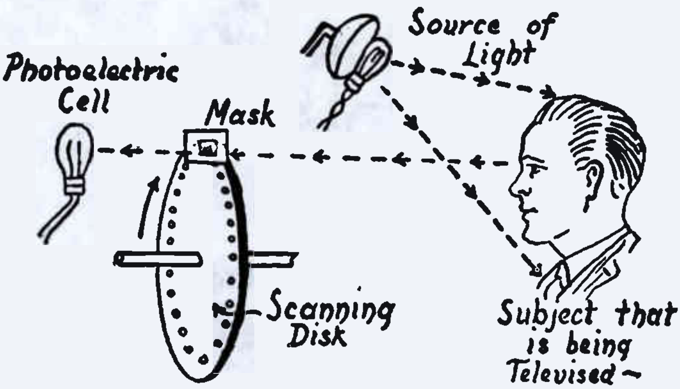


FIG. 31—How the Scanning Disk Breaks up the Picture into Elements.

How the Scanning Disk Scans.—As noted above, practically every television system makes use of the Nipkow scanning disk for breaking up the field of view into light impulses at the transmitting end and building up the image at the receiving end. Now the way that a scanning disk scans or explores a subject is like this. A strong source of light is made to fall on the subject or the screen as the case may be. By way of illustration let us consider a man's face as the subject. The rays within the field of view which are reflected from it in line with the holes in the rapidly rotating disk, strike a photo-electric cell that is on the opposite side of the disk, as shown in Fig. 31.

As the disk revolves, the sequence of holes covers every part of his face every time the disk makes one complete revolution, and as the light rays reflected successively from the various parts of his face are of different intensities, the current they modulate in the photo-electric cell varies the current proportionately.

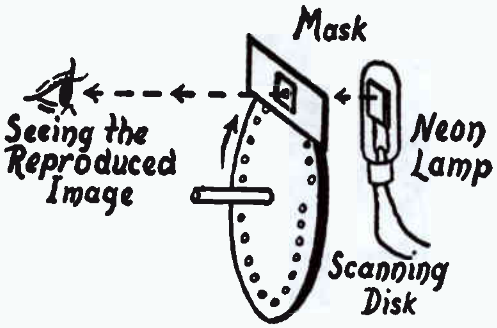


FIG. 32—How the Scanning Disk Recomposes the Picture Elements.

The scanning disk used for receiving operates to change the electric impulses into light impulses, and the image is produced through the medium of a *Neon tube*. This is an electric lamp with a plate in it the size of the image of the subject, which in this case is the man's face that you are going to see. As the current that energizes the lamp varies, so the light all over the plate likewise varies, and, as the rapidly rotating disk makes each complete revolution, you see a point of light on the plate as many times per revolution as there are holes in the disk.

Since the transmitting disk and the receiving disk revolve at exactly the same speed, or *synchronously*, these variations in the intensity of the rays of light from the plate that strike the retina through the holes in the disk are built up by the persistence of vision, and you see an image of the subject at the receiving end, as shown in Fig. 32. What I have told you about the scanning disk is the simplest statement of its action. Now we can consider some detailed facts about it.

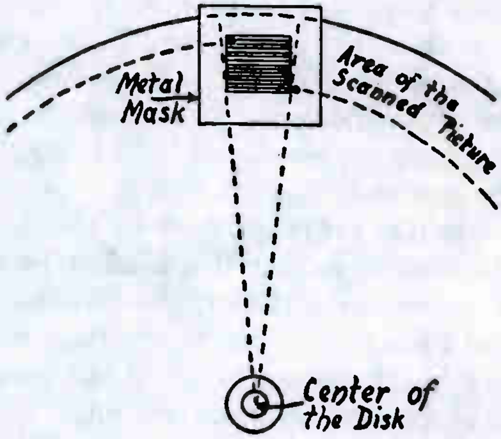


FIG. 33—The Proportions of the Scanned Picture.

Some Facts About the Scanning Disk.—*The Size and the Shape of the Light Area.*—What is called the *light area* is the size of the actual picture that is thrown on the scanning disk and which is scanned by the spiral series of holes, as shown in Fig. 33. The size of the light area that the disk is able to scan is, then, very small when compared to the size of the disk itself; as you will see from the drawing, its height is limited by the first hole of the outer end and the last hole of the inner end of the spiral, while its width is limited by the distance between any two of the adjacent holes, as is also shown in Fig. 33. The shape of the light area that is made up of the moving spots of light is about like that shown in the same picture.

The Number, Size, and Shape of the Holes.—There is no hard and fast rule for determining the number of holes that a scanning disk should have. Thus, the General Electric Company uses a disk that has 24 holes; the Baird Company one with 30 holes; the Radio Manufacturers Association advocates the use of one with 48 holes, while the Radio Corporation of America employs one with 60 holes. You can, therefore, use any number of holes between 24 and 60 with equally good or bad results.

It is obvious that the larger the holes are, the more light will pass through them, but this is offset by the greater blurring of the details of the received picture. A good size to make the holes of both the transmitting and receiving disks is .075 (roughly about 1/16) of an inch in diameter, as this is the happy medium which will allow the maximum amount of light to pass through them with a minimum amount of blurring.

The holes in the scanning disk can be round, square or wedge-shaped. A round hole is the easiest to make, and will serve for experimental purposes. A square hole, however, lets more light go through it for a given area, and this is the kind that is used for all commercial transmitting and receiving apparatus. Theoretically a slightly wedged-shaped hole with curved inner and outer edges, converging by virtue of the design of the outer edge, gives the best results, but the extra work required to make it does not result in any practical advantage over the square hole.

The Speed of the Scanning Disk.—When the scanning disk is revolved slowly, you can easily follow the spot of light that each hole makes as it passes over the light area or screen; when the disk is made to revolve a little faster the spots of light moving over the light area or screen take on a flickering aspect, and, finally, when the disk is revolving rapidly enough, the flicker disappears, due to your persistence of vision, and the light area or screen appears to be equally illuminated at every point.

The speed at which this smoothing out takes place is in the neighborhood of 750 revolutions per minute; but the speed of the scanning-disk should be considerably higher than this and it will be found that 1,000 or 1,200 revolutions per minute will give the best results.

The Use of the Frame or Gate.—The *frame*, as we call it here, or the *gate*, or *mask*, as the English call it, consists of a diaphragm with a variable opening so that the width and the length can be adjusted. This is placed in the active area as close to the disk as possible. The reason a variable frame can be used to advantage is to prevent the spot of light that passes through each succeeding hole from sweeping over the light area until the preceding one has left it. It follows then that there will be a small interval of time between any two successive sweeps of adjacent holes in which there will be no light on the light area. The way to make a frame will be described as we push along.

The Direction of Rotation.—The common practice is to run the transmitting and the receiving disks in a counter-clockwise direction, *i.e.*, opposite to that in which the hands of a clock move. The frame which regulates the light area, is placed in front of the disk, and the photo-electric cell of the transmitter is placed in front of the frame, and the neon tube of the receiver is placed back of the disk. The direction of rotation of the disk is shown in Fig. 30.

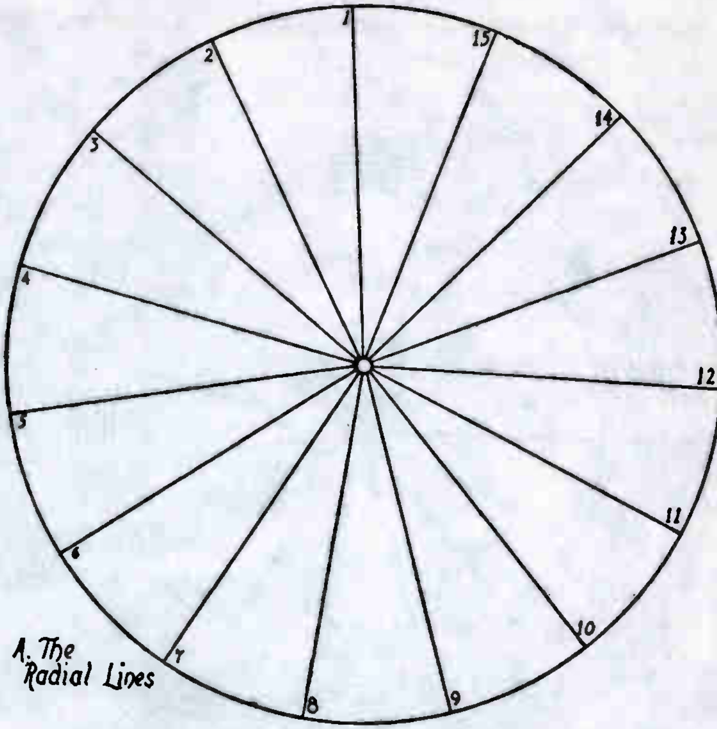
How to Make a Scanning Disk.—The scanning disk is a very simple piece of apparatus, and one that you can easily make for experimental purposes. For a practical television set it must be made with a fine degree of precision, to the end that the picture may not be distorted. There are several ways to lay out and make a scanning disk, but the one described in this chapter is at once simple and accurate enough to serve your needs if you are not too far advanced in the art.

For simple experiments you can make the disk of cardboard, but for practical work it must be made of metal. Whatever kind of material is used, it must be perfectly flat, and at least 1/32 of an inch thick. If it is of metal you can use either aluminum, brass, or duralumin (pronounced *du'-ra-lu'-min*), one of the new alloys, which is 95.5 parts of aluminum, 5 parts of copper, 1 part of manganese and 0.5 parts of magnesium. It is almost as hard and strong as soft steel, and is easier to machine than aluminum.

Having the sheet of cardboard or metal, draw or scribe a circle 12 to 15 inches in diameter[1] and then divide this into as many parts as there are to be holes in the spiral. For example, a 15-hole scanning disk makes it necessary to divide the circle into 15 equal parts.

[1] The larger the disk, the larger will be the light area, providing the number of holes remain the same.

Now with a pair of dividers mark off 15 equi-distant points on the circumference, then scribe a line from each point



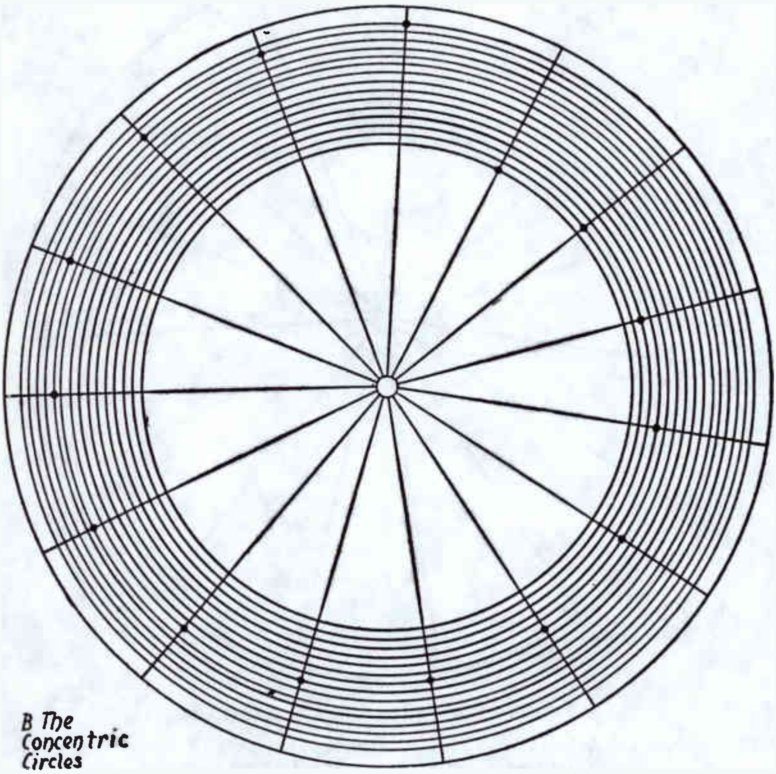
A. FIG. 34—How to Lay Out a Scanning Disk.

(This and the two following cuts show a Scanning Disk with 15 holes. This is done to make clearer the way it is laid out.)

marked to the center of the disk. The arrangement for 15 sectors appears in diagram *A* of Fig. 34.

The next thing is to decide upon the size of the holes. Let us say that you are going to use holes of 1/16 inch diameter.

Draw or scribe, with a pair of beam compasses,[1] 15 concentric circles, (see *B*, Fig. 34) spaced a trifle less than 1/16 inch. This spacing permits the overlapping of successive spots of light on the screen when the disk is in operation. Otherwise there



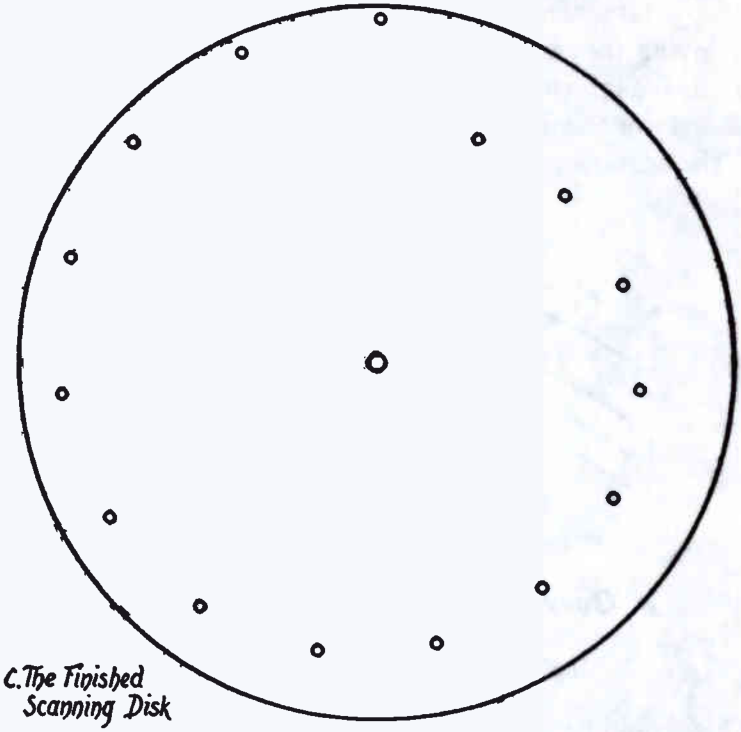
B. Fig. 34—How to Lay Out a Scanning Disk.

will be spaces between the scanned areas, or picture elements. The arrangement is indicated at *A* in Fig. 34. The circumference of the diagram at *B* in Fig. 34 indicates where the

[1] Obtainable at any hardware store where tools are sold. Sometimes called *Trammels*.

disk should be cut out, and the edge should be smoothed with a file or by any convenient method.

The drilling of the holes is a particular job, and the exact



C. FIG. 34—How to Lay Out a Scanning Disk.

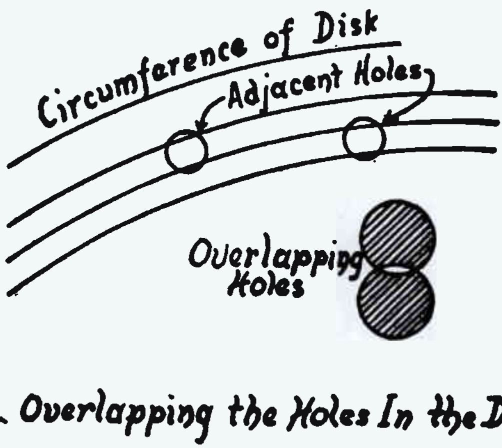
center of each hole must be determined before using a center punch to start the drill accurately.

To do this, lay the disk on a perfectly smooth, flat metal plate, or, lacking this, on a thick hardwood board. Now hold the sharp end of the center punch[1] exactly on the point

[1] You can get this at any hardware store.

where the outside circle crosses one of the radians and indent it by giving it a light tap with your hammer. This done, hold the punch on the next left hand radian at the exact point where it crosses the second circle, and indent it by giving the center punch a tap. Keep on indenting the successive intersections of radians and circles until you have made 15 of them, as shown at *B*.

The next operation is to drill the holes with a 1/16-inch drill.



D. Fig. 34—How to Lay Out a Scanning Disk.

This should be done on a bench drill. It can be done with a hand drill, but it is a hard job to get the holes exactly at right angles to the surface of the disk. After you have drilled the holes it is a good scheme to countersink them slightly, to remove the burred edges which would interfere with the sharpness of the scanning and consequently with the definition of the image. Finally drill, exactly in the center of the disk, a hole of the same diameter as the shaft upon which the disk is to be mounted. The disk will now look like *C* in Fig. 34.

From what has been said above, you will have gathered that a scanning disk, to be of practical value, must be made with almost mathematical precision, and unless you are a skilled machinist and have the proper tools it will fall far short of the requirements for any but the roughest experimental work. So my advice is to buy a disk, or a pair of them, if you are going to build a television apparatus and want to get the best possible results.

How to Mount the Disk.—You can mount the scanning disk in either one of two different ways: (1) on the projecting shaft of an electric motor or (2) on a separate shaft driven by a belt or otherwise from the motor shaft. The shaft of any motor that you are likely to use will probably not be more than ¼ of an inch in diameter and you can mount the disk on it either (1) by using a pair of collars or (2) by threading it and using a pair of nuts. Whichever way you do it, the disk must be held on tight enough so that it will not slip, and it must run perfectly true.

By Using Collars.—This is a simple way to mount the disk on a shaft. Get a pair of flanged collars with a set screw in each one. Slip one of them over the shaft with the flange outward, and screw it up tight. Now slip the disk on the shaft and then slip on the other collar with the flange toward the disk, force it up tightly against the latter and then screw it to the shaft. The way all of this is done is shown in the cross-sectional drawing in Fig. 35.

By Using Nuts.—A better method than the one described above is to cut a thread on the projecting end of the shaft with a die. This done, drill a hole in the center of the disk slightly smaller than the shaft, then make two brass washers, each of which is 2 inches in diameter, and drill holes in these that are a shade smaller than the shaft. Now tap out the holes in the disk and in the washers so that they can be

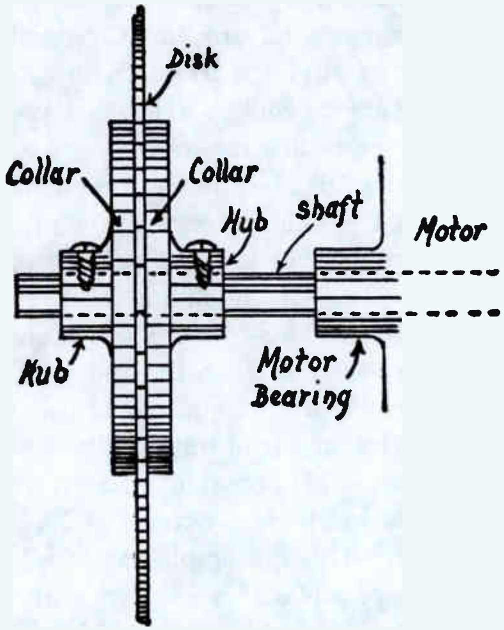


Fig. 35—How to Mount the Disk (*By Using Collars*).

screwed on, and, finally, get a pair of nuts that will fit the thread on the shaft.

To mount the disk, put a nut on the shaft, then a washer, next the disk, then the other washer and, finally, the other nut, and you will have an assembly in which there can be no slippage of the disk. When you tap out the hole in the disk you must do it accurately or it will not run true.

How to Run the Motor.—For purely experimental purposes you can use any direct or alternating current motor except a toy motor, which develops too little power to be of any real service. A motor that develops at least $^1/_{30}$ horsepower is necessary to get the best results, and you can control

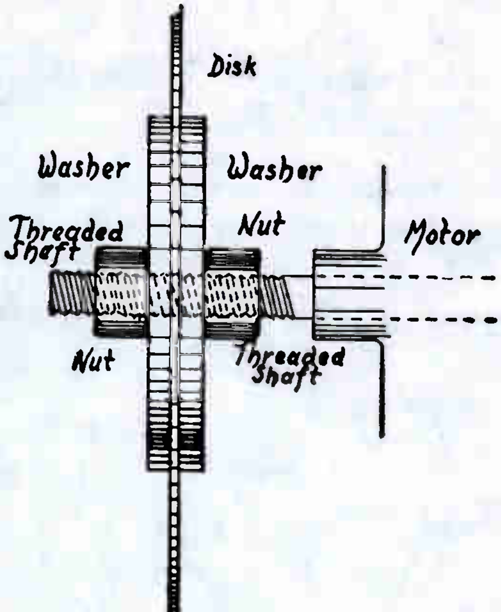


FIG. 36—How to Mount the Disk (*By Using Nuts*).

the speed of it with a rheostat, or variable resistance, connected in circuit as shown in Fig. 37. For the actual transmission of television pictures, your motors at the sending and receiving ends will have to be synchronized, that is, made to run at exactly the same speed, and I shall tell you how to do this in *Chapter VIII*.

Experiments with the Scanning Disk.—*The Size of the Picture.*—The size of the visible area of the picture that is formed of the subject which is being televised is limited by

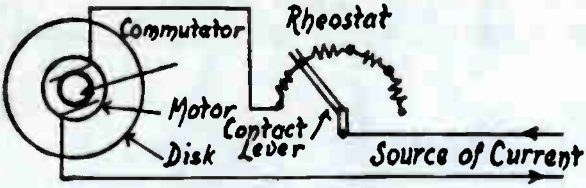
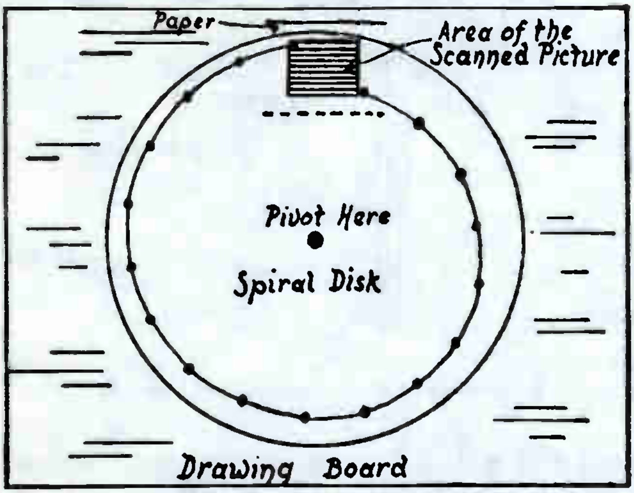


Fig. 37—How to Connect up the Motor.

the diametrical and circumferential distances between any two adjacent holes in the scanning disk, as pictured in

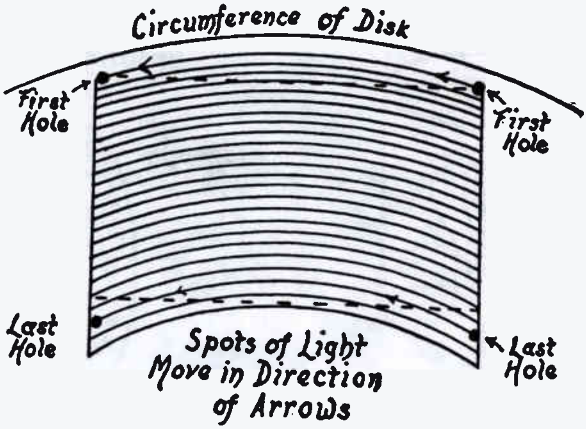


A. Fig. 38—How the Light Area is Formed of Curved Lines of Light.

Fig. 33. Now to show experimentally that the series of spiral holes in the scanning disk will scan, or cover, every point of the field of view, tack a sheet of paper to a drawing-board

or other flat surface and lay the scanning disk[1] on it so that the end holes will be over it, and then pivot it to the drawing board as shown at *A* in Fig. 38.

Now put the point of a hard, sharp pencil in the outside end hole and turn the disk counter-clockwise over the light area, drawing a line across the paper. Do the same thing with a second hole and so on with each succeeding hole until



B. Fig. 38—How the Light Area is Formed of Curved Lines of Light.

you have drawn lines across the visible area on the paper. This done, remove the disk and you will see that the paper has been ruled with slightly curved concentric lines, as shown at *B*. This is exactly the way that the spots of light, which are formed by the holes in the revolving disk, sweep across the visible area.

Scanning with a Beam of Light.—For the following experi-

[1] Instead of the regulation scanning disk which I have told you how to make in the preceding pages, you can make a 6 or a 9 inch one out of cardboard and have ten or fifteen ⅛ inch holes in the scanning spiral.

ments the scanning disk must be mounted on the shaft of a motor, and a 50-or a 100-watt lamp that is mounted in a hood must be used. You can make the hood out of a quart tin can or of sheet metal. Cut a hole in the front of it about 1 ½ inches in diameter and an opening in the top of it for ventilation as shown in Fig. 39. Next get a piece of ground-glass about 2 by 3 inches on the sides, or you can use a sheet of tracing paper glued to a little wooden frame.

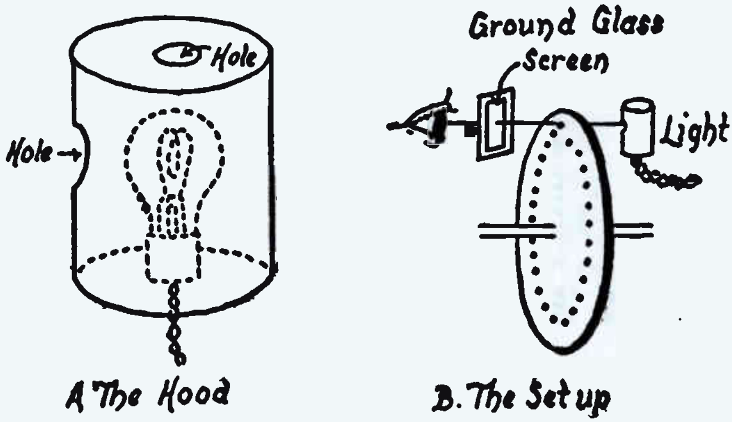


FIG. 39—Scanning with a Beam of Light.

Now mount the hood with the opening directly in front of the spiral row of holes so that the axial center of the former is exactly between the first outer and last inner hole of the spiral. Finally, mount the ground-glass or tracing-paper screen on the opposite side of the disk, close to it, with its center in an axial line with the opening of the hood, all of which is shown at *B*. The following experiments must of course be performed in a dark room.

(1) Revolve the disk very slowly with your hand while you

look at the screen, when you will see successive spots of light move across the screen in slightly curved concentric lines.

(2) Having observed this effect, start the motor and throw in enough resistance with the rheostat so that the disk will turn very slowly. You will see that the spots of light apparently run together as each hole moves across the visible area, just as the pencil lines did in the previous experiment, only in this case the lines are wider.

(3) Now speed up the motor, and, when it is turning over 700 revolutions or more per minute, you will see that the sweeps of light formed by the rays passing through each hole of the disk apparently remain there, and that every point of the visible area on the screen is equally lighted up. As you have already learned, this phenomenon is due to the persistence of vision.

Experiments with a Lens.—Mount a convex lens in the opening of the hood and fix a reflector back of the lamp, when you will get a concentrated beam of light instead of just a few rays, and the resultant effects will be much better. If you will get a toy magic lantern, put an incandescent lamp in the hood, and remove the projecting lenses, leaving only the condensing lens, you will have a very good source of light.

Get a single picture, or *frame* as it is called, of a strip of moving picture film, which the operator at any moving picture house will give you, and mount it over an opening ¾ by ⅞ of an inch, cut in a piece of cardboard or sheet brass. Now set this in front of the convex condensing lens and directly back of the disk.

This done, set your scanning disk to revolving and then look at the visible area of it (1) either with your eye alone, or through the ground-glass screen. You will see in the first instance the picture itself, and in the second case the image of the picture. In either event the picture is broken up into lines or sweeps of light, and you see them recomposed only by virtue of the persistence of vision.

To Find the Speed of the Disks.—It is of prime importance to have the scanning disk of the transmitter and the reproducing disk of the receiver revolving not only at (1) a given rate of speed, and (2) both of them revolving at precisely the same speed, or *isochronously*, as it is called, but also (3) with the corresponding holes in both of them exactly even, or *synchronously*, as it is termed.

In this chapter I shall tell you how to find the speed at which a scanning or reproducing disk revolves, and in another chapter, how to make the disks of both revolve at the same speed and with the corresponding holes in phase, that is, running in step. There is a simple way to find the speed at which the disks revolve, and this is to use a *speed indicator*.

This device, which is shown at *A* in Fig. 40, in its simplest form consists of a worm gear, the spindle of which has threads cut on it, and these mesh with the teeth of the worm wheel, to which an indicator dial is fixed.

(1) To find the speed at which your scanning disk is running, you need only to set the indicator so that the hand on the dial points to 0, then watch the second hand of your watch and, when it is at the 60 mark, press the pointed end of the spindle against the end and in the center of the revolving shaft on which the disk is secured; hold it there until the second hand is again on the 60 mark, that is, when one minute has elapsed. Then remove the indicator from the shaft and

read off on the scale the number of revolutions the shaft, and, it follows, the disk has made.

(2) Should you want to find the *surface*, or *rim speed*, as it is called, or, in other words the number of linear feet per minute the rim, or periphery of the disk is traveling, you can use a *surface-speed wheel*; this is simply a rubber-tired wheel

A. Revolution Speed Indicator

B. A Surface Speed Indicator

FIG. 40—Indicators for Finding the Speed of a Motor or Disk.

that is slipped over the end of the spindle of the indicator as pictured at *B*. To use it, set the indicator at 0 as before and then hold the rim of the wheel gently against the rim of the disk for one minute, and then divide the number of revolutions of the dial by two. Since each revolution of the dial indicates six inches and twice around it equals one foot, the quotient will be the number of feet the rim of the disk is traveling. You can get a speed indicator of this kind for $1.25.

Some Other Scanning Devices.—There are several modifications of the scanning disk, and various other devices that have been invented from time to time with the idea of providing something better. Chief among these are (1) the staggered disk, (2) the lens disk, (3) the scanning drum, (4) the scanning belt, (5) the prismatic disk, etc.

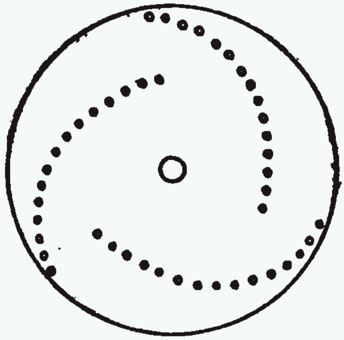


FIG. 41—The Staggered Scanning Disk.

The Staggered Scanning Disk.—(1) To the end that the speed of the scanning disk might be reduced, Baird, of London, devised the *staggered disk*, which has three sets of holes arranged in spiral form, of fifteen holes each, as shown in Fig. 41, and such a disk scans the subject three times at every revolution.

Thus with a disk having forty-five holes, the first spiral scans the 1st, 4th, 7th, 10th, and 13th lines; the second scans the 2nd, 5th, 8th, 11th, and 14th lines, while the third scans the 3d, 6th, 9th, 12th, and 15th lines. With this disk, each point, or *picture element*, is covered by the holes, not in a sequence of lines as in the case of a single spiral disk, but in alternate lines. The result of this scheme prevents the eye from responding to the definite pattern of scanning, and thus tends to reduce the flicker that is generally found in television reproduction.

(2) The staggered scanning disk is also used in the Baird system of *color television*, that is, the transmission of scenes and objects in natural colors. This is based on the three-color process of photography in which the three additive primary colors, red, green, and blue will, when properly combined, produce any of the other colors. Thus, when red and green light are mixed they produce yellow; when green and blue are mixed, they produce peacock-blue; when blue and red are mixed, they produce purple; finally, red, green, and blue light combined in correct proportions produce white.

The difference in results between combining colored light and applying pigments is explained by the terms designating these operations. The *additive* process signifies the projection of light rays upon a reflecting surface, whereupon the color value of the rays is added to the normal reflection. The *subtractive* process refers to the use of pigments upon a reflecting surface, resulting in the absorption of part of the light which would otherwise be reflected. In the additive process the ultimate result is white, whereas in the subtractive plan it is black. Therefore, the primary colors of either process are complementary to those of the other.

In color scanning, one of the sets of holes is covered with a *red color-filter*, which is simply a piece of red glass of the proper hue; the next set of holes is covered with a *green color-filter*, or green glass, and the last set of holes is covered with a *blue color-filter*, or blue glass. A color scanning disk of this kind is used in both the transmitter and the receiver.

The Lens Scanning Disk.—This disk was devised by Baird, and it consists of thirty-two lenses mounted in spiral formation in the scanning disk. As the disk revolves, each lens scans, in turn, a line of the scene or object, and throws the light that passes through it on to the photo-electric cell. The lens disk acts, in all essential respects, like an ordinary perforated scanning disk, but it provides a much more intense illumination than one in which holes alone are used, and in

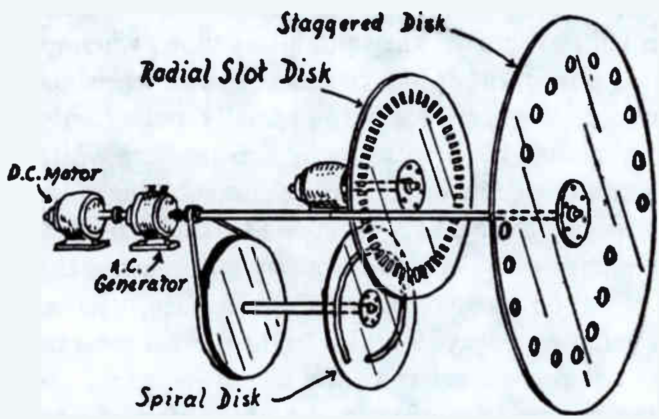
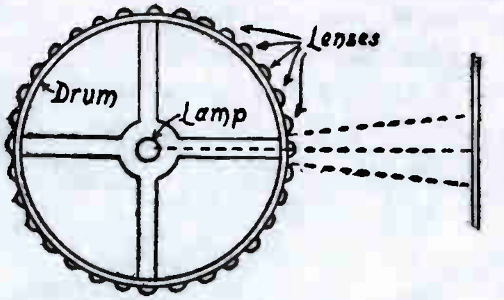


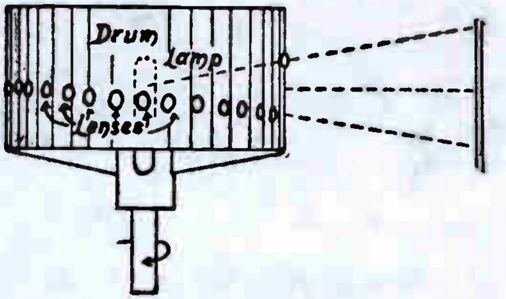
Fig. 42. A Staggered Disk Scanner with Radial Slotted Disk and Spiral Disk.

this respect the result is comparable to the amount of light admitted by a pinhole camera and that admitted by one that has a lens in it.

In the Baird system a second disk, that has 64 radial openings in it, is mounted directly back of the lens disk. The second disk revolves in the opposite direction to that of the original one. The radial openings in this disk act as a chopper; that is, this action cuts up the continuous rays of light which pass through the lenses, and so makes sharp impulses of them. The object of this is to obtain a greater degree of amplification when the interrupted currents from the photo-electric cell reaches the amplifying tube. Finally, back of the radial disk is a third disk that has a spiral slot in



A. Top View of the Drum



B. Side View of the Drum

FIG. 43—The Drum Scanner with Lenses.

it. Its purpose is to produce a *finer grain* of the scene or object than can be had with the scanning disk alone. The arrangement is shown in Fig. 42.

The Scanning Drum.—Three different kinds of drums have been devised to take the place of the disk for scanning. (1)

The first of these was made with a progressive series of holes in spiral formation, and this was mounted on a vertical shaft with the light inside of it, as shown in Fig. 43. (2) The same scheme was used later with a lens in each hole.

(3) Alexanderson, of the *General Electric Company*, considered that a large screen could not be illuminated intensely enough with a single spot of light in the small fraction of a

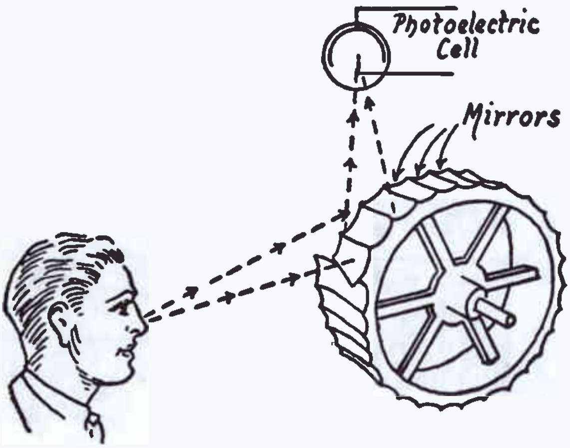


FIG. 44—The Mirror Scanning Wheel.

second that television work requires, and to overcome this objection he devised a scanner that used seven beams of light instead of the single one employed with an ordinary scanning disk. To do this he devised a reflecting scanner, which consisted of a drum on the circumference of which he mounted a series of plane mirrors placed at slightly varying angles so that the rays of light that were reflected by the subject would be projected through a lens on to a photoelectric cell, as shown in Fig. 44.

The Scanning Belt.—After you have experimented with the scanning disk, you can try out the *belt scanner*. This consists of a strip of thin flexible metal with holes drilled diagonally in it from one end to the other, as shown at *A* in Fig. 45. By brazing or riveting the ends together, it is made

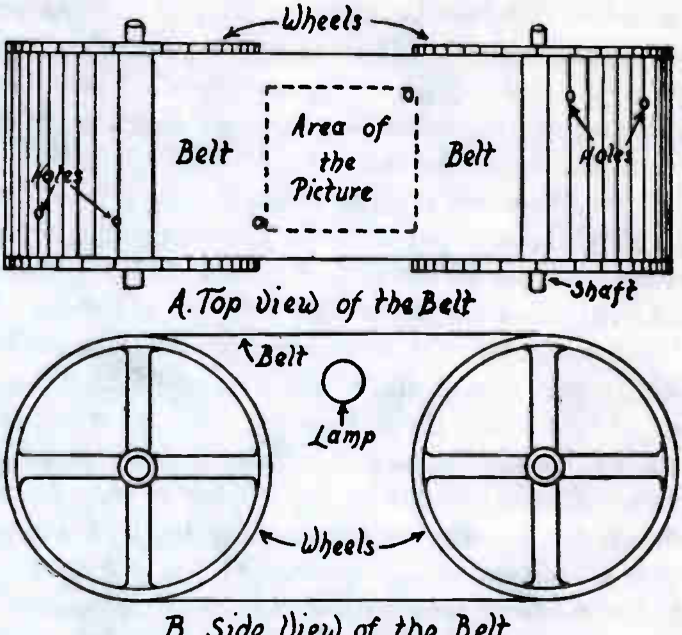


FIG. 45—The Scanning Belt.

into a belt. This operates on a pair of pulleys, one of which is, of course, driven by a motor. The source of light is placed between the bands, as pictured at *B*, and the size of the picture depends on the distance lengthwise between any two successive holes, and crosswise between the first and the last holes, as shown at *A*.

The Prismatic Scanning Disk.—With the idea of better controlling the rays of light that are reflected from the subject, the *prismatic disk* was devised. This consisted of a thick glass disk, the edge of which was so cut that it formed a circular prism, just as though an ordinary glass prism had been heated and then bent into a ring. In the disk prism, however, the angle of the bevel becomes smaller and smaller until, at the half-way point, the two opposite sides of it are parallel; as the ring follows on, the angle slopes in the opposite direction to that of the first half.

The way in which a prism bends the rays of a beam of light is well known, but if special information concerning it is desired, it may be found in my book *The Boy Scientist*, published by *Lothrop, Lee and Shepard Co.*, of Boston, Mass.

In experimental television work, two of these prismatic disks are used at each end of the line, one that moves the beam of light across the picture and the other which moves it up and down. The subject is scanned at the point where the two edges of the prisms are moving at right angles to each other. The disk used for moving the light across the picture is revolved at high speed, while the one moving the light up and down runs at a comparatively low speed.

Other Scanning Schemes.—Numerous other scanning schemes have been devised, and, if one is sufficiently interested in the way they are made and work, it is an easy matter to look up the patents which have been issued for inventions relating to television. Go to the public library of any large city, and get the *Index of the Patent Office*, which gives the number and date of the patents and the patentees' names. The *Index* is published every year by the United States Patent Office and it gives an alphabetical list of the patentees and of the inventors to whom patents were granted for that year.

Having found the patents you want to know about, then

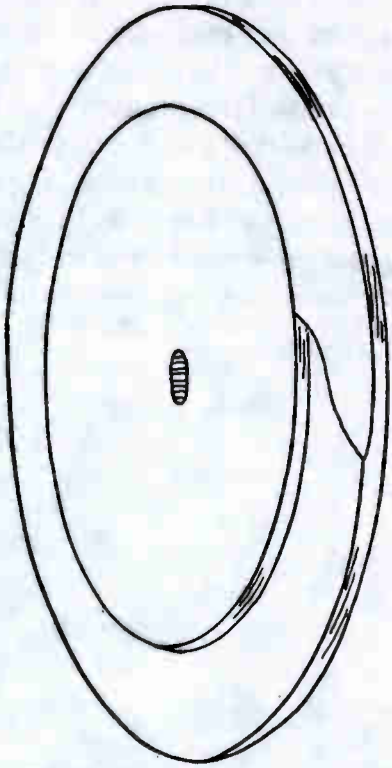


FIG. 46—The Prism Scanning Disk.

get the *Official Gazette* of the Patent Office for the same year, and by looking up the number or patentee or the inventor, or all of them, you can find an excerpt of the patent, with the drawings and principal claims. The *Official Gazette* is published every week, and by looking over these reports as they are issued, you can keep posted on all of the new inventions for television that are patented.

Should you require more information about a patent than is given in the *Gazette*, you can look up a copy of the patent, or *full specification*, as it is called. These are generally bound in volumes of one hundred patents each, or at least this is the practice of the New York Public Library. In every library that has a *patent section*, that is, a room devoted to patents, the librarian in charge will either find for you the patents you want, or he will show you how to use the *Index*, *Official Gazette*, and the volume which contains the full specifications.

CHAPTER IV

EXPERIMENTS WITH THE PHOTO-ELECTRIC CELL

Photo-electric[1] *effect* means (1) any change in a charge or a current of electricity that is produced by the action of light, and (2) the production of electricity by means of light, or the other way about. The *photo-electric cell* is a device that is used, either (1) to vary the strength of a current of electricity that flows through it by varying the intensity of the light that falls upon it, or (2) to set up a current of electricity in which the strength varies in proportion to the intensity of the light that falls upon it.

The Invention of the Photo-Electric Cell.—Television had its very beginnings in 1817, when J. J. Berzelius, a Swedish chemist, discovered a new borderland[2] element which he named *selenium*,[3] and this he separated from the deposits found in sulphuric acid chambers which are a commercial source of supply. Selenium has a very high electrical resistance, and the fact that it is a better conductor when a beam of light falls upon it was learned a little more than half a century after its discovery.

[1] The word *photo-electric* was compounded from the Greek word *photos*, which means *light*, and the Latin word *electrum*, which means *amber*. The first electrical action recognized by man was produced by rubbing amber.

[2] So called because in one of its forms it appears to be a non-metal, and in another form it is a metal.

[3] Berzelius named it from the Greek word *selene*, which means the *moon*, because of its resemblance to another element called *tellurium* (from *tellus* the Greek word for *the earth*). It is found in small amounts in sulphur and combined with it in such native sulphides as the mineral *clausthalite* and in a few other *selenides*.

In 1873, Willoughby Smith was in charge of the Atlantic Cable Station at Valentia, Ireland, and he had installed some small resistance rods made of selenium. His assistant, Mr. May, observed that the instruments were not functioning properly and called his chief's attention to their erratic behavior. Upon investigation, Mr. Smith found that when a light fell on the selenium rods it greatly reduced their resistance, and that when it was removed, the normally high

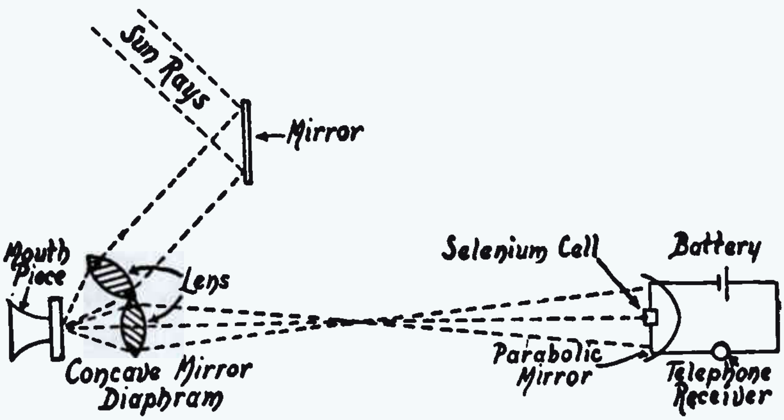


FIG. 47—The Bell Radiophone.
(For Telephoning on a Beam of Light.)

resistance was again restored. The announcement of this curious property led to the construction of the *selenium cell*, and this to the invention of various devices for utilizing it, and among these were the early television transmitters.

The first practical application of the selenium cell was made by Alexander Graham Bell, who used it as one of the elements of his *photo-phone*, an apparatus for telephoning by means of a beam of light, as shown in Fig. 47. The selenium cell of Bell was improved upon by various other workers, including Shelford Bidwell, Minchin, and Giltay, who made it more sensitive and more constant, and reduced the time of its response[1] or *time lag* as it is called. As a selenium-cell of even the latest improved type is far too sluggish for television transmission, let us look into the photo-electric cell, which has no time lag, and so is of service for this purpose.

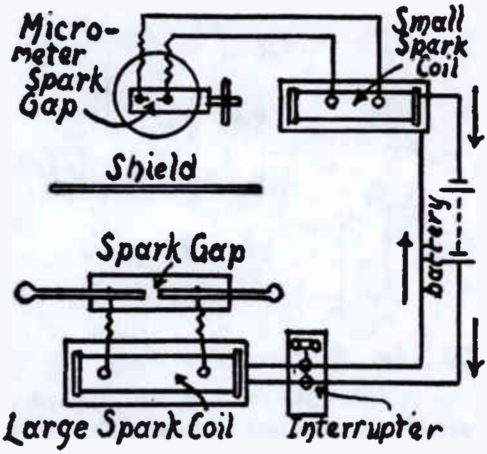


FIG. 48—Hertz's Classic Photo-Electric Experiment.

The photo-electric cell which is now used for television work had its beginnings in 1887. Heinrich Hertz, of Karlsruhe, Germany, who made wireless telegraphy and telephony possible by his discovery of electric waves, observed that when the violet light from the spark of a small induction coil fell upon the spark gap of another and larger induction coil, the sparks set up by the latter became more energetic.

By *response* is meant the time it takes for it to recover its normally high resistance after the light has struck it and reduced its resistance.

A diagram of the apparatus which Hertz used for this experiment is shown in Fig. 48.

Following this research came that of Hollwachs of Germany who, in 1888, let the light of an arc lamp pass through an opening in a zinc plate to where it fell on a second polished zinc plate connected to the leaves of an electroscope, as pictured in Fig. 49. When the leaves were charged with positive electricity, the light had no effect upon them, and they re-

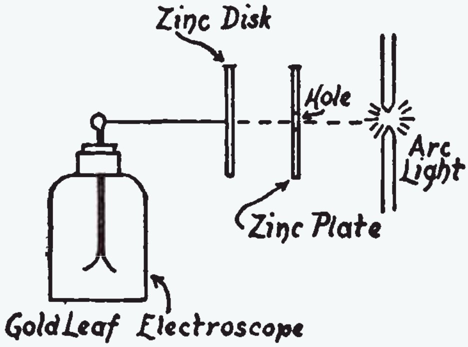


FIG. 49—Hollwachs' Photo-Electric Apparatus.
(It was his experiments that led to the development of the photo-emissive cell.)

mained spread apart, and, oppositely disposed, when the leaves were negatively charged, and the light was allowed to fall on the zinc plate, the leaves collapsed.

In the following year, 1889, Elster and Geitel, of Germany, showed that the alkaline *metals*, namely, potassium, sodium, rubidium, caesium and calcium, possessed photo-electric properties, and the photo-electric cells they made were the forerunners of those which are in use today for television. Their first cell was a glass tube with an *anode* [1] made of a loop

[1] The *anode* is the positive electrode.

of tungsten wire. The *cathode* [1] was formed by coating the inside of the tube with a thin film of silver and then heating a little part of it to drive off the metal. A clear space, thus formed, about the size of a quarter, permitted the rays of

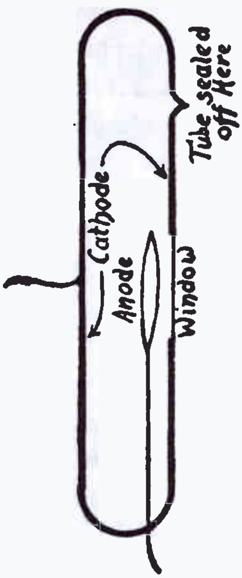


FIG. 50—Elster and Geitle's Photo-Electric Cell.
(*This was the first photo-emissive cell.*)

light to pass inside to the sensitive surface. The film of silver was coated with a very thin layer of a sodium or a potassium amalgam.[2] Finally the air was pumped out of the tube and the latter sealed, making the cell ready for use. See Fig. 50.

Later on the physicists found that the hydride crystals of sodium and potassium [3] were much more sensitive to light

[1] The *cathode* is the negative electrode.
[2] An *amalgam* is a metal of some kind dissolved in mercury.
[3] These are hydrogen compounds of sodium and potassium.

than were the amalgams made of the pure metals. The next step in the development of the photo-electric cell was made by these physicists in 1912, and it proved to be a far reaching one. This was a process by which they were able to *sensitize* the cathode element, and the method consisted of filling the tube with hydrogen and then passing a high potential current from a spark coil through it. This action converted the surface of the cathode into a *colloid*[1] of the alkaline metal, and, when this was done, the sensitivity of the cell was increased at least one hundred times, as against that of a cell in which the cathode was made with an amalgam of the pure metal. This process, called *hydrogenation*, is used by several of the makers of photo-electric cells at the present time.

How Photo-Electric Cells Are Made.—*The Selenium Cell.*—The latest and most sensitive form of selenium cell consists of a slab of *stearite*, an insulating material that does not absorb moisture, with a pair of solid gold wires[2] wound on it so that they are parallel with but separated from each other by about one 1/100 of an inch, as shown at *A* in Fig. 51. A layer of crystalline selenium is deposited on these wires, and the cell is then mounted in an airtight and waterproof hard rubber case as pictured at *B*, or else in a glass tube as at *C*, when the air is pumped out of it.

Because of the fine spacing of the wires, the cell is very sensitive to light and the time lag is cut down considerably. A selenium cell of the Bidwell type is available at as low a price as $10.00, or one that is sealed in an evacuated tube for $13.75 and a still more sensitive one for $27.50.

[1] A *metallic colloid* is one in which particles of the metal are in a very fine state of suspension.
[2] Silver or copper wires will serve the purpose.

The Current-Operated Photo-Electric Cell.—The term *current-operated cell* is used to designate a photo-electric cell that requires a battery to generate a current which flows

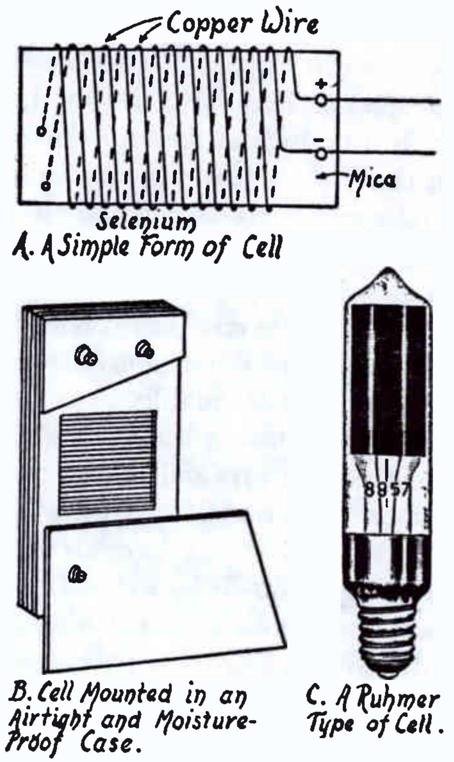


FIG. 51—The Selenium Cell.
(*This is a photo-conductive Cell.*)

through it. There are two types of this cell: namely, (1) the vacuum-tube cell and (2) the gas-filled cell. The vacuum-tube cell is not nearly so sensitive as the gas-filled cell and is not, therefore, used for television transmitters; but chiefly for photometric measurements. The sensitivity of the gas-filled cell reduces its reliability, while the lack of it in the vacuum cell makes it a precision cell, and one which always gives a current exactly proportional to the intensity of the light that falls upon it.

The Current-Operated Vacuum Cell.—In this type of cell a film of silver is deposited on the inside of the glass tube; this coating makes the surface a conductor and a wire is sealed in the tube which makes contact with the coating. A thin layer of potassium, or some other one of the alkaline metals, is then deposited on the silvered surface, and this is accomplished by vaporizing and then condensing the metal. This film of silver and potassium forms the cathode, while a ring of metal in the center of the tube forms the anode The air is pumped out of the tube with a *mercury air pump*, which was invented by Gaede in 1915 and improved upon by Langmuir of the Western Electric Co When a high vacuum is reached, the tube is sealed off and the cell is ready to use.

The Current-Operated Gas-Filled Cell.—In this type of cell the concave part of the tube is coated with a film of silver, and on this is deposited a layer of *sensitized potassium*. The layer of potassium is made still more sensitive by the Elster and Geitel method of hydrogenation. As in the vacuum tube, the silver-potassium surface forms the cathode, and a metal ring in the center of the tube forms the anode The air is pumped out of the tube and replaced by one of the inert gases, generally neon or argon, but occasionally helium is employed. The tube is then sealed and is ready for use.

Some photo-emissive cells are constructed by coating a curved metal plate with silver and a deposit of one of the alkaline metals, then sealing it in the tube, which has been highly evacuated with an air pump and fitted with a standard type of base such as is used for radio tubes, as shown in Fig. 52.

The Current-Generating Cell.—This is a combined photo-

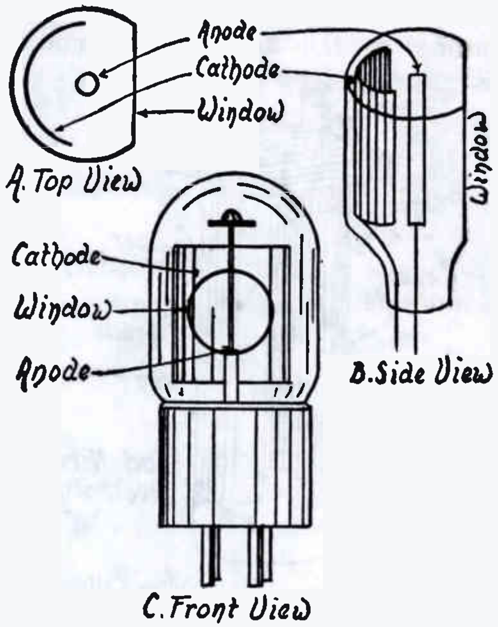


FIG. 52—The Photo-Emissive Cell.

electric cell and voltaic cell, that is, a cell which is sensitive to light and at the same time generates an electric current. For this reason it is called a *photo-voltaic* cell, and in its simplest form it consists of a plate of copper that is coated with a film of cuprous oxide (Cu_2O) and bent into a semi-cylindrical shape to form the cathode; the anode is formed of a thick strip of lead placed inside of the cathode, and together these plates are set in a jar containing a dilute solution of lead nitrate, as shown in Fig. 53. This type of cell is very sensitive to light, but is more sluggish in its response than the selenium cell and cannot be used for television purposes.

How Photo-Electric Cells Work.—*Action of the Selenium Cell.*—According to the modern electronic theory, the

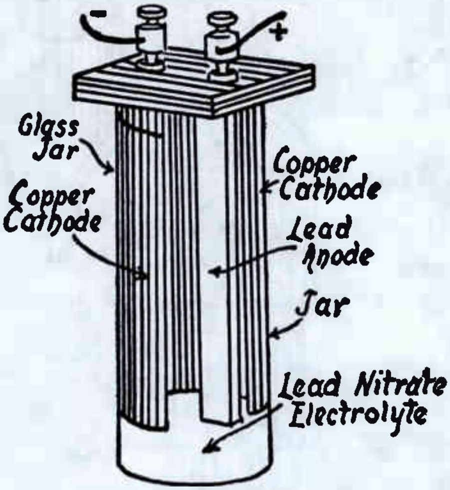


FIG. 53—The Photo-Voltaic Cell.

action of selenium when a light falls on it is a *photo-conductive* one, that is, it sets some of the electrons of its atoms free, and these furnish a conducting path for the current which is flowing through it. The more intense the light, the more rapid becomes the detachment of the electrons and the greater the flow of the current. The lag, or length of time it takes for the selenium to recover after the light has been cut off from it, is supposed to be due to the free electrons combining with the positive ions[1] to produce neutral atoms again, that is, atoms which are neither positive nor negative. To conform to the electronic theory, the resistance of the selenium cell should vary as the square root of the intensity of the light that falls on it, and this is exactly what it does do.

The Action of the Vacuum Cell.—Likewise, in accordance

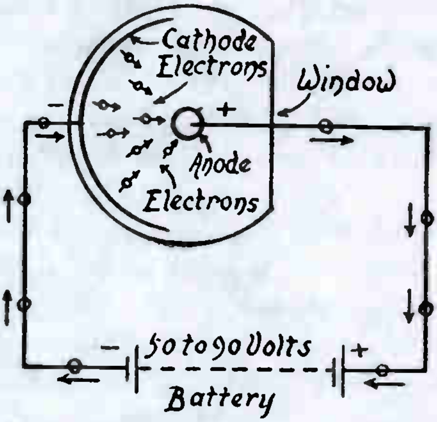


FIG. 54—How a Photo-Emissive Cell Works.

with the electronic theory, the action of potassium, or other alkaline metal, when a light falls on it, is a *photo-emissive* one. Thus, when a light falls on the layer of the alkaline metal that forms the cathode of a vacuum cell, it sets free the electrons of the atoms of which it is made, as pictured in Fig. 54. These electrons do not recombine with the positive ions again to form neutral atoms,[2] but, instead, the electrons are thrown off, and these travel over to the metal anode with

[1] What is called a *positive ion* is an atom that has lost one or more of its electrons.

[2] Atoms which have all of their *protons* (positive electric charges) and *electrons* (negative electric changes) are neither positive nor negative and are regarded as neutral.

the speed of light, and therefore there is no appreciable time lag; in fact the response is practically instantaneous.

This property of the vacuum cell makes it extremely well suited for television work as compared to the selenium cell, but where it is woefully deficient, as against the latter, is that the current which flows through it is limited to a few micro-amperes only; in fact it is so small that it is hard to amplify it to an extent necessary for television work.

The Action of the Gas-Filled Cell.—As in the vacuum cell, the action of a gas filled cell is a *photo-emissive* one; but there is so great a difference in the behavior of the two types that more must be said about it. In the first place, the gas-filled cell is much more sensitive than the vacuum cell and the current that flows through it is considerably larger. This being true, a light of given intensity will vary the strength of a current several hundred times as large as that which can be varied with a cell of the vacuum type.

This great increase in sensitivity and current-carrying power is due to what is called *gas amplification.* To make its action clear, you must consider that at ordinary temperatures and at ordinary atmospheric pressure no kind of a gas will conduct an electric current. A gas, to be conductive, must be *ionized*, that is to say, in the case of a photo-electric cell, electrons must be broken off from the atoms of which the cathode is formed. This is done by the light that falls on the layer of potassium or other alkaline metal of which it is made.

The electrons that are thrown off by the cathode are called *primary electrons*, and, as these travel out from it toward the anode, they collide with the atoms of the gas in the tube and break off electrons from them; these latter are called *secondary electrons*, and, as these travel toward the anode, they break off electrons from more atoms and so on, in geometrical progression, with the result that the conducting path between the anode and the cathode for the battery current is increased many fold. This is the reason you must use a gas-filled cell when you undertake to build a practical television transmitter.

As a final word, let me say that the voltage of the current passed through the cell must be accurately adjusted to the density of the gas in it, or its operation will be unstable and, therefore, very unsatisfactory. So that you will know just what the right voltage is for a given photo-electric cell, the maker specifies the characteristics of each one.

Some Modern Photo-Electric Cells.—*The Makers of Them.*—There are quite a number of photo-electric cells on the market, and chief among them are (1) the Ruggles Electric Eye, as it is called, made by the General Electric Co. of Schenectady, N. Y.; (2) the Zworykin cell, made for the Radio Corporation of America, Camden, N. J.; (3) the Burt cell, made by Dr. R. C. Burt of Pasadena, Cal.; (4) the Kunz Visitron cell, made by the G-M Scientific Co. of Urbana, Ill.; (5) the Alexander "K-H" cell, made by the Argco Laboratories, Inc., and sold by the Radio Electric Works, 150 West 22nd Street, New York City; (6) the Wein Phototron cell, made by Samuel Wein, 1985 Davidson Ave., New York City; (7) the Case Barium cell, made by Case Research Laboratory, Auburn, N. Y.; (8) the Ives-Olpin cell, made for the Bell Research Laboratories, 463 West Street, New York City; (9) the Raytheon Foto-cell, made by the Raytheon Mfg Co., 30 East 42nd Street, New York City; (10) the Koller-Thompson Caesium Oxide-Silver cell, made by the General Electric Co., Schenectady, N. Y., and (11) the Cambridge cell, made by the Cambridge Instrument Co. of London, England, and with offices at 3512 Grand Central Terminal Building, New York City.

How Photo-Electric Cells Are Made.—*The Ruggles Electric Eye.*—This cell, which the makers call an *Electric Eye*, was designed by W. A. Ruggles. It is made of *pyrex glass*, has a diameter of about 2½ inches and a length of 5½ inches over all. The *window*, or clear part of the bulb, where the light enters, is about 1¾ inches in diameter. The tube is fitted with an Edison screw base, and screws into a standard Edison socket.

The anode is made of a nickel disk, ⅛ of an inch in diameter, fixed in the center of the bulb; the cathode is formed of a layer of potassium hydride, deposited on the inside surface of the bulb, which is filled with neon gas and requires a current of 250 volts to energize it. This cell is made for general use and sells for $25.00.

The Zworykin Caesium-Magnesium Cell.—This is a combined photo-cell and amplifier. It was designed by V. K. Zworykin in an attempt to eliminate the noises that are set up by the flow of electrons through the wires that connect the cell and amplifier tube when they form separate units. The upper portion of the glass bulb contains the photo-electric electrodes, while the lower part, which is separated from it by a light-tight diaphragm, contains the amplifier electrodes.

The anode of the photo-electric portion is formed of a wire ring, and the cathode is made by depositing a layer of magnesium on the inside surface of the bulb; finally, an invisibly thin film of caesium is deposited on the layer of magnesium, and this is sensitized by hydrogenation. The hydrogen is then pumped out and a high vacuum is formed. The sensitivity of this cell is about ten times that of an ordinary vacuum cell.

The Burt Sodium Cell.—This cell is made by Dr. Robert C. Burt, of Pasadena, Cal. The bulb is made of soda glass, and

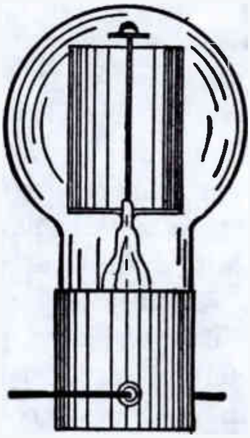


FIG. 55—The G-M Visitron Photocell.
(79*A Type.*)

the base, which is of *bakelite*, has the standard type of radio-tube prongs. It has a diameter of 3¾ inches and an over-all height of 6 inches. The anode is made of nickel and tungsten, while the cathode is formed of pure sodium, which is deposited on the inside of the glass bulb *through* the wall of it by immersing the latter in a bath of melted sodium nitrate and then connecting this and the bulb with a 220-volt source of current. The tube is of the vacuum type and is very stable in its action but, unfortunately, it is not as sensitive as the gas-filled tube. It sells for $25.00.

The G-M Visitron Cell.—J. Kunz, of Urbana, Ill., is the designer of this cell. It is made of pyrex glass and has a window one inch in diameter. It has a bakelite base with standard type of prongs. The anode is made of a hexagonal bar of nickel 3/8 of an inch thick by one inch long; the cathode is formed by a silver deposit on a metal plate with a film of potassium hydride crystallized on it. The bulb is evacuated and filled with argon to a pressure that will make it the most sensitive. This cell, shown in Fig. 55, sells for $18.00.

The Alexander "K-H" Tube.—This cell, designed by M. Alexander, has a bulb 2 inches in diameter and an over-all length of 5 inches; it is made of *Uriol* glass, which has the properties of quartz to a remarkable degree. The lead-in wires are connected with a pin base adapted to a standard Edison screw plug. The anode is a ring of nickel 3/8 of an inch in diameter. This is placed edgewise toward the window so that it will not cast a shadow on the cathode. The bulb is filled with neon gas and operates on potentials of between 180 and 250 volts. It is pictured in Fig. 56, and the list price is $15.00.

The Case Barium-Silver Cell.—In this cell, which was designed by T. W. Case of Auburn, N. Y., the bulb is made of pyrex glass and has a diameter of 2½ inches and an over-all length of 5½ inches. It has a window one by one inches on the sides, and is fitted with a metal base. The anode consists of a metal ring, and the cathode is formed by depositing barium oxide on the inside of the tube. This is accomplished by filling it with hydrogen and passing a high voltage electric current through it, causing the molecules of gas to bombard those of the barium oxide and drive them on to the surface of the glass. The bulb is then exhausted to a high degree and filled with neon gas. This cell can be used for general photo-electric purposes, but it is particularly adapted for measuring the variations of light. It sells for $25.00.

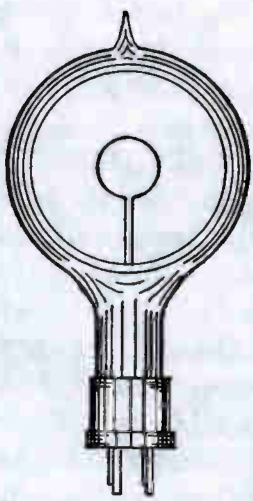


FIG. 56—The K-H Photocell.
(*Type G S*-1.)

The Wein Phototron Cell.—A. H. Pfund showed, in 1916, that cuprous oxide (Cu_2O) had photo-electric properties, and on this observation Samuel Wein built up a photo-voltaic cell, that is to say, one which is sensitive to light and at the same time generates an electric current.

The cell consists of a glass tube with a bakelite base cemented to it. The anode is formed of a strip of lead, and the cathode, which is bent to the shape of a cylinder with an arcuated piece cut out of it, is made of a sheet of copper coated with a film of cuprous oxide. The anode and the cathode are connected to a pair of binding posts that are screwed to a bakelite top, and the two electrodes are then immersed in the tube, which contains a solution of lead nitrate. This photocell, which is shown in Fig. 53, is inexpensive to make, has a large output of current, and is very uniform in its characteristics, and in these respects it is superior to other types of photo-sensitive cells. It has been used with success in making talking moving pictures, but is not sufficiently sensitive for television purposes. It sells for $15.00.

The Rayfoto-Voltaic Cell.—This cell, like the Wein Cell, is of the electrolytic type. Like the latter it is formed of a sheet of copper bent into a semi-cylinder, and this is coated with a layer of cuprous oxide. The anode is a strip of sheet lead, which, along with the cathode, is immersed in a dilute solution of lead nitrate. The cell is listed at $12.00.

The Koller-Thompson Caesium Oxide Silver Cell.—This cell, which was developed by L. R. Koller and H. E. Thompson, is the most sensitive cell that has yet been produced. In this cell the cathode is formed by silvering the bulb and then depositing a film of caesium chloride and calcium on it; this is done by heating a small quantity of these materials until they are vaporized, and condense on the silver as they cool.

After this operation the cell is baked in an electric furnace, thus causing the metals and the oxygen in the tube to react with each other and form a monatomic film, that is, one in which the atoms of the metals are separate and distinct from each other instead of being combined and forming molecules. The price of this cell is $25.00.

The Cambridge Cell.—This cell was developed by a staff of experts of the Clarendon Laboratory of Cambridge, England. The diameter of the bulb is 1 5/8 inches and the over-all length of it is 2¾ inches. It has a window one inch in diameter, and a metal cap forms the base. The anode is ring shaped, while the cathode is formed of a film of silver deposited on the inside of the bulb; this film is coated with a thin layer of

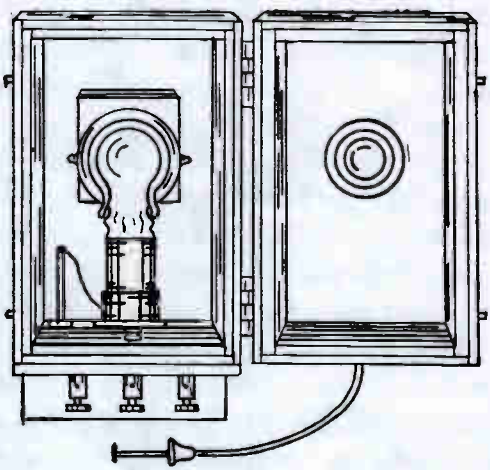


FIG. 57—The Cambridge Photocell.
(*Mounted in a Light-tight Cell*)

potassium hydride. The bulb is evacuated and then filled with helium gas at a suitable pressure. The cell, which is shown in Fig. 57, sells for $50.00.

How to Make Experimental Cells.—The photo-electric cells which I shall tell you how to make are not intended for practical work, but for simple experimental purposes. If you are building a television transmitter or other apparatus for actual service, you should buy a good cell, for it is as hard to make a high-grade one as it is to make a sensitive photographic plate, and unless you have the technical skill and proper equipment, you may be certain of failure.

How to Make a Selenium Cell.—The first thing to do is to get a fairly thick sheet of mica and cut out a piece 1 inch wide and 2 inches long, and cut a series of fine notches in the edges of it, as shown at *A* in Fig. 58. This done, take two 4-foot lengths of No. 30 copper wire and wind them on the mica plate parallel with each other. The notches will hold them so that they will be very close together and yet not touch each other.

The next step is to heat the *base*, as the mica with the wire wound on it is called, and this you can do by laying it on a piece of sheet-iron and holding the latter with a pair of pliers over the flame of an alcohol lamp or a bunsen burner, as shown at *B*. Now lay some *vitreous selenium* [1] on the base, let it melt, and then spread it over the surface of the wire; next let it cool and then repeat the process. The black, lustrous selenium will quickly change into a dull and, finally, a gray looking substance. In performing these operations you must be careful to exclude humidity, and keep it away from the direct action of the flame.

Vitreous selenium is not a conductor of electricity, but when it is heated it is converted into metallic selenium, and it then becomes a poor conductor. The completed cell is shown at *C*. To use the selenium cell, you need only to connect it in series with a battery and a telephone receiver or a galvanometer and then let a bright light fall on it. It is a

[1] You can get this from Eimer and Amend, 18th Street and Third Ave., New York City.

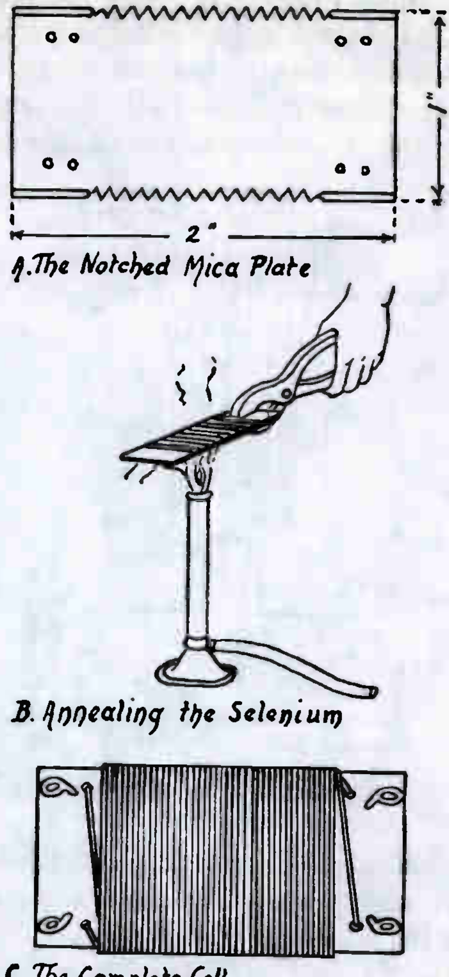


FIG. 58—How to Make a Selenium Cell.

good scheme to mount the cell in a little wooden case with a glass window in it, as pictured at *B* in Fig. 51, and then seal up all of the cracks so that it will be air tight.[1]

How to Make a Photo-Emissive Cell.—In 1921, T. W. Case found that the oxide filament of a high-vacuum amplifier tube

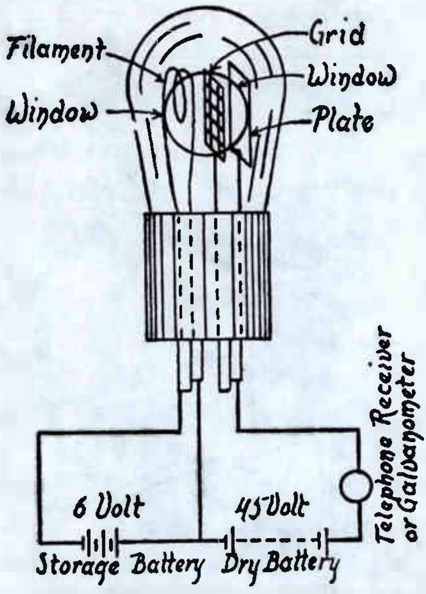


FIG. 59—How to Make a Photo-Emissive Cell.

produced a small photo-electric effect, both when cold and when hot. A slightly greater action is obtained when the plate is made the cathode, or negative electrode.

The filament is the emissive electrode when it is used for amplifying radio currents. This is because the plate is

[1] A good kind of cement for this purpose is *De Kohtinsky's Cement*, obtainable from Eimer and Amend, 18th Street and Third Ave, New York City.

coated with a mixture of barium and strontium together with a trace of calcium, and these are all mildly photo-electric substances.

You can make a photo-electric cell of the emissive type by using an ordinary silvered amplifier tube, such as is used for radio work, and heating an area of the surface of the bulb that is next to the plate until the silvered film on the inside of it vaporizes and so leaves a clear space, or window, for the light to pass through as shown in Fig. 59. This done, connect the terminals of the filament with the carbon or positive terminal of the battery, and the plate and grid terminals with the zinc or negative terminal, and finally, connect a telephone receiver or a galvanometer in the circuit. Now, if a strong beam of light passes through the window and falls on the plate of the cell, you will hear a click in the telephone receiver or see the needle of the galvanometer swing around.

How to Make a Photo-Voltaic Cell.—To make a photo-voltaic cell, get a clear glass jar about 3 inches in diameter and 5 inches high, and make a tight-fitting cover of hard-wood, or of bakelite. Drill a 1/8 inch hole in the center of the cover and one 1¼ of an inch out from it, as shown in the top view of it at *A* in Fig. 60. This done, slip a machine screw through each hole and screw a binding-post on each one. Loop a piece of copper wire around each screw, between the washer and the cover, the purpose of which you will see presently.

To make the cathode, get a sheet of copper about 4 inches wide and 6½ inches long, and bend it to the shape of a semi-cylinder with its adjacent edges 1¾ inches apart, as shown at *B*, so that it will fit into the jar. Now hold the semi-cylinder in the flame of a Bunsen burner until all parts of it have been heated red hot[1], when two oxides will be formed on it, and these are (*a*) black cupric oxide (CuO) and (*b*) red cuprous oxide (Cu_2O).

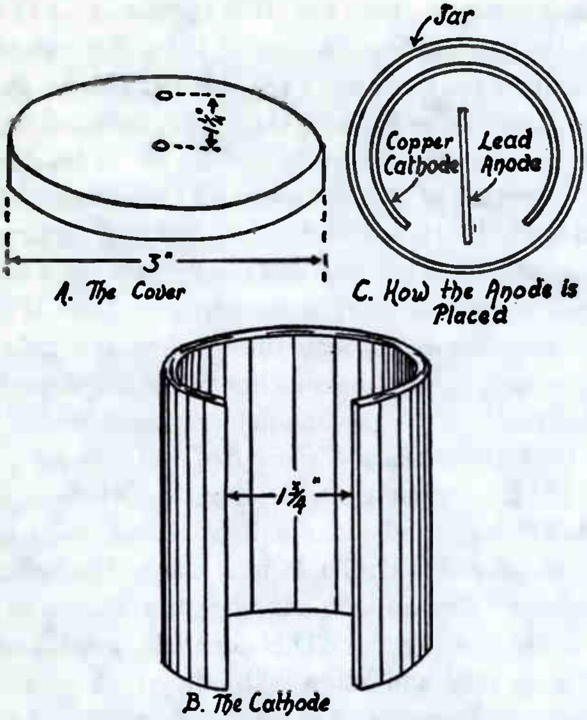


FIG. 60—How to Make a Photo-Voltaic Cell.

As the cuprous oxide is the one that is sensitive to light, you must get rid of the cupric oxide. This is done by immersing the plate in dilute hydrochloric acid (HCl), and after

[1] It is better to heat the copper plate after you have bent it to shape, because if you do so before bending it you are apt to destroy the film of cuprous oxide.

you have taken it out, wash it with running water. The next step is to solder, or otherwise secure, the wire from the outside binding-post of the cover to the middle of one end of the semi-cylinder.

Now get a strip of lead ⅛ of an inch thick, 1 inch wide, and 4 inches long, for the anode, and solder, or otherwise fix, the wire from the center binding-post of the cover to one end of it. Lastly, make enough of a one per cent solution of lead nitrate ($Pb(N_3O)_2$) and water to make the jar three-fourths full, then set the copper and lead elements in it, and the cell is ready to function. So that the light will reach as much of the inside surface of the cathode as possible, set the lead anode with its edge in a line with the open space of the copper cathode as pictured at *C*.

To test the cell, connect it in series with a telephone receiver, a galvanometer, or a sensitive ammeter.

Experiments with Photo-Electric Cells.—*Testing the Light Activity of a Cell.*—To test the photo, or light, activity of a *selenium cell*, connect one of the terminal wires of it to one post of a baby knife switch, the other post of this to the positive pole of a 45-volt dry cell battery,[1] the negative pole of this with one of the posts of a telephone receiver or a galvanometer, and the other post of this with the other terminal of the cell, as shown at *A* in Fig. 61.

(1) Now in a darkened room, throw a strong light on the cell, as pictured at *B*, and then pass your hand or a sheet of cardboard forth and back between the cell and the beam of light. The diaphragm of the receiver will click or the needle

[1] You can buy this, and other batteries used for the experiments described in this chapter, of any dealer in radio equipment.

of the galvanometer will swing, indicating that when the light strikes the cell the current flows through it, and when it is cut off the current practically ceases to flow.

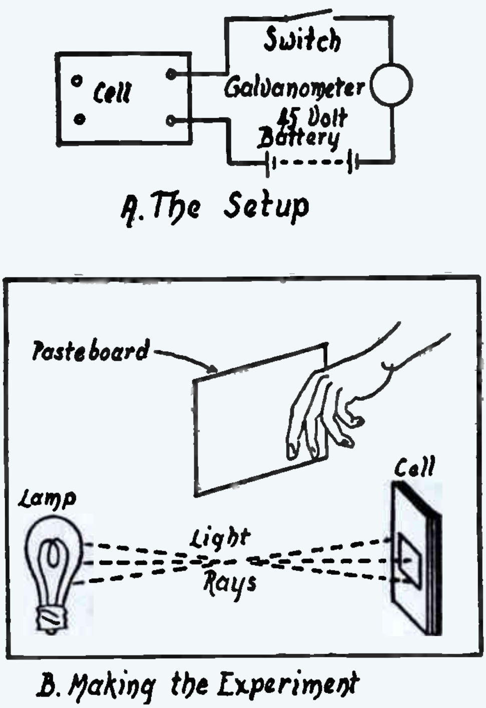


FIG. 61—Testing the Light Activity of a Selenium Cell.

(2) Now, instead of the galvanometer, connect a milliammeter in circuit with the selenium cell and the battery. Lay the cell on the table and cover it with a sheet of cardboard or other light-proof material, so that the light cannot strike its sensitive surface. Switch on the current and you will see by the deflection of the needle of the meter that a small current,

i.e., from 1 to 3 milliamperes,[1] is flowing, and this is called the *dark current*. Remove the cardboard or other shield from the cell and throw a strong light on it, when the needle will show that a current of from 5 to 10 milliamperes is flowing through the circuit and this is called the *light current*.

(3) To test the photo, or light, activity of a *photo-emissive cell*, connect the anode of it with one post of a telephone receiver, a galvanometer or a micro-ammeter,[2] the other post

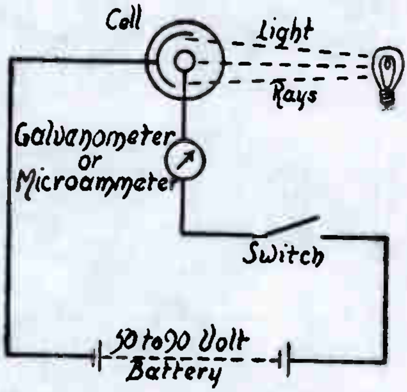


FIG. 62—Testing the Light Activity of a Photo-Emissive Cell.

of this with the positive pole of a 50- or 90-volt dry battery, and the negative pole of this with the cathode of the cell, as shown in Fig. 62. Now, make the same tests with it that you did with the selenium cell which I have just described.

(4) To test the photo, or light, activity of a *photo-voltaic cell*, connect the anode with one post of a milliammeter and the other post of this with the cathode of the cell, as shown in Fig. 63. Now, throw a strong light on the cell, when the

[1] A *milliampere* is the 1,000th part of an ampere.
[2] A *micro-ampere* is the 1,000,000th part of an ampere.

meter will show (*a*) that it develops a current of from three to ten milliamperes and (*b*) that any variation of the intensity of the light that falls on it is accompanied by a variation in the strength of the current output.

To Show that the Current Through the Cell Varies with the Light that Falls on it.—To show this characteristic of a selenium cell, a photo-emissive cell or a photo-voltaic cell, use the same set-up as in the preceding experiments. Place

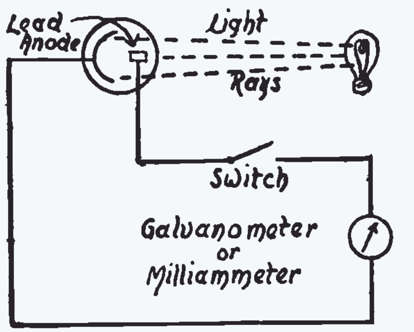


FIG. 63—Testing the Light Activity of a Photo-Voltaic Cell.

the cell near one end of the table in a dimly lighted room and (1) hold a light, which can be a flashlight if you are using a selenium cell or a photo-voltaic cell, or a 100 watt lamp if you are using a photo-emissive cell, 2 feet from it, and throw a beam of light on it.

Now read the meter and then bring the light to within one foot of the cell, where a higher reading will be obtained; bring the light closer in steps of 3 inches, and each time the meter will show a progressively higher current-strength. These results clearly indicate that as the light on the cell increases, the conductivity of it increases accordingly.

(2) A variation of the above experiment is to take the cell in one of your hands and the meter and battery in the other one and, with the circuit connected as before described, hold the cell six inches from a 100-watt electric light, or other source of strong artificial light, and take a reading of the meter. Then carry the set-up into the sunlight and let the rays of the sun fall directly on the cell. The needle of the meter will make a tremendous jump, thus clearly demonstrating the intensity of sunlight as compared to artificial light.

Connecting the Photocell with a Relay.—You can connect a selenium cell or a photo-voltaic cell directly with a sensitive 2,000 ohm relay, but in order to operate a relay by means of a photo-emissive cell, you must amplify the current with one or more amplifier tubes. In the next chapter I shall tell you how to do this and also explain a number of most interesting experiments with any of the above cells when they are used with a relay.

(1) To use a relay with a *selenium cell*, connect one post of the cell with one pole of the battery, the other pole of this with one of the terminals of the relay magnet, and the other terminal with the remaining post of the cell, as shown in Fig. 64. (2) Since the *photo-voltaic cell* generates its own current, and as this is large enough to operate a relay, you need only to connect the anode with one of the terminals of the magnet and the other end of this with the cathode.

Measuring the Current of a Photo-Emissive Cell.—Since the current of all types of photo-emissive cells is exceedingly small, *i.e.*, of the order of microamperes, a very sensitive instrument must be used to measure them. For this purpose you can use either an electrometer, a reflecting mirror gal-

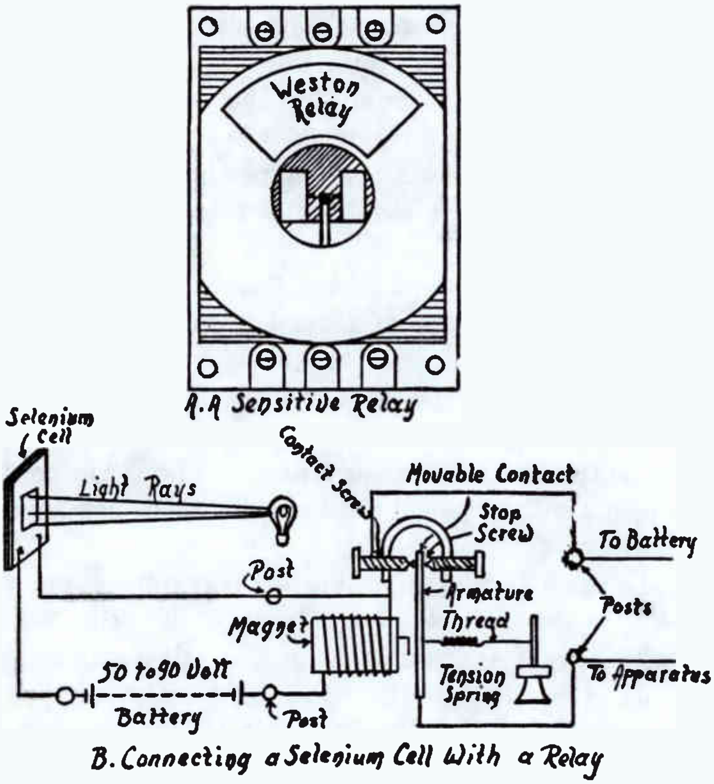


FIG. 64—A Relay and How It Is Used.

vanometer or a micro-ammeter. The latter will probably prove the most suitable for your purpose, as it is a direct reading instrument.

The set-up of the apparatus is shown in Fig. 65, and it consists of the cell, the anode of which is connected with the positive pole of a 50- to 90-volt dry battery; the negative pole of this is connected with one post of the meter, the other post of this is connected with one end of a 5,000 ohm resistance and, finally, the other end of this is connected with the cathode of the cell.

The amount of current indicated by the micro-ammeter varies inversely as the square of the distance between the

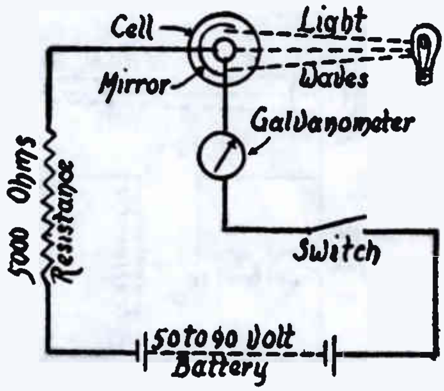
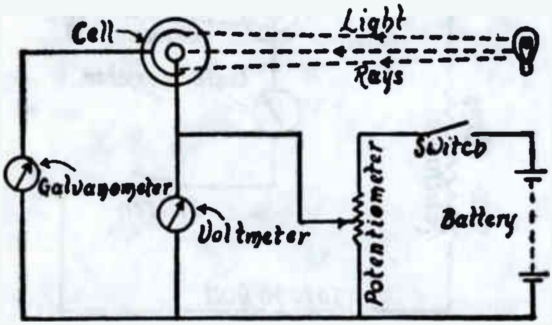


FIG. 65—Set-up for Measuring the Current of a Photo-Emissive Cell.

cell and the source of light. Therefore, the current increases or decreases directly with the amount of light that falls on it. This circuit constitutes a simple photometer and you can use it for the photometry of lamps, measurement of reflection, the light absorption and transmission power of materials, and for many other purposes.

To Determine the Volt-Ampere Characteristic of a Cell.—Just as there is a definite relation between the amount of light that falls on a photocell and the current which will flow through it, so also there is a definite relation between the voltage that you apply to the cell and its current output. This ratio of the cell, or *volt-ampere characteristic*, as it is termed, can be plotted by means of the set-up shown at *A* in Fig. 66.

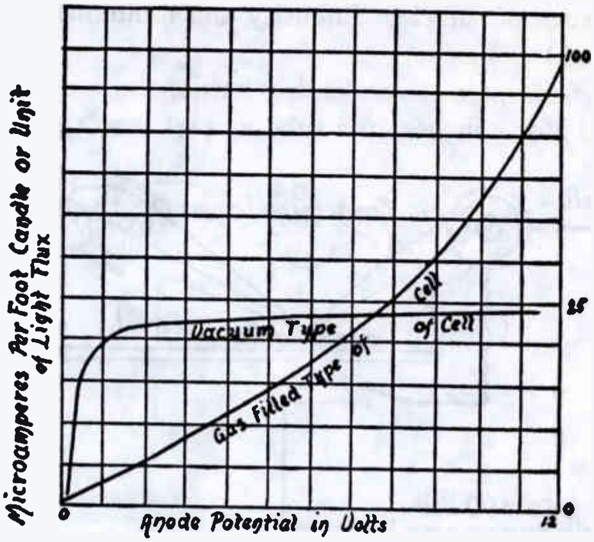
In plotting a curve of this characteristic, you can use a 100-volt lamp and set it at a distance of one foot away from the cell. For the set-up, connect the anode of the cell with the movable point of a potentiometer which is connected



A. FIG. 66—Set-up for Determining the Volt-Ampere Characteristics of a Photo-Emissive Cell.

across a battery. The cathode of the cell is connected to one of the posts of a galvanometer or a micro-ammeter and the other post of this to the negative pole of the battery. A voltmeter connected across the cell completes the apparatus.

The first step is to gradually increase the voltage from zero by means of the potentiometer and, at every ten volts of increase, mark the voltage and micro-ampere reading on your plotting paper. As you increase the voltage of a vacuum photocell the amperage does not rise very fast, as the curve at *B* clearly shows, but with a gas-filled photo cell, the current rises rapidly, as is also shown at *B*. In either type of cell the ratio differs according to the voltage that is applied to the anode and, as the curves show, there is a marked difference



B. FIG. 66—Curves Showing the Volt-Ampere Characteristics of Vacuum and Gas Filled Tubes.

between the volt-ampere characteristics of a vacuum cell and those of a gas-filled cell.

Measuring the Reflecting Power of Materials.—To measure the reflecting power of various materials, such as metals, paints, varnishes, etc., you can use the optical system shown in Fig. 67, in conjunction with the photometer circuit which I have just described. The optical system consists of a 32-candle power 6-volt lamp, one terminal of which is connected with one of the poles of a regular 6-volt A battery, the other pole of which is connected with one of the posts of a rheostat. The contact arm of the latter is connected with the other terminal of the filament and a voltmeter is connected across the lamp terminals. (For this experiment any convenient light source of sufficient intensity and limited area may be employed.)

Now fix a pair of condensing lenses, the focal length of which is 4 or 5 inches, in a tube, and set it so that the light

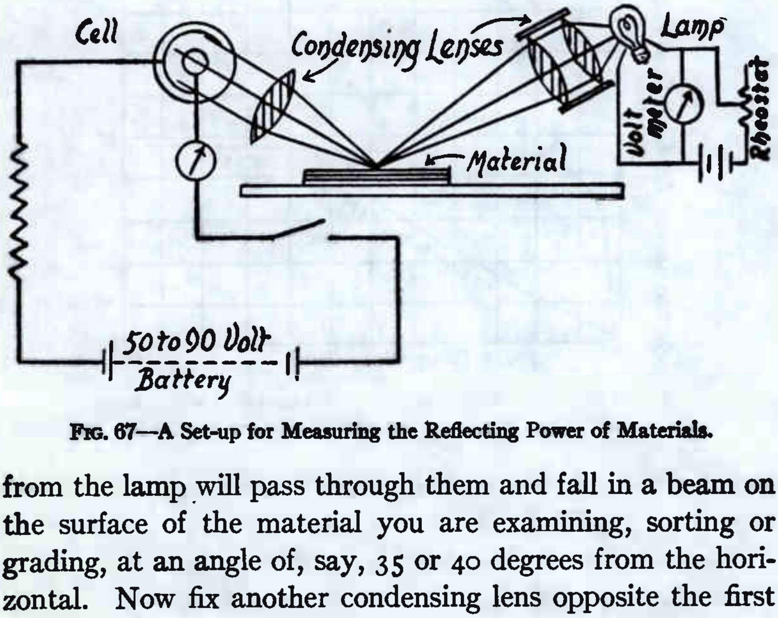


FIG. 67—A Set-up for Measuring the Reflecting Power of Materials.

from the lamp will pass through them and fall in a beam on the surface of the material you are examining, sorting or grading, at an angle of, say, 35 or 40 degrees from the horizontal. Now fix another condensing lens opposite the first pair and at the corresponding angle to the reflecting surface. Place a photocell back of it in such a position that the reflected rays will be projected through the window of the cell (see Fig. 67), and you are ready to go ahead with the tests.

(1) To make them, lay a piece of polished metal on the table where the incident rays are reflected from it, then note the reading of the galvanometer. Now test pieces of other polished metals in the same way, and you can easily determine the value of their respective powers of reflection. The same test will determine the reflecting power of surfaces of any kind. (2) An easily made test, and a very pretty one, is to use strips of different-colored papers. You will find that each color has a characteristic reflecting power of its own.

The Reflecting Power of a Television Object.—As I have previously mentioned, the intensity of the light rays reflected by one's face is only about 1-1000th as great as that of the source itself. You can easily demonstrate this by making the two following experiments.

(1) Place the set-up shown at *A*, in Fig. 68, on a table and fix a 100-watt lamp in an axial line with the window of the photocell and at a distance of two feet from it. Now read the galvanometer or micro-ammeter and make a note of it. (2) Having made the above experiment, have a subject sit opposite the set-up and so that his face will be in a line with the cell, as before, but at a distance of one foot from it.

Next fix a 100-watt lamp over the cell and project the light of it onto his face. Light that has not been absorbed by it (as most of it has been) will be reflected into the cell, as pictured at *B*. Now read the meter again, and a simple calculation will show that only about 1-1000th part of the direct light that is thrown off by the lamp in the first experiment is received by the cell when it is reflected by the subject's face.

Experiments With the Photo-Electric Cell and Scanning Disk.—There are two chief methods by which the source of

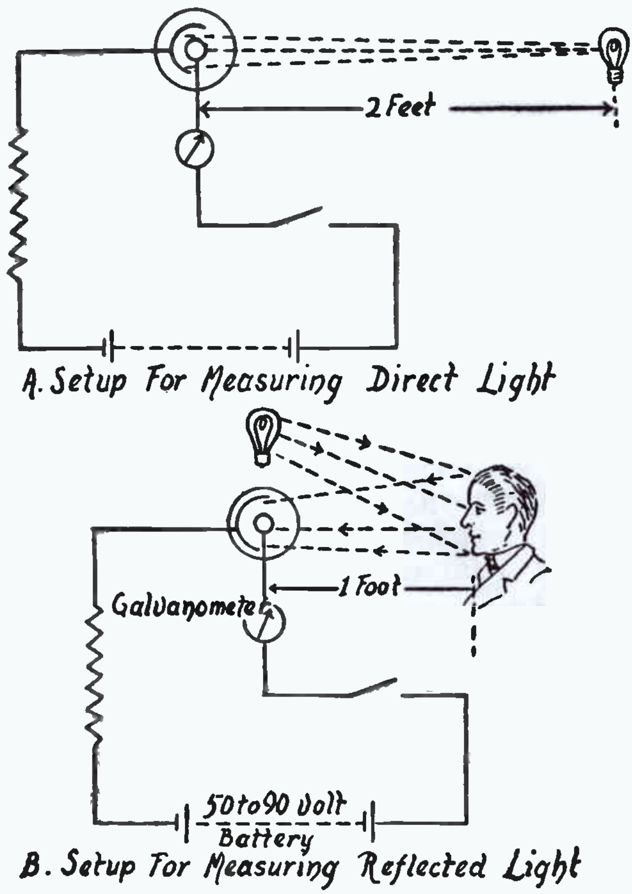


FIG. 68—Measuring the Intensity of Direct and Reflected Light.

light, the scanning disk and the photocell can be used in combination with each other. These are (1) the Nipkow, or reverted method, and (2) the Ekström, or inverted method. The word *reverted*, used in connection with the former method, means simply that it is the older and incorrect way, while the word *inverted*, used in connection with the latter method, means that its components are turned in the opposite, or right way.

The Nipkow Reverted Method.—To make an experimental set-up to demonstrate the Nipkow method, mount the source

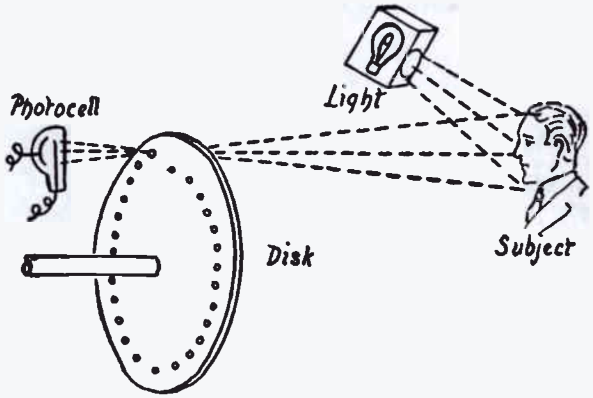


FIG. 69—The Nipkow Reverted Method of Scanning.

of light on the same side of the scanning disk as the subject to be scanned and mount the photocell on the other side of it so that it is in an axial line with the holes and the subject, as shown in Fig. 69. With this method, the light from the subject that is scanned is split up into a large number of stationary spots, so that the image cast upon the cell is divided into as many elements.

It is evident, that with this method (*a*) the faintness of the reflected light, and (*b*) the exceedingly short time the light lasts as it passes through each hole—a millionth of a second or less—with the most sensitive cell television is all but an impossibility.

The Ekström Inverted Method.—To make an experimental set-up for demonstrating the Ekström method, place the source of light on one side of the scanning disk, and the subject to be scanned and the photocell on the other side of it, as pictured in Fig. 70. The result of this arrangement is that the object is scanned, not by a large number of station-

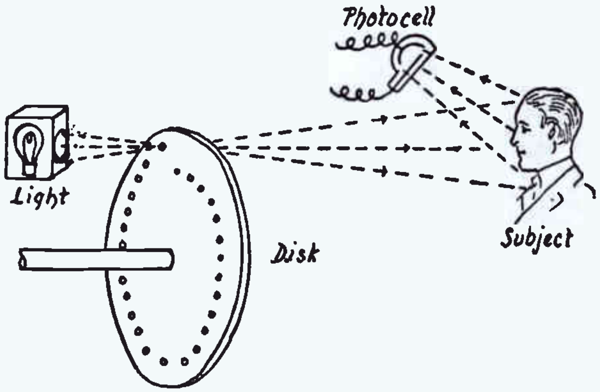


FIG. 70—The Ekström Inverted Method of Scanning.

ary points of light, as in the Nipkow method but by a single moving spot of light and, furthermore, the photocell can be placed up very close to the subject.

The gain that is derived by using this method is two-fold, because (*a*) a very bright single spot of light can be used and (*b*) the amount of reflected light that the photocell receives from the subject is greatly increased. This is the reason the Ekström method is used in all television transmitters which employ a scanning disk.

In order to get the largest amount of light from the lamp through the scanning disk into the photocell, you can use (*a*) one or more arc lamps, or (*b*) several large photocells connected together *in parallel*, which means that the anodes are connected to one side of the line and the cathodes to the other. To make a practical television transmitter, you must use two or more stages of amplification, and the purpose of this is to amplify the very feeble currents that flow through the photo-electric cell, to a point where the current modulation is sufficiently effective.

CHAPTER V

EXPERIMENTS WITH THE AMPLIFIER TUBE

An *amplifier tube* is a vacuum tube, or a gas-filled tube, that has three electrodes, and its function is to *amplify*, or increase, the strength of feeble currents. In commercial telephony, the amplifier tube is used as a relay and, as such, it increases the strength of telephonic currents from 10 to 1000 times. In radio telephony, the amplifier tube is used to increase the output of the oscillating currents of the transmitter and the input of the oscillations of the receiver, and it is used in the same way to increase the transmitted and received currents in television.

The Invention of the Amplifier Tube.—When Thomas A. Edison was working on the incandescent lamp in 1884, or thereabouts, he made all manner of experiments with it and in one of them he placed a metal plate above the filament in the bulb. He then connected the plate with the positive pole of a battery, the negative pole of this with one of the binding posts of a galvanometer and the other post of this with one of the terminals of the filament. The terminals of the latter were connected with a source of current to heat it. A diagram of this experiment is shown in Fig. 71.

Edison found that when the filament was heated to incandescence the needle of the galvanometer was deflected, indicating that the space between the filament and the plate had become a conductor. The cause of this phenomenon was not known for more than a quarter of a century, but ever since its discovery it has been called the *Edison effect.*

In the early days of wireless telegraphy, the great desiratum was to get an electric wave detector that was at once sensitive, constant, and stable. Every experimenter, from the boy amateur to the physics instructor, was trying out one thing after another. In England, Dr. J. A. Fleming, of the University College of London, who was Marconi's technical advisor, found, in 1905, that when oscillations set up by the incoming waves from a distant station were made to pass through a lamp having a plate in it for the second electrode, *i.e.*, one for producing the Edison effect, it became a fairly sensitive detector, in which the sensitivity did not change and, therefore, it required no adjusting, and moreover, it would last as long as an ordinary lamp.

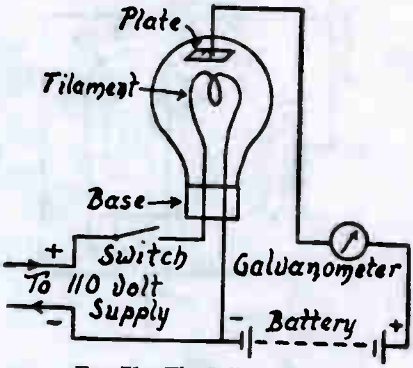


FIG. 71—The Edison Effect.

Fleming also found that if the plate was kept charged with positive electricity, its sensitiveness was greatly increased. To insure this positive charge, all that was necessary was to connect a dry battery of fifteen or more cells in the plate circuit. The two-electrode tube, or *thermionic valve*, as Fleming called it, was, then, the long-looked-for detector. It is shown with its circuits in Fig. 72. Fleming patented this new detector and turned his rights in it over to the British Marconi Company.

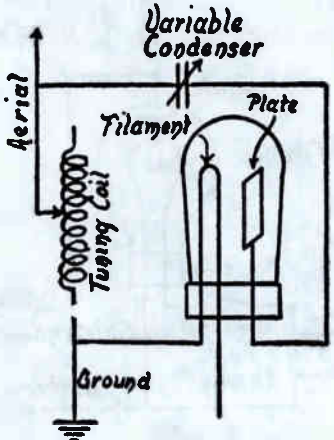


Fig. 72—The Fleming Two-Electrode Detector Tube.

The next step was taken by Lee Deforest, about 1907. He was impressed with the good qualities of the detector valve, or *vacuum tube*, as we called it over here, and, seeking a way to get around the Fleming patent, he put a third electrode in the tube; this consisted of a number of fine wires, or *grid* as it came to be known, and this he placed between the filament and the plate, as shown in Fig. 73. He patented the three electrode tube, gave it the trade name of *audion*, and turned his rights in it over to the Deforest Radio Telegraph Co.

Long before wireless telegraphy was invented, the American Telegraph and Telephone Co., or Bell Telephone Co., as it is popularly called, had been looking for a relay that would do for telephony what the Morse relay did for telegraphy, namely, to amplify a feeble current and make it into a strong one, so that telephony would be possible over long distances.

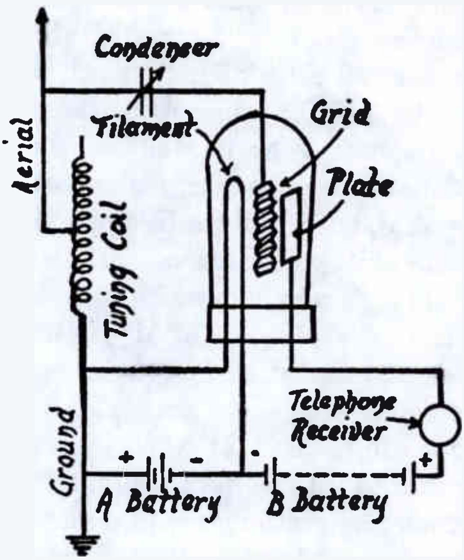


FIG. 73—The Three-Electrode Detector Tube.

So it was that in the Bell laboratories the research engineers began to experiment with the three electrode tube and made the startling discovery that it was not only a detector of feeble currents, but that it was an amplifier of them as well.

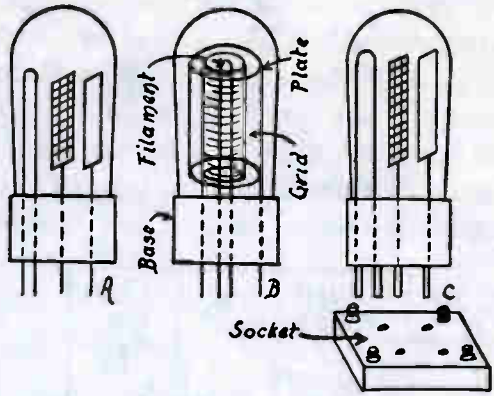
As a result, the telephone company bought the patent rights of the Deforest Company. A little further experimenting proved that the three electrode tube was not only a very sensitive detector and amplifier, but also an oscillator, that is to say, it would generate oscillations as well as detect and amplify them.

It was these three remarkable properties of the three electrode tube that made the wireless telephone, or *radio*, a simple and practical apparatus. Without its power of amplification, television could never be realized, for the amount of current that can be varied by the light acting on a photo-emissive cell is so infinitely small that it could not of itself alone be used for transmitting the picture impulses.

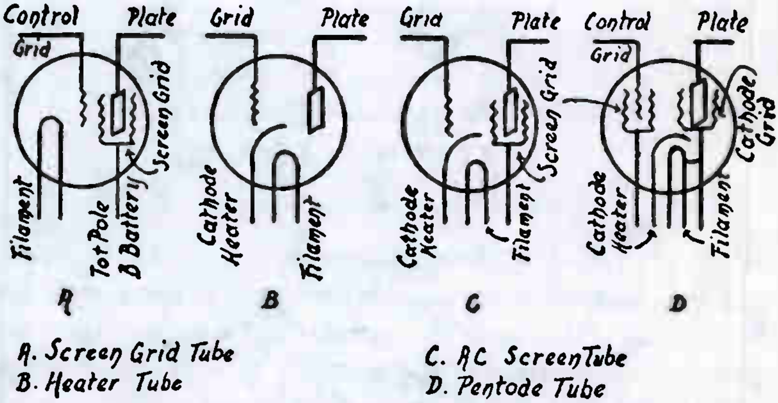
How the Amplifier Tube is Made.—From the foregoing discussion of the valve, or audion, you can see how the Edison effect was applied, but it will not be amiss to go a little more into the details of its construction. Primarily, an amplifier tube consists of a glass bulb in which there is (1) a filament, (2) a grid, and (3) a plate. The air is pumped out of the bulb, which is then sealed, or, before sealing, it is filled with nitrogen, or some other inert gas. Either the vacuum or gas-filled tube can be used for television work, though it is somewhat easier to get the right plate and filament voltage for the best working conditions with a vacuum tube.

The filament is made of fine tungsten wire and this is formed into a loop like that of an incandescent lamp. To increase the number of electrons that are thrown off from the filament, it is coated with barium, calcium, or thorium oxide. The grid is made of a sheet of tungsten, nickel, or copper gauze, while the plate is made of sheet aluminum or nickel.

The grid and the plate may be made either flat or cylindrical. If the plate is flat, the grid is placed between the filament and the plate, as shown at *A* in Fig. 74, so that it (the grid) will be directly in the path of the electrons that



A. Fig. 74—How the Amplifier Tube Is Made.



B. Fig. 74—New Kinds of Amplifier Tubes.

are given off by the former. If they are made cylindrical, then the grid is set over and around the filament and the plate is set over and around the grid, as shown at *B*. Of course these electrodes are insulated from each other. The base of the tube is made of *bakelite*, or other insulating material, and firmly holds the four metal terminal pins, or *prongs*, as they are called. The ends of the filament are connected with a pair of the prongs, the grid with the third one and the plate with the remaining one, as shown at *C*.

How the Amplifier Tube is Connected.—The amplifier tube is used in television as follows: (1) at the transmitting end, to amplify the feeble currents that flow through, and

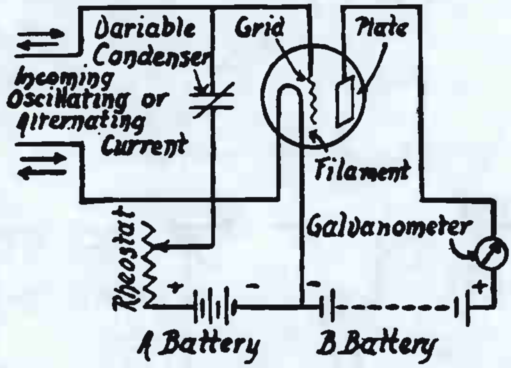


FIG. 75—A One-Stage Radio-Frequency Amplifier Tube Circuit.

which are varied by, the photo-electric cell; (2) at the receiving end, to amplify the feeble currents that come in or are set up and which vary the current that energizes the neon tube. The operation of the amplifier tube in either case is just the same, and to understand the way it works you must know how it is connected in the circuit.

A look at the diagram in Fig. 75 shows how a single amplifier tube, or *one-step*, or *one-stage*, amplifier is connected up. The filament is connected with a storage battery, called the

A battery, of 6 volts, or whatever voltage the tube is made for. The plate is connected with the positive pole of a dry battery, called the *B* battery, designed to develop from 50 to 350 volts, as may be required. The negative pole of the *B* battery is connected with one of the posts of a galvanometer or milliammeter, the other post of which is connected with the positive pole of the *A* battery. Usually another dry battery, or a *C* battery, as it is generally called, is connected in series with the positive pole of the *A* battery and the grid. The input leads are connected with the positive pole of the *A* battery and the grid.

How the Amplifier Tube Works.—When an amplifier tube is thus connected, it becomes a powerful amplifier of the feeble currents which are impressed upon its grid by either (1) the photo-electric cell of the transmitter, or (2) the currents that reach the receiver, as the case may be.

The current developed by the *A* battery heats the filament, and this throws off electrons. Since these are negative particles of electricity, they are attracted by the cold plate, which is positively charged by the *B* battery. If the grid were not interposed between the filament and the plate, these particles would all pass from the former to the latter in a stream and form a conducting path for the current from the *B* battery, thus completing the circuit.

If you connect up the filament and the plate of the amplifier tube and do not connect in the grid, the electrons that are thrown off will get no farther than the grid for any great length of time, no matter how high a voltage is applied to the plate. This is because a large number of the electrons that are thrown off by the filament strike the grid instead of going through it; these give it a negative charge and, it follows, they can't get any farther, hence, there is no conducting path for the plate current to flow through.

Thus, when the grid is properly connected in the circuit, a very small negative voltage impressed on it by the incoming impulses will keep a very large positive plate voltage from passing a current to the filament; oppositely disposed, a very small positive voltage impressed on the grid by the incoming impulses will allow a comparatively large plate current to flow through the tube. Since this is so, it is clear that the very small variations of the voltage from positive to negative, or the other way about, that are impressed on the grid by the current which flows through the photoelectric cell, or which comes into the receiver, will vary proportionately a large current that flows through the plate circuit of the amplifier. In other words, the grid simply acts as a valve to cut off and turn on the large current from the *B* battery.

Experiments With the Amplifier Tube.—*The Edison Effect.*—You will remember that the tube, or rather the lamp, which the great inventor used to produce this effect with had only two electrodes, *i.e.*, a filament and a plate. You can, however, use a three electrode amplifying tube[1] to duplicate his classic experiment by the simple expedient of not connecting in the grid.

The first thing to do is to connect one end of the filament with the positive pole of a 6-volt *A* battery,[2] or one of whatever voltage the tube is made for, the negative pole of

[1] Any amplifier tube will do for this experiment.
[2] This is usually a storage battery.

it to one of the posts of an adjustable rheostat having a resistance of, say, 30 ohms, and the other post of this to the other end of the filament.

This done, connect the negative end of the filament with one of the posts of a galvanometer or a milliammeter, the other post of this to the negative pole of a 90-volt adjustable *B*-battery,[1] and the positive pole of this to the plate of the tube, as shown in the diagram in Fig. 76.

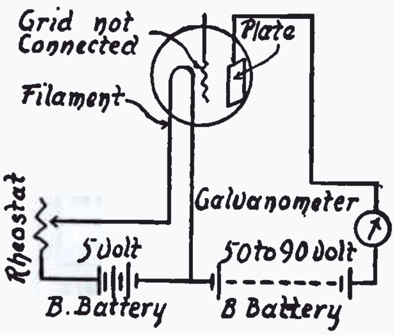


FIG. 76—Set-up for Producing the Edison Effect.

(1) When the apparatus is connected and the filament is heated, the needle of the meter will swing over to a point which indicates that the space between the filament and the plate is carrying a definite amount of current of the *B* battery. (2) The meter further shows that the current gradually gets smaller until it finally stops altogether. In a three-electrode tube the current would hold to its maximum value but, as previously stated, when the grid in the tube is not connected in the circuit, the electrons which are thrown off by the

[1] This is usually a dry battery.

filament strike it (the grid) instead of going through it, with the result that it takes on a negative charge and repels the other electrons that approach it until, finally, the current from the *B* battery is entirely cut off.

The Fleming Thermionic Valve.—In England the vacuum tube is called a *valve*, and an *oscillation valve*[1] originally meant a *two-electrode detector tube.* (1) To make the equivalent of a two-electrode tube for detecting feeble electric oscillations

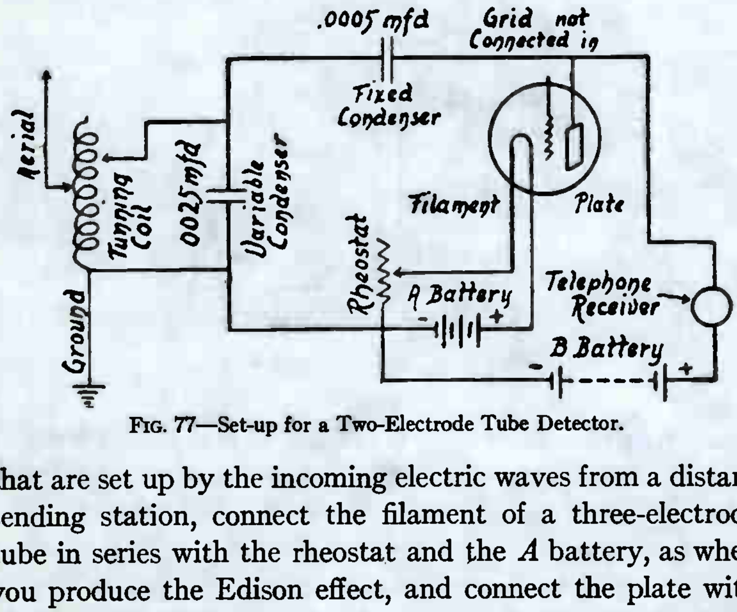


FIG. 77—Set-up for a Two-Electrode Tube Detector.

that are set up by the incoming electric waves from a distant sending station, connect the filament of a three-electrode tube in series with the rheostat and the *A* battery, as when you produce the Edison effect, and connect the plate with the *B* battery, but instead of a meter, connect a high-resistance telephone receiver as shown in Fig. 77. Now listen in and you can hear the electric current flowing through the

[1] Fleming, who invented the valve, so named it because it would allow a current to pass through it in one direction only. In more scientific language it possesses *unilateral conductivity*, or *asymmetric resistance.*

circuit, or, to be exact, you can hear the effect of the electrons moving through it, for the current consists of a movement of electrons.

(2) Now connect the terminal of the plate of the tube to one end of the secondary inductance of a tuning coil, see Fig. 77 again, the other end of the latter to one side of a .001 microfarad fixed condenser, and the other side of this to the negative terminal of the filament, and connect a pair of high-resistance head-phones around the fixed condenser; connect

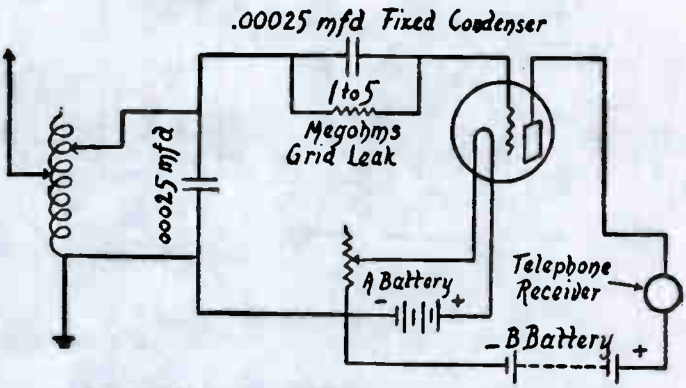
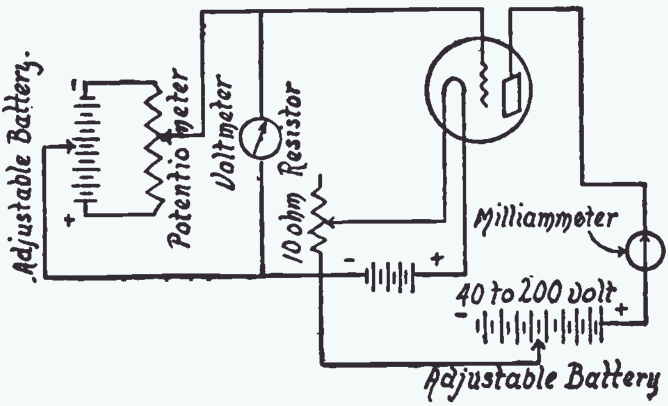


FIG. 78—Set-up for a Three-Electrode Tube Detector.

one end of the primary coil of the tuning inductance to the aerial and ground the other end. With such a circuit you can tune in on the carrier wave of a broadcasting station within its range.

The Three-Electrode Tube as a Detector.—To use a three-electrode tube as a radio detector, you can use the method shown in Fig. 78. Connect the negative pole of an *A* battery of the right voltage for the tube to one end of the filament, the positive pole of the battery to one post of a rheostat, and the other post of this to the other end of the filament. Then connect the plate of the tube with the positive pole of a 22½-volt *B* battery (or a battery of whatever voltage is needed for the tube), the negative pole with one side of a high-resistance head-phone, and the other side of this with the positive pole of the *A* battery.

The next thing to do is to connect the grid to one side of a .0005 microfarad fixed condenser and the other side of this



A. FIG. 79—Set-up for Plotting the Characteristic Curve of a Three-Electrode Amplifier Tube.

to one end of the secondary of the tuning coil. Now connect the other end of this to the positive terminal of the *A* battery and shunt the secondary of the tuning coil with a variable condenser that has a capacitance of .0005 microfarads. Finally connect one end of the primary of the tuning coil to the free end of an aerial wire and the other end of the coil with the ground wire. If you tune in a station and adjust the different circuits which include the electrodes of the tube, you will find the received signals many times as loud as with a two-electrode tube detector.

The Three-Electrode Tube as an Amplifier.—It is, however, as an amplifier for very feeble currents that flow through a photo-electric cell in the television transmitter, or through the receiver, that the tube interests us just now.

To demonstrate how an amplifier tube amplifies feeble currents, you need a three-electrode tube, a galvanometer or milliammeter, an *A* battery, a rheostat, *B* battery, potentiometer and *C* battery. The way that these are connected up is shown at *A* in Fig. 79. The filament, a 6- to 10-volt *A* battery and a 30-ohm rheostat are connected in series; the plate, a 45- to 200-volt *B* battery, the galvanometer or milliammeter and the negative pole of the *A* battery are, likewise, connected in series. The grid is connected with the sliding contact of a *voltage divider*, or *potentiometer*,[1] as it is commonly but incorrectly called, and the ends of this are connected with a *C* battery that develops from 45 to 200 volts.

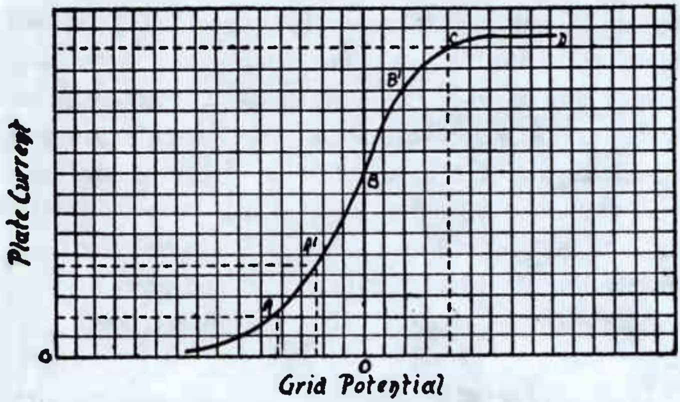
(1) If the sliding contact is moved forth and back on the potentiometer, the voltage that the *C* battery impresses on the grid will be changed, and this, in turn, produces corresponding amplified changes in the plate current, as will be shown by the meter.

(2) A characteristic curve of the action of a three-electrode amplifier tube is shown at *B*. A like one can be plotted for any other tube by keeping the voltage of the *B* battery at a fixed point while changing the voltage of the grid to

[1] This consists of a coil of fine wire having a high resistance and a sliding contact so that the voltage can be controlled.

either a negative or a positive value, by means of the potentiometer.

Thus for the tube whose curve was plotted in the diagram, the plate current reached its highest value when the grid was charged with a potential of 3 volts; oppositely, when the grid was charged with a negative potential of 5 volts the current in the plate circuit was in the neighborhood of zero. That part of the curve from *A′* to *B′* is practically straight,



B. Fig. 79—Characteristic Curve of a Three-Electrode Amplifier Tube.

showing that the current in the plate circuit is directly proportional to the electromotive force (voltage) in the grid circuit. It follows, then, that when a small alternating current voltage is impressed on the grid, the current in the plate circuit will rise and fall in proportion to it.

Experiments with the Photo-Electric Cell and the Amplifier Tube.—*Coupling the Photocell with a Single Stage Amplifier.*—The photo-electric cell develops currents that are much too feeble to be used for television, or, indeed, for any other practical purpose, without being amplified, which can be done as shown in the wiring diagram in Fig. 80. For this set-up, connect the filament with the *A* battery, the plate with the positive *B* battery terminal and galvanometer or milliammeter, and the grid with the *C* battery negative terminal, as in the foregoing circuit. This done, connect the

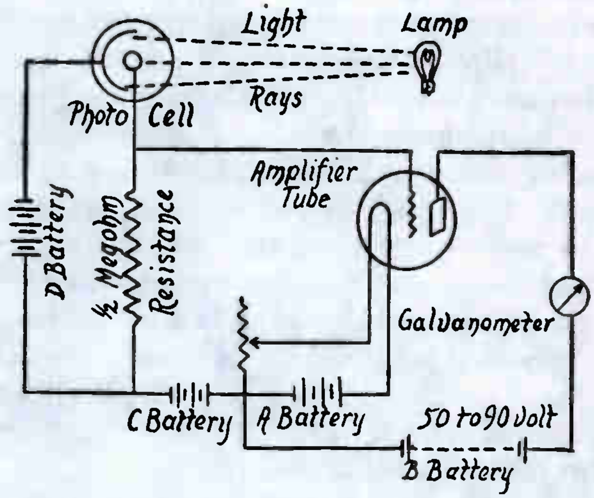


FIG. 80—Coupling a Photocell with a Single-Stage Amplifier.

anode of the photo-electric cell with one end of a ½ megohm resistance that leads to the negative pole of the *C* battery, then connect the cathode of it (the cell) with the negative pole of the *D* battery, and, finally, the positive pole of this with the other end of the resistance.

Now, when you throw a beam of light on the photo-electric cell, you will find that the throw of needle of the meter will show a current output of 100 to 1000 times as great with the amplifier tube as against that which is developed by the photo-electric cell alone.

The Light-controlled Relay.—The relay is not employed in television, but as there are dozens of other practical uses to which it can be put, I shall explain how to make a set-up for it. You can use the light-controlled relay, or *optical relay*, as it is also called, for an *optical counter*, which is an apparatus for counting persons that pass a given point, for example, traffic over bridges, thoroughfares, etc., *controlling artificial illuminants*, such as warning lights for alarms in case of fire, smoke, burglars, prison breaks, etc.; *safety devices*, such as stops for elevator doors, warning signals for cars entering and leaving dangerous passages, etc., and also for *timing devices*, for operating cameras at the finish-line in races, etc.

It is useful for controlling *laboratory instruments* for starting, stopping or reversing motors and other machines, controlling high-speed switches, etc., and, lastly, for *industrial control devices* for the inspection of materials or parts, for finding flaws or defects, control of heat for blast furnaces, automatic smoke control for boilers, etc.

To make a light-controlled relay, you will need a photo-electric cell, an amplifier tube, and a 2,000 ohm relay. The first thing to do is to connect the filament of the amplifier tube with the *A* battery and rheostat, then connect the negative pole of the *A* battery to the negative pole of a 90-volt *B* battery, and connect the positive pole of this with the anode of the photo-electric cell, as shown in Fig. 81.

Connect one post of a 10- to 50-megohm resistance to the cathode terminal of the cell and the negative pole of the *C* battery, the positive pole of this to one post of an adjustable 1/10 megohm potentiometer, and the other post of this to the negative pole of the *C* battery. Now, connect the adjustable contact of the potentiometer to the negative pole of the *A* battery.

The next step is to connect the anode of the cell with one of the posts of the relay magnet, and the other post of this with the plate of the amplifier tube and, lastly, con-

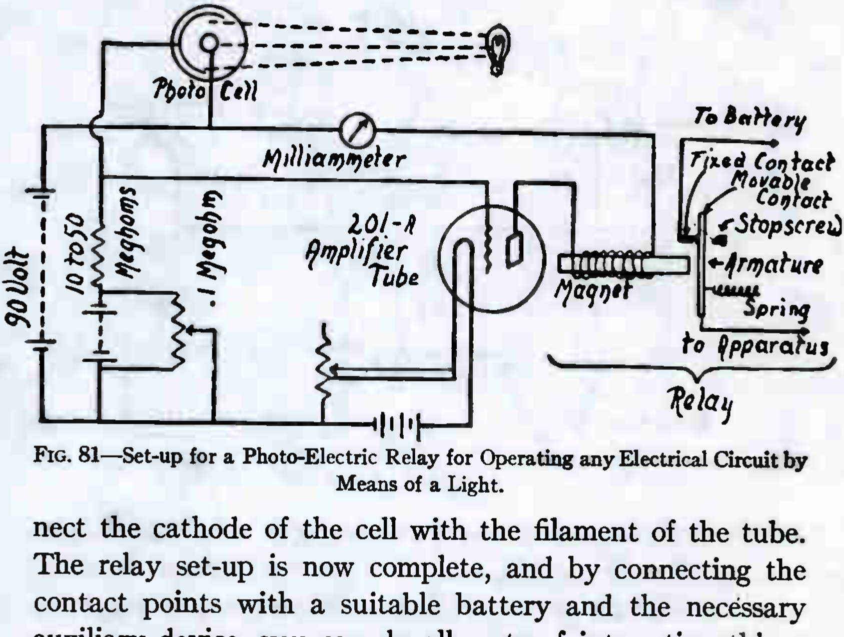


FIG. 81—Set-up for a Photo-Electric Relay for Operating any Electrical Circuit by Means of a Light.

nect the cathode of the cell with the filament of the tube. The relay set-up is now complete, and by connecting the contact points with a suitable battery and the necessary auxiliary device, you can do all sorts of interesting things with it.

Lighting a Lamp with a Flashlight.—For this experiment connect the fixed contact point of the relay with one pole of a 6-volt battery, the other pole of this with one terminal of a 6-volt miniature lamp, and the other terminal of the lamp with the movable contact point, as shown in Fig. 82. Now set the apparatus in a dimly lighted room and adjust the contact points of the relay so that the feeblest current from the amplifier tube will close them.

(1) Hold your flashlight a foot or so from the photo-electric cell and let the light fall on it, when the current set up

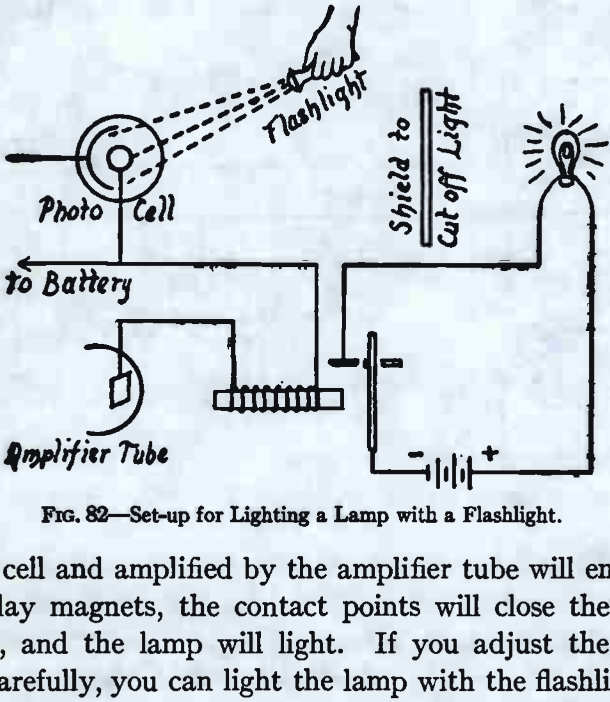


FIG. 82—Set-up for Lighting a Lamp with a Flashlight.

in the cell and amplified by the amplifier tube will energize the relay magnets, the contact points will close the lamp circuit, and the lamp will light. If you adjust the relay very carefully, you can light the lamp with the flashlight at a distance of 10 or 15 feet. (2) By using a mirror, and reflecting a beam of sunlight onto the photo-electric cell, you can operate the relay at a distance of several hundred feet.

Lighting an Incandescent Lamp with a Match.—The effect of this curious little experiment is quite startling when it is properly performed. To do it, use the same set-up as in the preceding experiments, then strike a match and hold it close to the incandescent lamp, when it will instantly light up and stay lighted. What takes place is that the light from the match acts on the cell, which in turn closes the relay, and after that the light from the lamp falling on the cell keeps the relay closed.

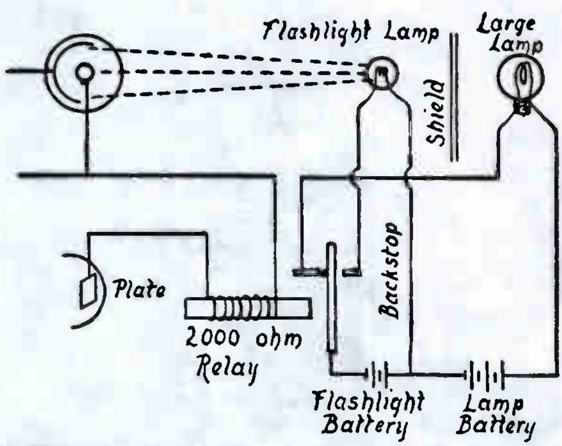
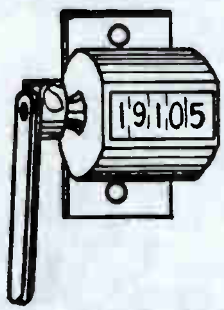


FIG. 83—Set-up for Making an Electric Light Turn Itself Off.

Making an Electric Light Turn Itself Off.—The action of this curious experiment is seemingly contradictory. Connect up the photo-electric cell, the amplifier, the relay, and the 6-volt lamp as in the preceding experiment, then connect a flashlight battery cell and a flashlight lamp in series with the movable contact and the back contact, as shown in Fig. 83. The 6-volt lamp must be shielded from the photo-electric cell so that the lamp's rays will not strike the window of the cell.

To make the experiment, bring the flashlight lamp close to the window of the cell, causing the latter to actuate the relay. This will close the circuit of the 6-volt lamp and light it, and at the same time it will break the flashlight circuit and put it out. Immediately that the flashlight goes out the photo-electric cell becomes inactive, the current is cut off from the relay, and the tension spring pulls the movable point into contact with the back stop, when the flashlight circuit is made again and the cycle of operations is repeated.



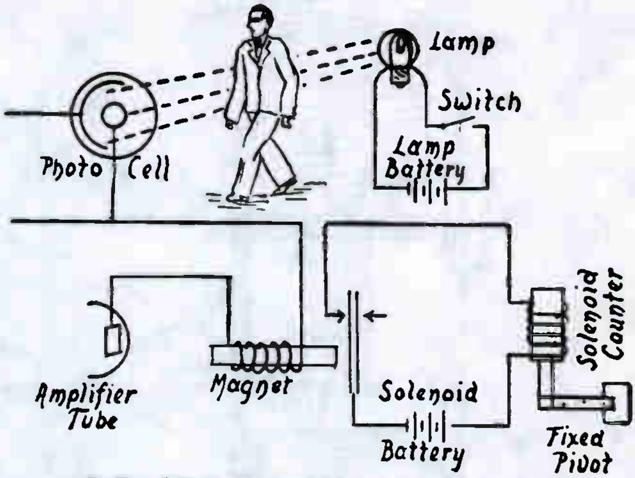
A. FIG. 84—A Veeder Rotary Ratchet Counter.

Both the 6-volt lamp and the flashlight lamp will blink alternately and at a speed which will depend on the tension of the armature spring of the relay. By bringing the flashlight closer to the cell and increasing the tension of the armature spring, the blinking of the lamps will be made more rapid, and, conversely, by moving the flashlight lamp farther away and decreasing the tension of the armature spring, the blinking can be slowed down.

A Light-Actuated Counter.—(1) A *counter*, or *odometer*,[1] is a mechanical device that counts things as they move progres-

[1] This word comes from the Greek *odos*, meaning *way*, and *metron*; meaning *measure*.

sively past a given point. A small counter that has five wheels and which will register up to 99,999, see *A* in Fig. 84, can be bought for $2.00[1] or less. To operate the counter when a light is thrown on the photo-electric cell, connect the last-named, the amplifier, and the relay as in the foregoing experiments, but instead of the 6-volt lamp connect in a *solenoid* as shown at *B*.



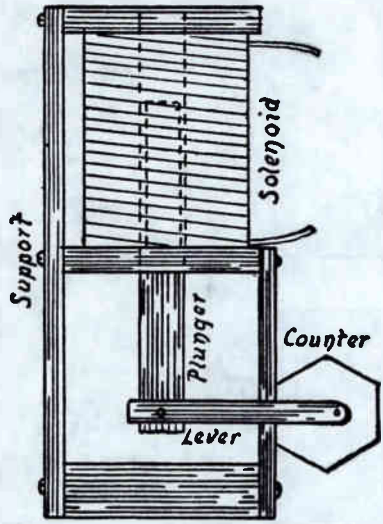
B. Fig. 84—Set-up for a Light-Actuated Counter.

A solenoid, or *sucking magnet*, as it is sometimes called, consists simply of a coil of wire wound on a spool just as it is for an electro-magnet, but it is usually larger, see *C*, and it has an *air core* instead of an iron core; in other words, a solenoid has a hole through the longitudinal axis of the coil of wire. If one end of a soft iron core, or *plunger*, of such diameter that it will slide freely through the hole, is slipped into it, and a current is made to flow through the solenoid,

[1] This is a *Veeder Rotary Ratchet Counter.*

the attraction of the magnetic lines of force that are set up inside of the coil will pull the plunger all the way in. Oppositely, when the current is cut off, the lines of force collapse and the plunger is again released, when it will drop.

If you pivot the plunger to the lever of the counter, so that every time the former is drawn into the solenoid, it will



C. Fig. 84—The Solenoid and Counter.

pull the latter up, and this will turn the wheels of the counter. When a light strikes the photo-electric cell, the relay will close the solenoid circuit and this will operate the lever of the counter. The way it is connected up is shown at *B* in Fig. 84.

(2) If the photo-electric counter is to count things that are constantly moving along over a given path, the light is placed on one side of it and the photo-electric cell and its associated units on the other side. In this case you connect

the solenoid to the movable contact point and to the back-stop as shown at *B*. Now every time an object moves across the path of the beam of light, it is momentarily cut off, the relay becomes inactive, and the spring pulls the armature back into contact with the back-stop; when this takes place the solenoid circuit is closed, this pulls up the plunger, and this, in turn, throws the lever of the counter.

(3) A complete photo-electric relay that is controlled by a beam of light is made by the *G-M Laboratories, Inc.*, 1731–1735 Belmont Avenue, Chicago, Ill. The lamp, photo-electric cell and all other electrical components are mounted

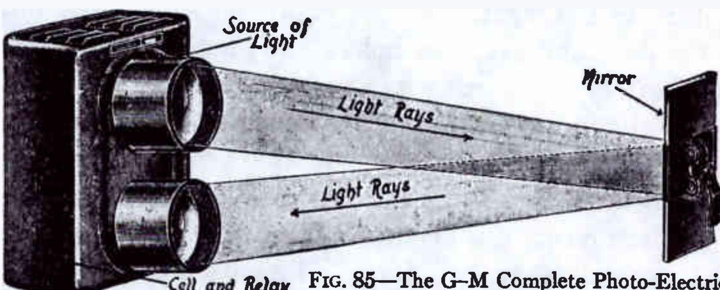


FIG. 85—The G-M Complete Photo-Electric Relay with Source of Light.

in a metal case. The light from the lamp is focused, by means of the upper lens, on a mirror placed at a distance from it, and the beam of light is reflected by the latter back again to the lower lens, as shown in Fig. 85. The light that passes through the lower lens falls on the photo-electric cell, the current passing through it actuates the amplifier tube, this operates the relay circuit, and, finally, the plunger works the counter.

A Light-Actuated Bell.—To ring a bell by the action of light on a photo-electric cell, you need only to connect an electric bell in the place of the solenoid which is shown at *B* in Fig. 84. This is the fundamental circuit that is used in most of the alarm systems, a few of which will be described below.

A Public Garage Alarm.—Ordinarily the doors of public garages are closed at night during the winter months, and the belated motorist must honk his horn, to the discomfiture of all in the immediate neighborhood, before he can enter the garage. To obviate this annoyance, some of the garage owners have installed light-actuated bells.

A hole is cut in the garage door at about the level of a motor car headlight, and the photocell is mounted inside of the door and over the hole. The photocell is connected to a battery and a relay as above described, with a switch in the circuit so that it can be left open in the day time. When the garage doors are shut, the cell circuit is closed, and when a car pulls up in front, the light from the headlights falls on it; this actuates the relay, and the bell rings.

A Light-Actuated Fire Alarm.—Fire-alarm systems depend in general on the heat developed by the fire, but the one about to be described depends on the light from the flames. The photo-electric cell is mounted on the wall or ceiling of the room to be protected, the cell is connected with an amplifier, relay, and bell in the usual way.

If a fire should break out, the light from the flame will actuate the photo-electric cell and the bell will ring out the alarm. This kind of fire alarm is useful only in rooms that are dark, since those into which daylight enters would set off the alarm when there was no fire, and this would defeat its own purpose.

A Light-Actuated Burglar Alarm.—A burglar alarm of this type can be worked in two different ways, namely: (1) a beam of light is kept constantly shining across the room onto the photo-electric cell so that the circuit is broken when an intruder walks through it, which he would be unlikely to do, and (2) the cell is so placed that when the trespasser throws his flashlight around to find the safe, the beam would accidentally strike the cell, in which case he would very likely be frightened away. To make either kind of alarm, connect up the components in the usual way and put the bell in the contact circuit of the relay.

Multistage Amplifying Circuits.—*With a Battery Voltage Supply.*—If you want a greater amplification than you can get with a single amplifier tube, you must use two or more tubes. In this case you will need a separate voltage supply for each plate if the voltage that is needed to energize them is different. For television transmission circuits it is customary to use what is called a *resistance coupling*, and this can be energized with either (1) a battery voltage supply, or (2) a commercial 110-volt power supply.

The reason for using a resistance coupling is that a resistance has neither inductance nor capacitance, and consequently it maintains the same ratio of amplification whatever the frequency of the oscillations may be. In a properly designed resistance-coupled multistage amplifier, all frequencies from 25 to 50,000 cycles get uniform amplification.

(1) For purely experimental purposes, you can couple up two or more stages of amplification with separate sources of voltage supply by using an individual *A* battery for heating the filament of each amplifier tube and an individual

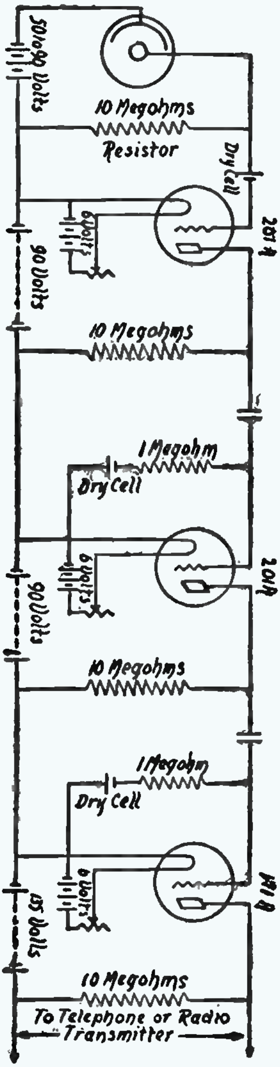


FIG. 86—
A Multistage Amplifying Circuit.
(*With Battery Current Supply.*)

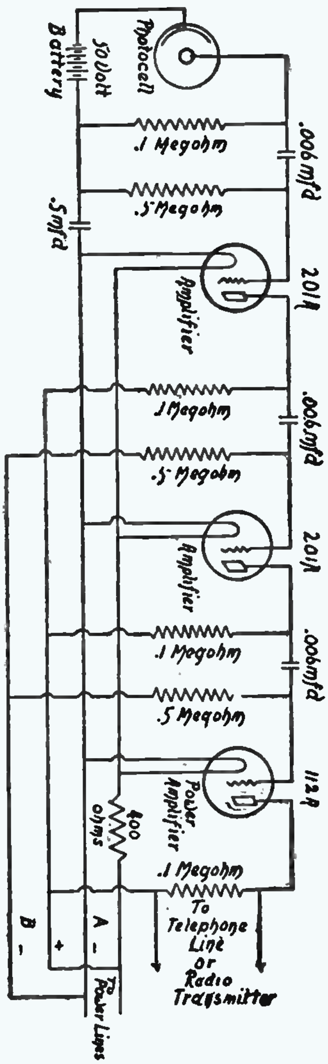


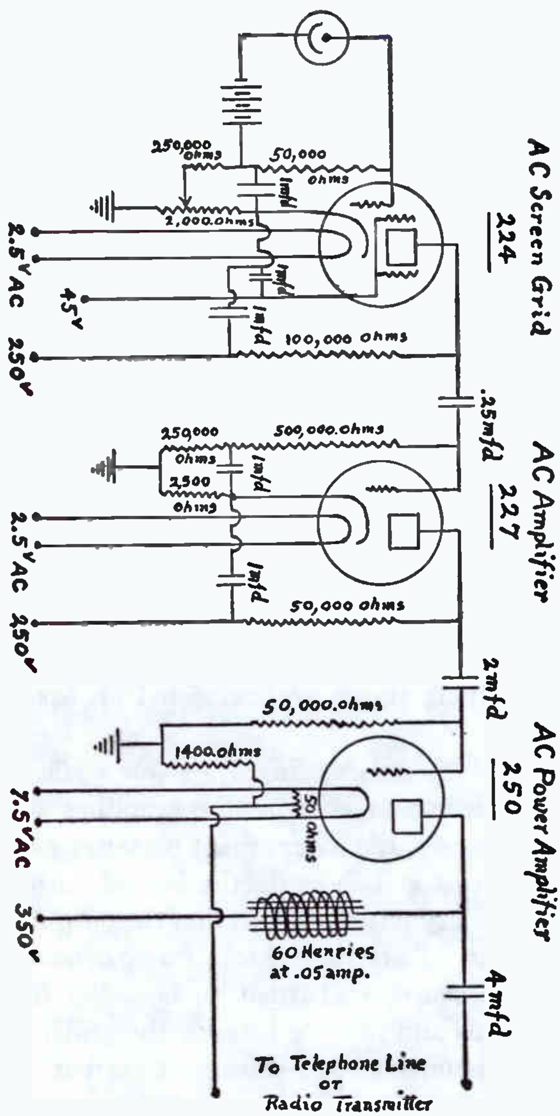
FIG. 87—
A Multistage Amplifying Circuit.
(*With 110-Volt Direct Current Supply.*)

B battery for energizing the plate of each tube, as shown in the circuit diagram in Fig. 86. A better way is to use a single *A* battery to heat the filaments of all of the tubes, as pictured in the diagram at *B* in Fig. 159, in *Chapter X*.

The plate of each tube (see Fig. 86 again) is connected with one end of a 20-megohm resistor, the outer end of this with the positive pole of the *B* battery, the negative pole of which is connected with the positive pole of the *A* battery. The grid of each tube is connected with the negative pole of a *C* battery, to give it the necessary *grid bias*, while the positive pole of the *C* battery is connected with one end of a 20-megohm resistor, the other end of this with the negative pole of the *A* battery and with the positive pole of the photocell battery. The negative pole of the latter is connected with the cathode of the photocell and, finally, the anode of this with the positive pole of the *C* battery. The second and third amplifying stages are connected up exactly like the first one.

With a 110-Volt Power-line Supply.—Now while you can use a battery current to energize the amplifier tubes for experimental purposes, the independent batteries needed for a multi-stage circuit will show fluctuations of current, and these will have a very untoward effect on the output circuits of the transmitter. To obviate this unstable condition, you can use a single source of current to heat the filaments, energize the plates and provide bias for the grids, and this can be either a commercial 110-volt direct current or a 110-volt alternating current.

With a 110-Volt Direct-Current Supply.—If you use a 110-volt direct current taken from the service lines, you can



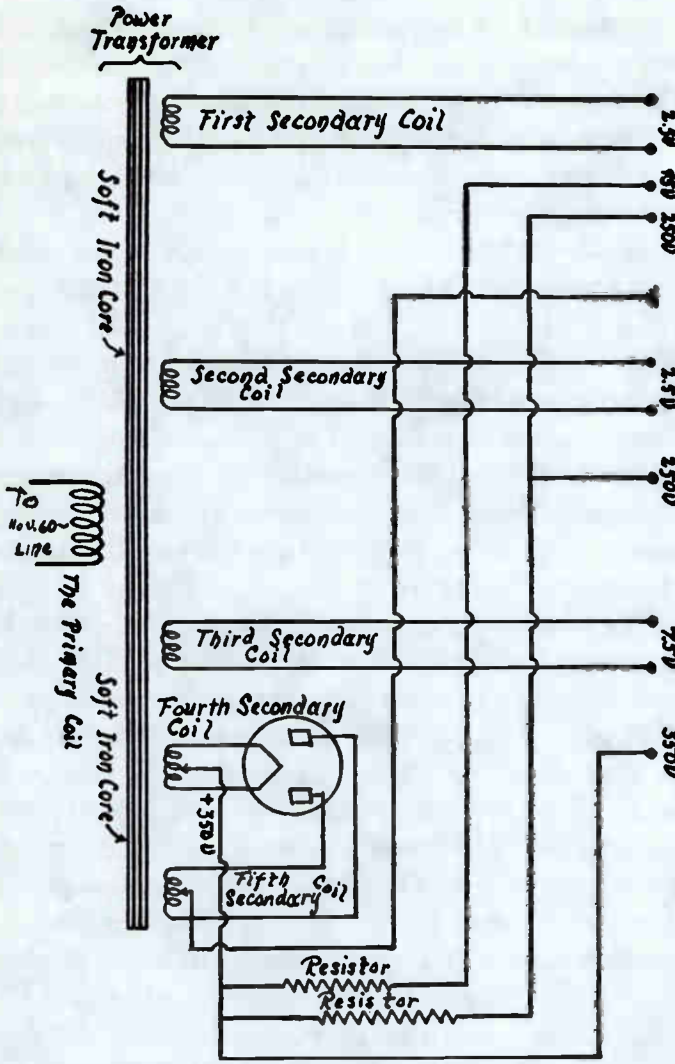
A. Fig. 88—Diagram of a Multistage Amplifying Circuit.
(*With* 110 *Volts Alternating Current Supply.*)

connect the main *A*+ line with one terminal of each of the filaments through a 400-ohm resistor and the main *A*− line with each of the other terminals of them, as shown in the wiring diagram in Fig. 87. The plates are energized by the current taken from the shunt *B*+ line, and the grid bias from the shunt *B*− line.

The anode of the photocell is connected with one terminal of a 1 megohm resistor, the cathode of it with the negative pole of a 50-volt battery, and the positive pole of this with the other terminal of the resistor. The first terminal of the 1 megohm resistor is then connected to one side of a .006 mfd. condenser, and the other side of this with a 5 megohm resistor. The other terminals of these resistors are connected together.

The first terminal of the 5-megohm resistor is connected with the grid of the first amplifier tube and the other terminal of the resistor with one side of a 0.5 mfd. blocking condenser. The grids of the second and third amplifier tubes are likewise connected with the shunt *B*− line. The plate of each tube is connected through a 1-megohm resistor with the *B*− line. Finally, the outlet line, consisting of those terminals which are connected to the telephone line or radio transmitter, is connected to the terminals of the last plate resistor.

With 110-Volt Alternating-Current Supply.—If you want to work with a 110-volt alternating current supply, you should use a No. 224 a.c. screen-grid heater amplifier tube for the first stage, a No. 227 a.c. heater tube for the second stage, and a plain No. 250 a.c. power tube for the third stage, as shown in the wiring diagram at *A* in Fig. 88. The reason for using the heater type of tube in the first and second stages is to get rid of the alternating-current hum.



B. Fig. 88—Diagram of the Transformer Circuits.
(For a Multistage Amplifying Circuit.)

The No. 224 type of tube is especially good for the input stage by virtue of its favorable characteristics, which make it just the proper thing for coupling with the photo-electric cell. The No. 227 type of tube likewise gives the best results when it is used in the second stage, while the No. 250 standard three-electrode power-tube can be used instead of the heater type, since by the time the electric impulses reach this point for final amplification, the a.c. ripple is very low.

In operating this circuit you will need a special transformer, and this consists of a primary coil, which is connected with the 110-volt a.c. service line, and five secondary coils, as shown at *B*. The first two secondary coils, which develop 2.5 volts each, are connected with the filaments of the first and second amplifier tubes; the third secondary coil, which develops 7.5 volts, is connected with the filament of the power amplifier tube; the fourth secondary coil, which develops 10 volts, is connected with the filament of the rectifier tube, and, finally, the fifth secondary coil, which develops 350 volts, is connected with the two plates of the rectifier tube.

The rectified alternating current, which is the equivalent of a direct current, is used for energizing the plates and grids of the amplifier tubes. Thus the 350-volt d. c. current, as it comes from the rectifier tube, is used to energize the plate of the power amplifier tube. The rest of the rectified current is divided up, by means of suitable resistors, into currents of different voltages, the first of which gives 250 volts and is used to energize the plates of the first and second tubes; the 45-volt current is used to energize the screen grid of the first tube. The grid of the first tube is, of course, energized by the fluctuations of the current impulses through the photo-electric cell, while the grids of the second and third tubes are grounded through resistors, as shown in the *A* and *B* diagrams.

CHAPTER VI

EXPERIMENTS WITH GLOW TUBES AND NEON LAMPS

A *glow tube* is any kind of glass tube that contains a rarified gas, so made that an electric current can pass through it and produce a light. There are several kinds of glow tubes, used for many purposes, the two most important ones being lighting and television. The kind that is used for reproducing television images at the receiving station is the *neon tube* or, more properly, the *neon lamp*, though the argon tube, or lamp, is employed in special cases as, for example, in color television reception.

The Invention of the Neon Lamp.—*The Discovery of Neon.*—Before we take up the invention of the neon lamp, let us find out how *neon* came to be discovered. Neon is an inert gas[1] constituting about 2 thousandths of 1 per cent of the air we breathe. It was discovered by Ramsey and Travers, two eminent British chemists, who named it *neon* from the Greek word *neos*, which means *new*.

The first step leading to the discovery of neon began away back in 1868, when Sir Norman Lockyer, a British astronomer, detected a previously unknown gas in the sun, which he named *helium*, from the Greek root *helios*, which means *sun*. The way that he detected it was with a spectroscope which

[1]An *inert gas* is one that will not combine with any of the other elements. All of the inert gases are *monatomic*, which means that a single molecule of any one of them consists of a single atom.

was attached to the eye-end of a telescope. The gas was not then known to be present in any substance that existed on the earth.

In 1895 Sir William Ramsey was searching for a more fruitful source from which to obtain *argon*, another inert gas that forms a minute part of the air, and which he and Lord Rayleigh had discovered the year before in atmospheric nitrogen. In one of these experiments Sir William heated *uraninite*,[1] an ore of uranium, and isolated the gas that it gave off. He was surprised to find that it was not nitrogen, which Hillebrand, who had obtained it in 1869, thought it to be, nor was it argon, which Ramsey conceived it might be. On examining it with a spectroscope, he was even more surprised to find that the gas was identical with Lockyer's *helium*.[2]

When air is liquefied and then allowed to evaporate, the oxygen passes back into its gaseous state before the nitrogen does, and so the latter gas is left in its pure state except for the traces of the inert gases which are mixed with it. These include argon, helium, krypton, xenon, and neon.

In 1898, Ramsey and Travers obtained neon from the nitrogen of liquefied air by letting the former evaporate and then heating the mixture. A large amount of argon and smaller amounts of helium and neon passed off first, and these were collected in a suitable container. After these gases had escaped, the krypton and xenon still remained in a liquid state, and by heating them a little more they also

[1] This is a mineral that consists largely of uranium and is considered a uranate of uranyl. It contains radium, thorium, the cerium and yttrium metals, and lead.

[2] This gas has since been found in other minerals, and it is obtained in large quantities at the present time from natural gas and is used for inflating airships.

passed off and were collected. When the container which held the helium and neon was immersed in liquefied hydrogen, the neon froze to a white solid, and the helium, which still remained in a gaseous state, was then pumped off, thus leaving the neon behind.

The Commercial Production of Neon.—Neon occurs in the air in the proportion of one part of the former to 55,000 parts of the latter. Watson, of England, found that all gases other than neon, helium, and hydrogen have no appreciable vapor pressure when they are in contact with charcoal at the temperature of liquid air. It follows that these three gases can be easily separated from the others that form the air, provided a sufficient time is allowed for diffusion and absorption to take place. G. Claude, of France, who made the familiar neon signs popular, devised an apparatus, based on the above principle, for extracting neon from the atmosphere in commercial quantities. Space will not permit me to go into the details of it here, but if you are sufficiently interested you can read his original papers on the subject in *Comptes Rendus* 151, 1910, page 752, and 166, 1918, page 492, and his *British Patent, No.* 184, 1922, page 454.

The Invention of the Neon Lamp.—The neon lamp had its beginnings in the year of 1850, when Heinrich Geissler, an instrument maker and experimentalist of Germany, invented what has ever since been known as the *Geissler tube.* This consists of a glass tube in the ends of which are sealed a pair of wire electrodes, as shown in Fig. 89, and from which the air has been pumped out to a low vaccum, say to about 40 millimeters.[1]

[1] A millimeter is equal to about 1/32 of an inch.

When this tube is connected with the terminals of the secondary of a spark coil, or a static electric machine, the high voltage current delivered by the machine will pass through the tube and it will be filled with a soft glowing light, the color of which depends on the kind of gas that it contains. Thus a tube containing nitrogen or air, which latter is principally a mixture of oxygen and nitrogen, gives a reddish-violet color. Hydrogen gives a pale blue color, while carbon dioxide gives a weak white light.

The next step in the development of the glow tube was taken by Sir William Crookes, of England, in 1879, when

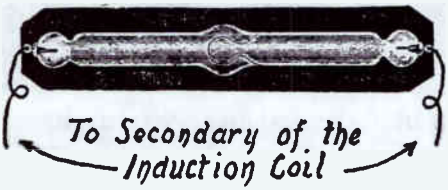


FIG. 89—A Geissler Tube.

he invented a high-vacuum air pump with which he was able to exhaust a tube to a much higher degree of vacuum than could be done with the Geissler air pump; that is to say, about .001 of a millimeter. When this tube is connected with a spark coil and a high voltage current is made to pass through it, the electrical discharge takes on very different characteristics from that exhibited by a low-vaccum Geissler tube. In this tube, which is called a *Crookes' tube*, the negative, or cathode, terminal throws off particles of negative electricity, or *electrons*, and the stream of electrons constitute what is termed the *cathode rays*.

The first glow lamp, that is, a lamp in which a film of light was formed on the cathode and provided the source of illumination, was made, so far as I have been able to ascertain, by D. McFarlan Moore in 1893. In this lamp the tube was 3/8 of an inch in diameter and 1½ inches long, and consisted of a pair of wire electrodes placed in the tube, from which the air was exhausted, when it was filled with nitrogen gas and the tube sealed off.

The first lamp developed by Moore for television reception was made in 1924 and was called a *corona glow lamp*. It was formed of a small spherical glass bulb, 1¼ inches in diameter, fitted with an Edison screw base. Inside of this bulb was an electrode made of a solid metal rod which had a hole drilled in one end, and this formed the cathode. This electrode was shielded by a cylindrical mica insulator that fitted over it, and over this a second cylindrical metal electrode formed the anode.

Terminal wires were secured to these electrodes and brought out at the bottom of the bulb, the air was exhausted and replaced by hydrogen, argon, or neon. The lamp was then sealed and fixed to an Edison base. The way the lamp worked was like this: The stream of electrons from the cathode passed out of the hole and over to the anode, with the result that the hole glowed with an intense light.

How Neon Lamps Are Made.—Neon tubes are made in different shapes and sizes and have electrodes of various forms and kinds. The type that is now generally employed in ordinary television receivers consists of a straight glass tube like an amplifier tube, but of larger diameter, and sealed in it is a pair of sheet iron or nickel electrodes and a wire-frame electrode, as shown in Fig. 90. Each of these latter measures from 1¼ inches to 1½ inches on the sides, and is placed parallel with, and separated from, the other by a space about 1/32 of an inch. The tube is exhausted to a high degree of vacuum, when a small amount of neon is admitted, and it is then sealed off.

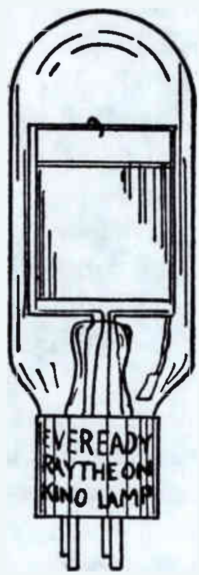


FIG. 90—How a Neon Lamp is Made.

Why Neon Is Used in the Lamps.—The primary reason that neon is used in preference to any other gas is because it takes far less voltage to make it glow.[1] Of course, the size of the electrodes and the distance between them affect the voltage required to set up the glow, or a *striking voltage*, as it is called. A neon lamp that is made for television

[1] Mercury vapor will work on 50 to 150 volts, but it requires a high initial voltage to heat it in order to start it off; hence, it cannot be used for television tubes.

reception usually works on a 160-volt current, but after it has been in operation for a short time it will take only about 140 volts to energize it. Another reason that neon is used is that it is an inert gas, and hence it does not combine with the element of which the electrodes are made, as would any of the active gases. Nearly all other gases are absorbed or *occluded* by the glass of which the bulb is made, while the neon remains intact.

How the Neon Lamp Works.—For television reception it is necessary to have a lamp that can vary its light from zero to maximum at least 100,000 times per second. The heat developed by the current which passes through the filament of an incandescent lamp is so intense that when it is lighted to brilliancy, it takes about 1/10 of a second after the current has been reduced for the light to fall off a proportionate amount.

Since television requires that variations in the brightness of the lamp shall take place with such high frequency, it is clear that this cannot be accomplished with an ordinary filament lamp. These high frequency variations can be had with a neon lamp because its light intensity depends on the voltage impressed, and not on the heating value of the current. The action of a neon lamp is very like that of an electric spark which takes place in air, and I shall begin by explaining the latter, as this will make it easier to understand the action of the neon lamp.

When a spark passes between the terminals of a spark gap (see *A* in Fig. 91), it does so because electrons, or negative particles of electricity, are torn from the atoms of the cathode, or negative electrode. These electrons are projected toward the anode, or positive electrode of the spark gap. To tear off these electrons from the metal cathode, in air, requires a very high voltage—in the neighborhood of 30,000 volts per linear inch of air between the electrodes, and this is

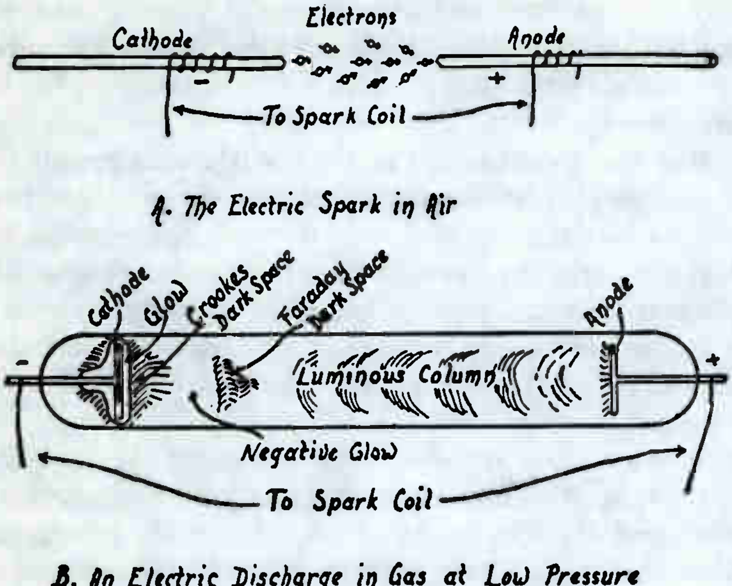


FIG. 91—The Electric Discharge in Air and Gas.

the reason a spark coil is used to set up the necessary high-voltage currents.

The electrons torn off by the high voltage currents are projected at high speed and with great force, and when they strike the atoms of the gases which form the air, these in turn tear off their electrons, which also move toward the positive electrode of the spark gap. Some of these electrons recombine with the *ions*, as the atoms are called which have lost their electrons, and it is the movements of the latter that set up electro-magnetic waves in the ether, as described in the first chapter. When these waves strike the retina of your eye they produce the sensation of light in the visual center of your brain.

Let us see just what happens when the wire electrodes are sealed in the ends of a glass tube and a little of the air is pumped out of it. If you connect it to the secondary of a spark coil, the voltage needed per linear inch to carry the discharge between the electrodes is very considerably reduced. This is because the electrons which are projected from the cathode, or negative electrode, can travel a much longer distance before they strike an atom of the gas that is in the tube. The spark takes on the aspect of a thin, flickering discharge, and this is accompanied by a thin crackling sound very much like that which you hear when you rub a cat's back in the winter time.

As you keep on pumping the air out of the tube, the spark grows fatter and crackles less until, finally, the whole tube is filled with a discharge that glows with a soft and steady light. In the beginning of the experiment, the discharge takes place between the points of the electrodes, but, as the vacuum gets higher, a faint, velvety glow covers the whole surface of the cathode.

It is at this stage that the marked characteristic features of the glow tube become apparent, and you will read a good deal about them in connection with the neon lamp. These features are (1) the *surface glow* on the cathode; (2) close around this the *Crookes dark space*; (3) beyond this is a luminous space called the *negative glow*; (4) the *Faraday dark* *space*, and (5) a soft light that fills the tube clear up to the anode, or positive electrode. This is called *the positive column.* It is not a continuous column of light, but is broken up into alternate bright and dark bands called *striæ*, across the axial line of the discharge. And there you have the Geissler tube. The glow discharge of such a tube is shown at *B*.

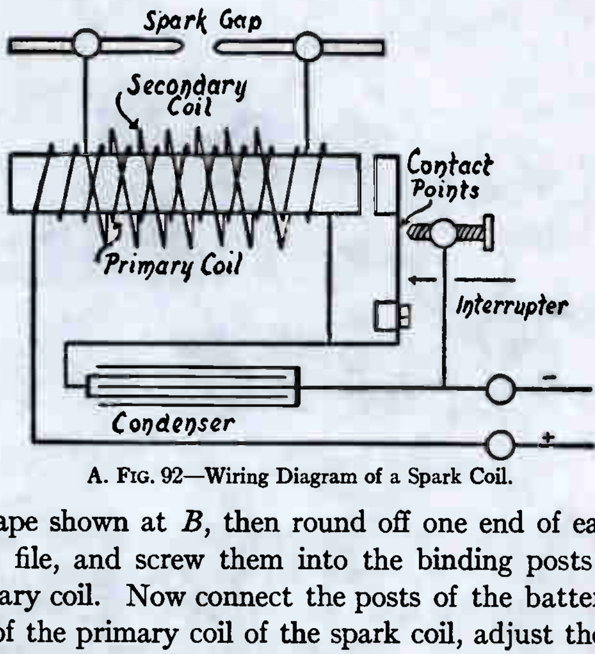
While the electrodes of a neon lamp have very large surfaces and these are placed close together as compared with those of the Geissler tube, the same phenomena occur in each case, though to the eye they bear little resemblance to each other.

In the neon lamp the discharge takes the form of a thin even film of red tinted glow on the cathode plate, and every minute change in the current that produces it is marked by a like change in the brightness of the light. It is this characteristic, together with the instantaneousness with which these changes take place, that makes it so well adapted for the reception of the picture impulse currents used in television reception.

Experiments with Glow Tubes.—*Experiments with the Electric Spark.*—Before you begin to experiment with glow tubes, you should make an examination of the electric spark in ordinary air. To do this you will need a small *induction coil*, or *spark coil*, as it is popularly called, a *battery* to energize it, and a *spark gap*. A ½-inch spark coil, or one that gives a maximum spark ½ of an inch in length, will be large enough.

The purpose of the spark coil is to raise the low voltage (say 10 volts) of the battery to a high voltage (say about 15,000 volts). The coil also changes the direct current of the battery into an interrupted current, and, as these impulses flow through the primary coil, they set up low frequency alternating currents of high voltage in the secondary coil. The structure of a spark coil is shown in the wiring diagram at *A* in Fig. 92, and a picture of the coil complete is given at *B*.

To make the spark gap, cut off two pieces of copper wire 1/16 of an inch in diameter and 3 inches long, bend them to



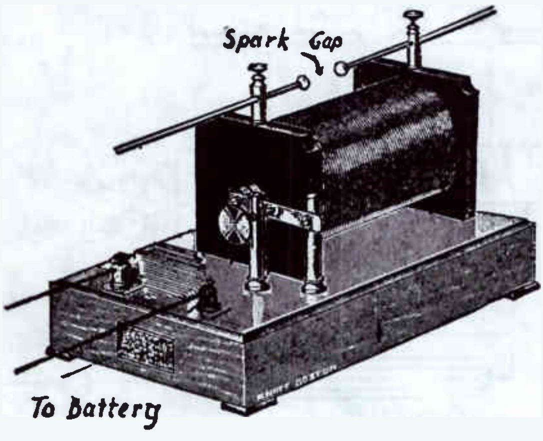
A. FIG. 92—Wiring Diagram of a Spark Coil.

the shape shown at *B*, then round off one end of each one with a file, and screw them into the binding posts of the secondary coil. Now connect the posts of the battery with those of the primary coil of the spark coil, adjust the interrupter, and you are all set to make the experiments.

(1) For the first experiment, separate the points of the spark gap[1], or *electrodes* as they are called, about ⅛ of an

[1] This term is used in two ways, namely (1) to indicate the electrodes and (2) to refer to the length of the gap between the points. The first is written *spark gap* and the second is hyphenated thus, *spark-gap*.

inch, then close the battery circuit, when a thick, white spark will fill the gap. Now gradually increase the length of the spark-gap by drawing the wire electrodes apart, when the spark will become thinner and redder as you increase the length of it. This shows that the shorter the spark is, the lower the voltage and the higher the amperage of the current which produces it.



B. FIG. 92—The Spark Coil Ready to Use.

(2) The voltage required for producing the spark may be reduced either by shortening the spark-gap or by reducing the air pressure between the electrodes, or both. To demonstrate this fact, separate the points until they form a gap an inch long.[1] (*a*) Now close the battery circuit and you will see that the voltage developed by the secondary coil is not high enough to break down the air between the points. (*b*) To

[1] This is assuming that your coil gives a ½-inch spark. Whatever the size of your coil, set the points just beyond the striking distance of the spark.

reduce the air pressure in and around the spark gap, all you need to do is to hold a lighted candle so that the flame will be between the points of the spark gap. Now close the battery circuit, and the spark will easily bridge the gap.

Experiments with the Vacuum Tube.—(1) It is easy to make the high-voltage current of a ½-inch spark coil pass between the points of a pair of electrodes that are 6 or 8 inches apart in a tube with some of the air pumped out of it.

FIG. 93—The Aurora Vacuum Tube.

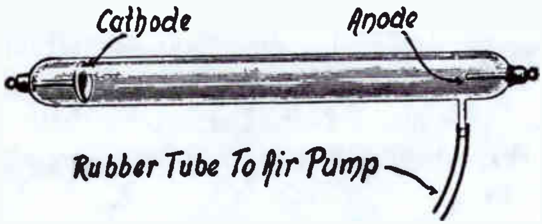
A *Geissler tube*[1] (see Fig. 89), is of this kind, as it has the electrodes sealed in the ends of a glass tube from which the air has been pumped to produce a low vacuum

The color of the light produced by a Geissler or other vacuum tube depends on the kind of gas there is in it; thus a tube containing nitrogen, or nitrogen and oxygen, *i.e.*, the air you breathe, gives a reddish-yellow color, hydrogen gives a somewhat bluish color, and carbon dioxide gives a pale whitish light.

(2) By using what is called an *aurora tube*, which is a tube about 1 inch in diameter and 10 inches long (see Fig. 93), you can see the glow set up by the high-voltage current of a spark coil to a much better advantage than with a Geissler tube, because it is so much larger. This tube is exhausted

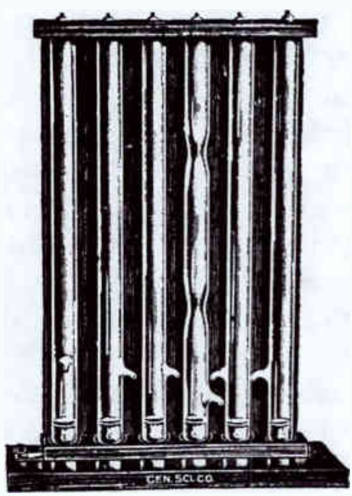
[1] A 6-inch Geissler tube is obtainable for 60 cents or an 8-inch tube for 80 cents, from the Central Scientific Co. of Chicago, Ill.

to about 40 millimeters of vacuum and gives a very pretty glow, while a small point of light appears at the cathode, and a violet band at the anode.



A. FIG. 94—A Vacuum Discharge Tube.

(3) To use the *vacuum discharge tube* shown at *A* in Fig. 94, you must connect it up with an air pump, so that the air



B. FIG. 94—A Set of Vacuum Discharge Tubes.

pressure in it can be reduced to .02 of a millimeter. The tube is 1⅜ inches in diameter and 15 inches long. To get the best results, you should use a 1-inch, or larger, spark coil as a source of energy.

The tube has a concave cathode and is fitted with a side outlet tube near one end, so that you can connect it to an air pump. Now when the air is pumped out of it until the pressure has been reduced to 2 millimeters (about 1/16 of an inch) you can see all of the effects previously described under the caption, *How a Glow Tube Works*, namely, (1) the Crookes dark space, (2) the negative glow, (3) the Faraday dark space, and (4) the positive column. It also shows

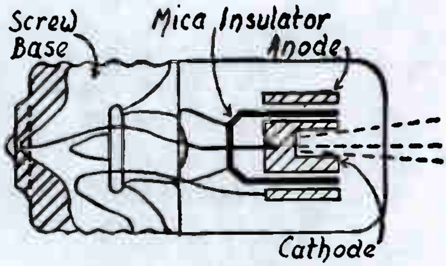


FIG. 95—The Corona Glow Lamp.
(*The Forerunner of the Neon Lamp.*)

(although this has nothing to do with neon glow lamps), (*a*) the focus of the cathode rays at the center of the cathode, (*b*) the greenish-yellow ring of X-ray fluorescence where the cathode rays strike the glass, and (*c*) the striking effects when the cathode rays are deflected by a magnetic field.

(4) A set of six vacuum tubes, or *vacuum scale tubes*, as they are called, see Fig. 95, will cost twice as much as the vacuum discharge tube described above, but they will save you the price of an air pump and the attendant work of exhausting them.

Tube No. 1 has a 40 millimeter (mm.) vacuum and gives a small point of light at the cathode and a violet band at the anode; tube No. 2 has a 10 mm. vacuum and shows the beginning of the cathode or Crookes dark space; tube No. 3 has a 6 mm. vacuum and is nearly filled with light, but the cathode dark space is no longer than in the No. 2 tube; the No. 4 tube has a 3 mm. vacuum and shows stratification and the beginnings of the second, or Faraday dark space;

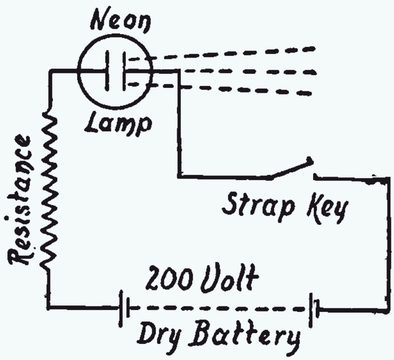


FIG. 96—A Set-up for Lighting a Neon Tube.

tube No. 5 has a 0.14 mm. vacuum and shows a green fluorescence where the cathode rays strike the glass; and finally, tube No. 6 has a 0.03 mm. vacuum, or *Röntgen vacuum*, as it is commonly called, and X-rays are given off.

Experiments with the Neon Lamp.—In making experiments of any kind with a neon lamp, always use a *limiting resistance* in series with it. The reason it is necessary to do this is because if the voltage of the battery is too high an arc will be formed across the electrodes, and this will permanently injure it. The neon lamps from the different makers do not have the same striking voltage, which ranges from 160 to 200 volts, and you must not try to pass a direct current through them larger than 20 milliamperes. For the following experiments you need a 2-watt neon tube that works on a 180-volt current, and this can be a battery current. You also need a milliammeter for all the tests, and a few other accessories, such as a switch, a variable resistance, and a variable condenser for some.

The Light of the Neon Lamp.—(1) Connect the neon lamp in series with the battery, a resistance of 10,000 ohms, and a baby knife-switch (or better, a strap key) as shown in Fig. 96. (*a*) Now throw on the current and examine the light the lamp gives, when you will see that instead of emitting the dazzling whitish light that an incandescent lamp gives, the neon lamp glows with a bright reddish light, if the glass it is made of is clear, or with a pinkish light if the glass has a little blue coloring matter in it.

(*b*) The light of a neon lamp is peculiar in that it is scarcely actinic; that is, it is not active in producing chemical changes, and yet its light is far-reaching and very penetrating. In the photographic dark room the neon lamp is a safe light for developing films and plates, provided, of course, these are of the ordinary kind and are not those which are sensitive to red light.

Telegraphing with Neon Lamps.—To telegraph with neon lights at night is very easy, for all you need is a pair of the above-described set-ups, so placed at the different points that there will be an unobstructed line of sight between them. Now fix a reflector back of each one, as shown in Fig. 97, and you are all ready to send signals, or telegraph messages, in the Morse code. As there is no time-lag in the neon lamp, in which respect it is different from an incandescent lamp, the light responds instantly to the make and break of the key.

The Neon Lamp as a Voltage Indicator.—A neon lamp is far more sensitive to high voltage currents than a Geissler tube, and, when it is brought close to a source of high tension current, it will glow without being connected. It is, therefore, used for detecting the presence of a high voltage current

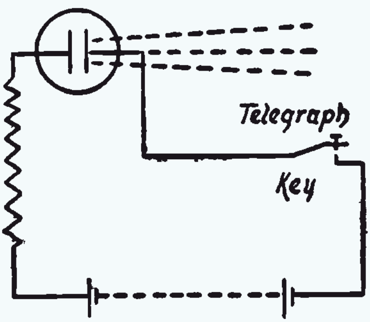


FIG. 97—A Set-up for Telegraphing with a Neon Lamp.

in a power transmission line, or for determining whether or not a high-voltage apparatus is functioning.

(*a*) Connect the spark coil with a battery and switch, and make a pair of spark gap electrodes of pieces of wire that are long enough to project from the binding posts of the spark coil about 2 or 3 inches, as shown at *A* in Fig. 98. Solder a wire 2 or 3 inches long to each one of the terminals of the neon tube, and bend these wires from each other as shown at *B*. Now start up your spark coil, and then hold the neon lamp close to it so that its wires will be parallel with those of the spark gap, as shown in the illustration, when it will light up.

(*b*) You can quickly find out whether the spark plugs of your motor car, motor boat, or airplane are in working order by holding a neon lamp close to each one in turn, or, better, hold one terminal of the tube against the spark plug. If the tube lights up it shows that the plug is firing and, conversely, if it does not light up you will know that the plug is dead.

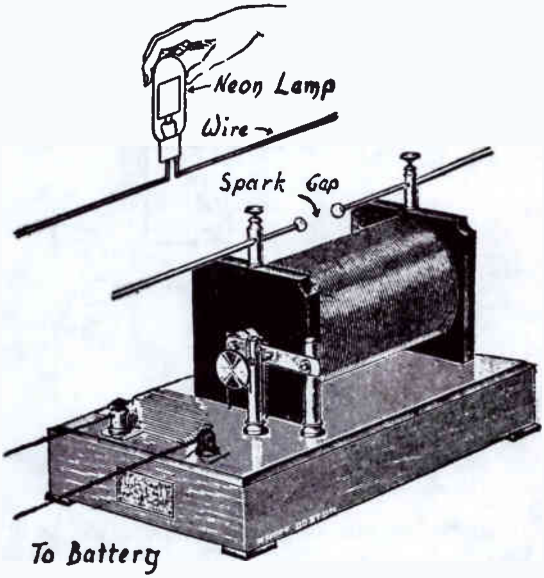


FIG. 98—The Neon Lamp as a Voltage Indicator.

One can get a little neon lamp that is mounted in the end of what looks to be a fountain pen barrel, and this is made for the particular purpose of testing spark plugs.

A Neon-Lamp Flasher.—This *flasher*, as it is called, is nothing more nor less than an automatic interrupter, and it is largely used for intermittently turning on and off the current which operates electric signs. (*a*) To make a flasher of this kind, connect the neon tube and a variable condenser of .10 microfarad capacitance in parallel, and then connect one side of this circuit with one post of a variable resistance of 10,000 ohms and the other post of this with one of the posts of a 200-volt battery or other source of current, and the other post of this to the other side of the lamp and condenser circuit. The above set-up is wired as shown in Fig. 99.

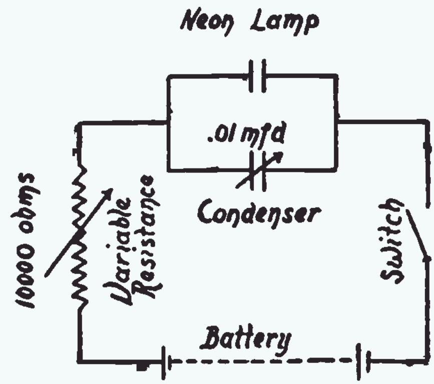


FIG. 99—Set-up For a Neon Flasher.

(*a*) Now when the current is turned on, the lamp will light up and then go out, and this cycle will be continually repeated until you cut off the current. (*b*) Change the variable resistance a little, when you will see that the frequency of the flashes will be altered. A change in the capacitance of the condenser likewise changes the frequency. By varying the resistance and the capacitance, the circuit may be tuned to make any number of flashes desired, from 1 per minute to 10,000 per second.

(*c*) To operate ordinary incandescent lamps, or any other kind of apparatus, with a flasher, you need only to connect the cathode terminal of the neon tube with one of the posts of a telegraph relay that leads to the magnet coil, the other post of this to the negative pole of the battery, and this with one terminal of the lamp or piece of apparatus you want to work. Finally connect the other post of this with the positive post of the battery and this to the anode terminal of the lamp, as shown in Fig. 100. Now every time the lamp flashes it closes the magnet circuit of the relay, and this, in turn,

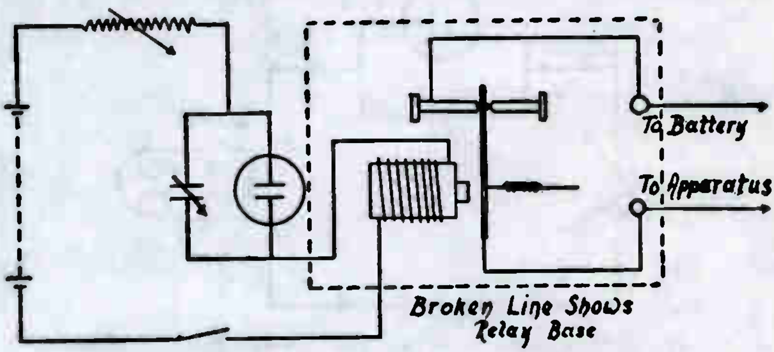


FIG. 100—Working a Relay with a Neon Flasher.

brings the points into contact and so closes the lamp or apparatus circuit.

The theory of the periodic flashing of the neon lamp as described above is, according to Mecke and Lambrez[1], due to the fact that it has two *critical voltages*, a high and a low one. When the voltage across the condenser and the lamp which are connected in parallel, rises to a value that is equal to the voltage which is required to start a flash, the lamp is lighted and this is its *high critical voltage;* when the flash

[1] See *Physikalische Zeitschrift*, 1926, pp. 27, 86.

takes place, the resistance of the space between the electrodes of the lamp drops and so, also, does the potential difference[1] between them.

The flash, however, does not end until the potential difference between the electrodes falls below the *low critical voltage*, and, as soon as the flash ends, the condenser begins to charge up to the high critical voltage. A milliammeter in the circuit will show a rise from 0, which is the low critical

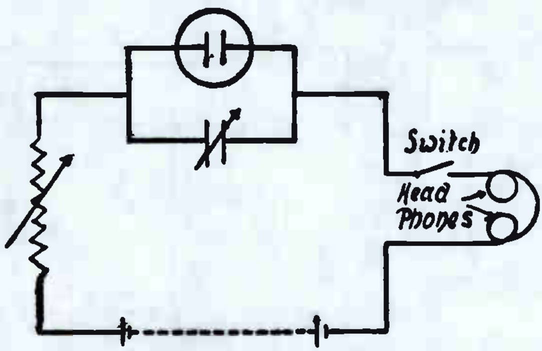


Fig. 101—How to Change Light Into Sound. (*With a Pair of Head-phones.*)

value, to as much as 30 milliamperes, which is the high critical value and the point where the flash takes place.

Changing Light Into Sound.—With the set-up shown in Fig. 101, you can translate light into sound, and to do this you need only to make the flashes take place with a frequency rapid enough to produce sound. Now (*a*) connect a *telephone receiver*, a battery, and the lamp, in series, and to vary the note emitted by the telephone receiver, vary the capacitance

[1] In electricity, the term *potential* is used in the same sense as the word *level* in mechanics or hydrostatics. *Potential difference*, therefore, means the difference in the level of electric pressure.

and you can vary the pitch of the tone over the entire audible range of from 16 to 10,000 vibrations per second.

(*b*) By connecting the above neon lamp set-up with a single stage audio-frequency amplifier and the primary coil of an audio-frequency transformer, and the secondary coil of this with a loud speaker, as pictured in Fig. 102, you can obtain a loud note of any frequency from the lowest to the

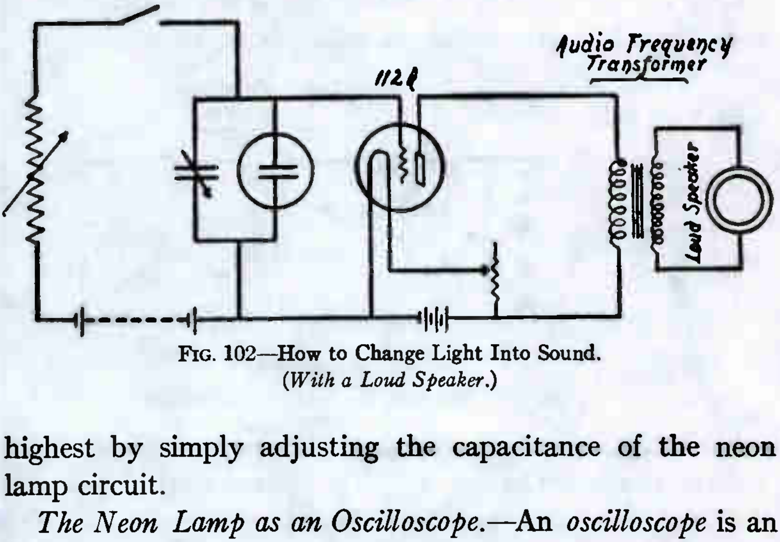


FIG. 102—How to Change Light Into Sound.
(*With a Loud Speaker.*)

highest by simply adjusting the capacitance of the neon lamp circuit.

The Neon Lamp as an Oscilloscope.—An *oscilloscope* is an instrument which visually indicates the changes that take place in a current of varying strength. You can easily make an oscilloscope with a neon lamp, which provides the fluctuating light, by connecting the anode of it with one of the secondary terminals of a telephone induction coil and the other terminal of this with the positive pole of a battery. Connect the cathode of the lamp with one post of a 100,000 ohm resistance, and the other post of this with the negative pole of the battery or other source of current. Connect a .01 microfarad condenser between the lamp and the secondary coil on the one side of the circuit and the high resistance on the other side of it, as shown at *A* in Fig. 103. Finally, connect one terminal of a microphone, or a regular telephone transmitter, with one end of the primary of the telephone induction coil, and the other end of this with one pole of a 10- or 12-volt battery, the other pole of which is connected with the other terminal of the microphone, as at *B*.

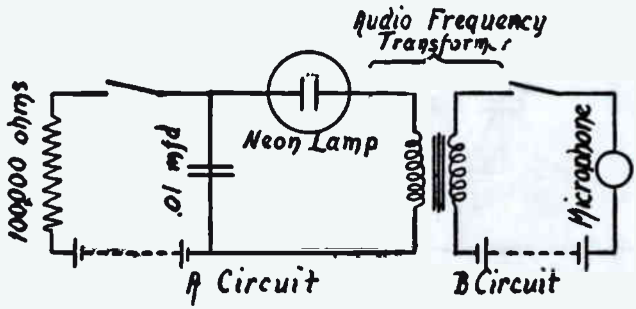


FIG. 103—The Neon Lamp as an Oscilloscope.

(1) For this experiment and the one to follow, throw enough resistance in the *A* circuit to just start the glow of the lamp, and then talk into the microphone; at the same time keep your eye on the neon tube, and you will see the light fluctuate on the plate, varying from a small spot at the bottom to an area that covers the whole surface of it; the rise and fall of the light will vary with the force of your voice and the wave form of it.

(2) Use the same set-up as in the preceding experiment and place a rotating mirror, see *A* in Fig. 104, so that you can see the reflected light of the neon lamp in it, as pictured

at *B*. Revolve the mirror by means of the electric motor, and talk into the microphone, and you will see the wave form of your voice

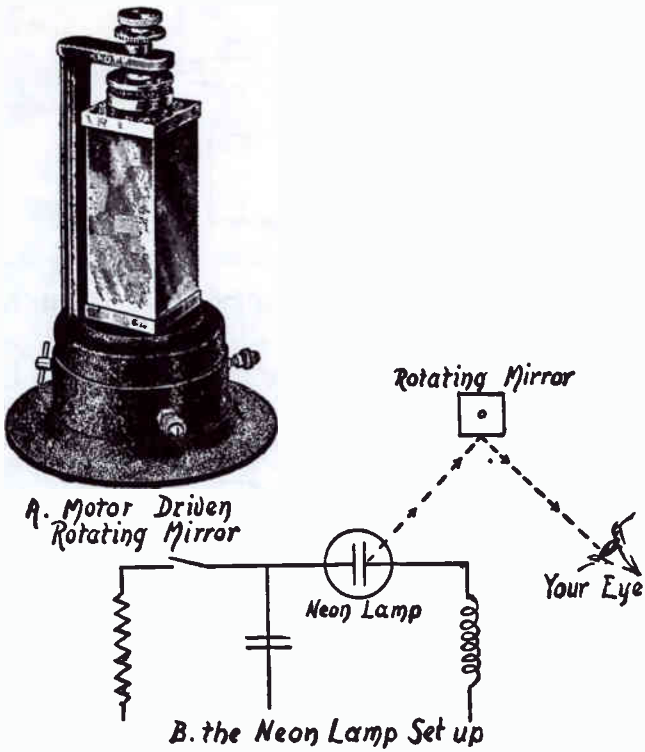


Fig. 104—How to See the Wave Form of Your Voice.

The Neon Lamp as a Photo-Electric Cell.—Nearly all neon lamps possess the characteristic property of the photo-electric cell, by which I mean that when the rays of light from an incandescent lamp, or other bright source, are made to fall on the plate of it, the sparking potential is lower than when it is dark.

To show this phenomenon, connect up a neon lamp with a galvanometer, a resistance, and a 200 volt battery, as

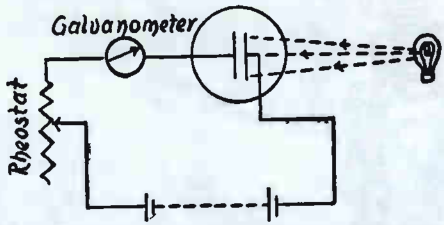


Fig. 105—A Set-up for Showing the Photo-Electric Action of a Neon Lamp.

shown in Fig. 105. Now take a reading of the galvanometer, then let a bright light fall on the neon lamp, and it will be found that the voltage required to operate the lamp is considerably decreased.

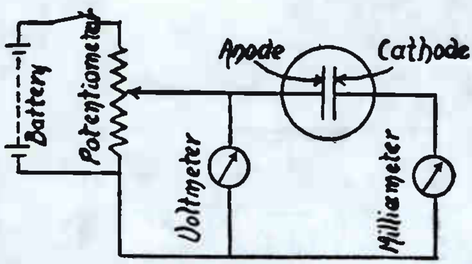
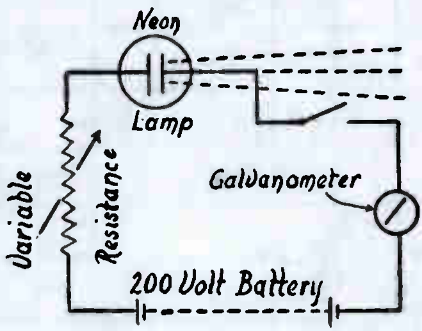


Fig. 106—A Set-up for Plotting the Volt-Ampere Characteristics of a Neon Lamp.

To Determine the Volt-Ampere Characteristics of a Neon Lamp.—There is a definite relation between the voltage that is impressed on the neon lamp and the current that is required to light it. The ratio between these two factors, or *volt-ampere characteristic*, as it is called, can be plotted by means of the set-up shown in Fig. 106.

For the set-up, connect the anode of the neon lamp with the movable point of the potentiometer, and the fixed terminals of this to the poles of a battery. The cathode of the lamp is connected to one of the posts of a milliammeter, the other post of which leads to the negative pole of the battery. A voltmeter connected across the lamp completes the set-up.

To plot the voltage-ampere curve, gradually increase the voltage from 0, by varying the resistance of the potenti-



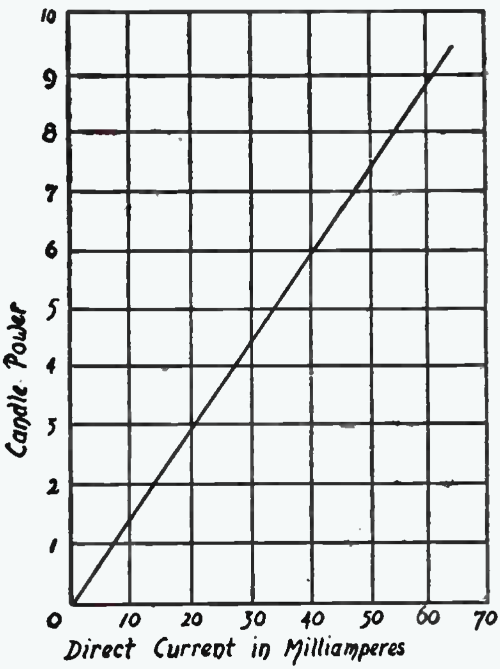
A. **FIG. 107—A Set-up for Showing the Relation of Brightness to Current-Strength.**

ometer, and, at every 5 volts of increase, mark the voltage and milliampere reading on your plotting paper.

Determining the Light Characteristics of a Neon Lamp.—To show that the light of a neon lamp varies *proportionately as the current that energizes it*, connect the cathode to one of the posts of a rheostat, the other post of this to the negative pole of a 200-volt battery, the positive pole of this to one post of a galvanometer, the other post of this to one post of a switch or key, and, finally, the other post of this to the anode of the lamp, as shown at *A* in Fig. 107.

A plot of the characteristics of the neon lamp will show that the candle power of the lamp versus the milliamperes of the direct current is represented by a straight line, as shown at *B*.

When you vary the resistance of the rheostat, the current that flows through it will be varied, and the intensity of the



B. Fig. 107—Relation of Brightness to Direct Current.

light will vary proportionately, as is shown in Fig. 107. You can easily see the changes in the brightness of the light by simply looking at it.

To Measure the Intensity of the Light of a Neon Lamp.—For this experiment, use the same set-up as that described above and a *photometer* of some kind. A photometer is an instrument for measuring the intensity of light in terms of *candle power*, and the easiest way to do this is to compare your neon light with that of a candle light. The simplest kind of a photometer is the one invented by Count Rumford, and it is called a *shadow photometer*. It consists of a wooden base, to one end of which is fixed a vertical sheet of cardboard, called a *screen*, and about 3 inches in front of this is secured a thin wooden rod, as shown in Fig. 108.

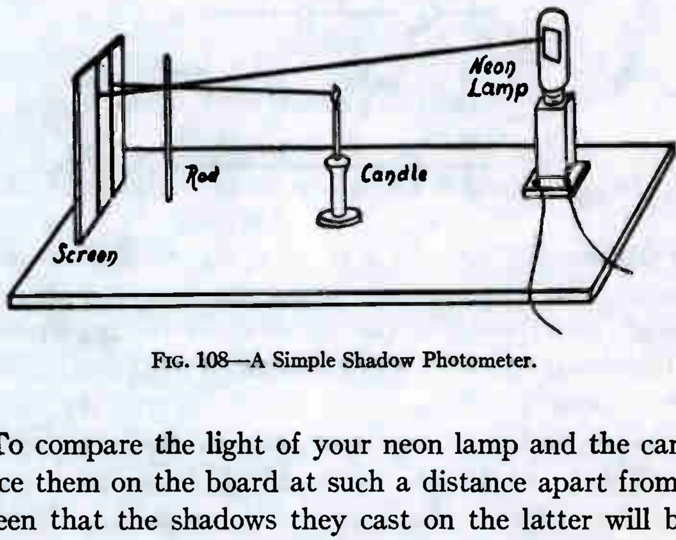


Fig. 108—A Simple Shadow Photometer.

To compare the light of your neon lamp and the candle, place them on the board at such a distance apart from the screen that the shadows they cast on the latter will be of equal density. Since the shadow cast by the neon lamp is illuminated only by that of the candle, it follows that if the shadows are equally dense the illumination of the screen by the two lights must be of equal intensity.

Since the intensity of the illumination on a surface from a given source of light is inversely proportional to the square of the distance of the surface from the source of light,[1] by measuring the distance from the neon lamp to the screen and from the candle to the screen, a simple calculation will give you the relative intensities of the two lights.

The Neon Lamp as a Rectifier and a Detector.—The neon lamp can be used as a rectifier for alternating currents and a a detector for electric oscillations, though it is not very sensitive for the latter purpose.

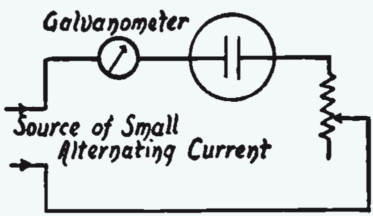


FIG. 109—A Set-up for a Neon Lamp Rectifier or a Detector.

(*a*) To use the lamp as a rectifier for small alternating currents, connect the cathode of the tube through a rheostat to one of the terminals of the source of alternating current, and the anode through a milliammeter to the other a.c. terminal as shown in Fig. 109. This done, read the meter, then reverse the a.c. connections and read the meter again. You will find that the ratio of the current in one direction to that of the current in the other direction is in the neighborhood of about 1 to 4. This being true, it is obvious that the tube can be used as a rectifier.

The reason it acts as a rectifier is due to the difference in the size of the surface areas of the two electrodes, and, it

[1] This is known as the law of *inverse squares*. For a fuller explanation of it see any college text book on *Physics*.

follows, that the current is spread over a much larger area on the one than on the other. Of course if both electrodes are the same size, as they are in some lamps, it cannot be used as a rectifier.

(*b*) To use the neon lamp as a detector for receiving incoming radio signals, you can employ the same set-up as was described for the Fleming two-electrode detector and which

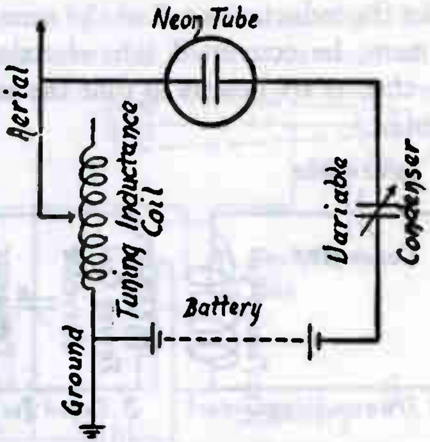


FIG. 110—The Neon Tube as an Electric Wave Detector.

is reproduced in Fig. 110. The action of the lamp as a detector depends on its rectifying properties, as explained in the preceding paragraph.

The Neon Lamp as a Tuning Indicator.—With this set-up you can instantly see when two circuits are in tune with each other. (1) To make the experiment, connect the primary coil of your spark coil with a battery and key and the spark gap terminals in series with a fixed inductance coil and a variable condenser, as shown at *A* in Fig. 111. Next connect a neon lamp, a fixed inductance coil, and a battery,

To find the wave length, you need only to divide the velocity (V), which is given above, by the frequency (F), which you can get with the wave meter.

Connecting the Neon Lamp with the Amplifier Tube.—You can connect the neon lamp to the output of the last amplifier tube in any one of several different ways, but it is usually done by means of a resistor, an *impedance coil*, or *choke coil*, as it is commonly called, or by an *audio-frequency transformer*.

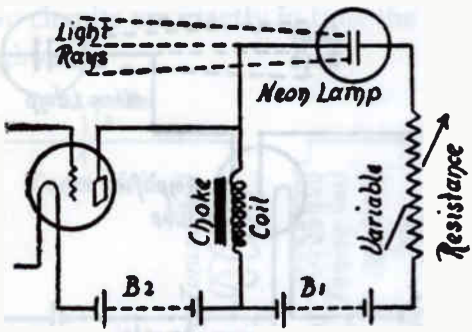


FIG. 113—A Neon Lamp Amplifier-Tube Circuit with a Choke Coil.

(1) The simplest way is to connect the anode of the neon lamp directly to the plate of the last (or output) amplifier tube, then the cathode of the lamp to the negative pole of the battery and the positive pole of this to the filament of the amplifier tube, as shown in Fig. 112. In using this circuit, you must see to it that the plate voltage of the amplifier tube is a little higher than the striking voltage of the neon tube.

(2) Another way is to connect the cathode of the neon lamp with the plate of the amplifier tube, the anode of the lamp with one post of a 1000-ohm variable resistance,

follows, that the current is spread over a much larger area on the one than on the other. Of course if both electrodes are the same size, as they are in some lamps, it cannot be used as a rectifier.

(*b*) To use the neon lamp as a detector for receiving incoming radio signals, you can employ the same set-up as was described for the Fleming two-electrode detector and which

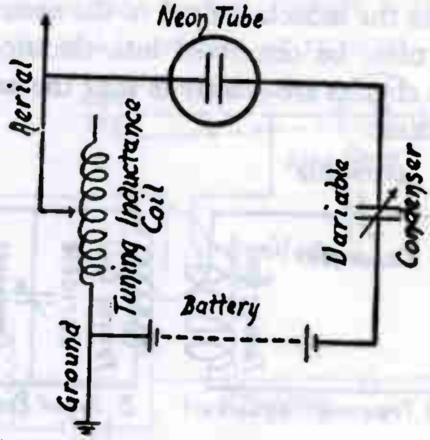


Fig. 110—The Neon Tube as an Electric Wave Detector.

is reproduced in Fig. 110. The action of the lamp as a detector depends on its rectifying properties, as explained in the preceding paragraph.

The Neon Lamp as a Tuning Indicator.—With this set-up you can instantly see when two circuits are in tune with each other. (1) To make the experiment, connect the primary coil of your spark coil with a battery and key and the spark gap terminals in series with a fixed inductance coil and a variable condenser, as shown at *A* in Fig. 111. Next connect a neon lamp, a fixed inductance coil, and a battery,

To find the wave length, you need only to divide the velocity (V), which is given above, by the frequency (F), which you can get with the wave meter.

Connecting the Neon Lamp with the Amplifier Tube.—You can connect the neon lamp to the output of the last amplifier tube in any one of several different ways, but it is usually done by means of a resistor, an *impedance coil*, or *choke coil*, as it is commonly called, or by an *audio-frequency transformer*.

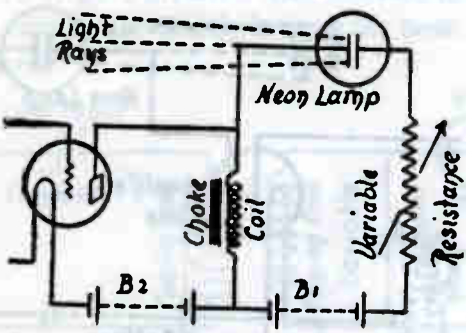


FIG. 113—A Neon Lamp Amplifier-Tube Circuit with a Choke Coil.

(1) The simplest way is to connect the anode of the neon lamp directly to the plate of the last (or output) amplifier tube, then the cathode of the lamp to the negative pole of the battery and the positive pole of this to the filament of the amplifier tube, as shown in Fig. 112. In using this circuit, you must see to it that the plate voltage of the amplifier tube is a little higher than the striking voltage of the neon tube.

(2) Another way is to connect the cathode of the neon lamp with the plate of the amplifier tube, the anode of the lamp with one post of a 1000-ohm variable resistance,

follows, that the current is spread over a much larger area on the one than on the other. Of course if both electrodes are the same size, as they are in some lamps, it cannot be used as a rectifier.

(*b*) To use the neon lamp as a detector for receiving incoming radio signals, you can employ the same set-up as was described for the Fleming two-electrode detector and which

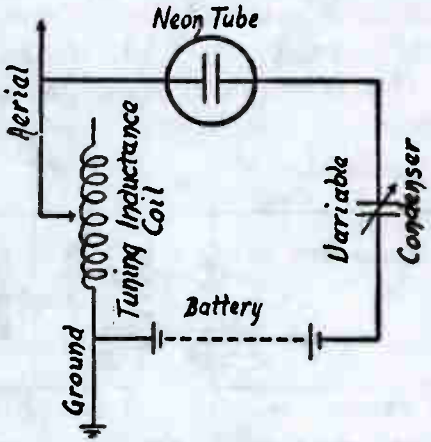


FIG. 110—The Neon Tube as an Electric Wave Detector.

is reproduced in Fig. 110. The action of the lamp as a detector depends on its rectifying properties, as explained in the preceding paragraph.

The Neon Lamp as a Tuning Indicator.—With this set-up you can instantly see when two circuits are in tune with each other. (1) To make the experiment, connect the primary coil of your spark coil with a battery and key and the spark gap terminals in series with a fixed inductance coil and a variable condenser, as shown at *A* in Fig. 111. Next connect a neon lamp, a fixed inductance coil, and a battery,

in series, and then connect a variable condenser across the circuit, as shown at *B*.

Set the inductance coils of *A* and *B* close to and in parallel with each other and make the spark-gap ⅛ of an inch long. Close the battery circuit, when strong *damped* electric oscillations[1] will be set up in the spark-gap circuit. These oscillations will send out periodic electric waves,[2] and when the latter strike the inductance coil of the neon lamp circuit they will, in turn, be converted into electric oscillations. When the two circuits are exactly in tune the neon lamp will glow the brightest.

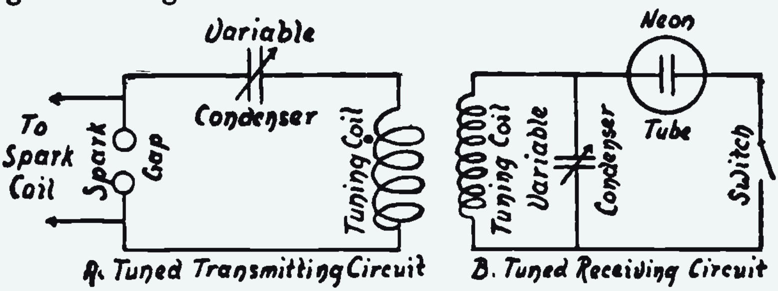


FIG. 111—A Neon Lamp as a Tuning Indicator and Wave Meter.

The Neon Lamp as a Wave Meter.—A *wave meter* is used to find the frequency of the oscillations that surge in a circuit. To make a wave meter with the set-up shown at *B* in Fig. 111 you must use a calibrated[3] inductance coil and a condenser.

To measure the frequency of the oscillations of a sending circuit, place the coil of the wave meter fairly close to and parallel with the coil of the circuit, and then vary the capacitance of the condenser until the glow of the lamp is the

[1] See Chapter VII. [2] See Chapter VII. [3] See Chapter VII.

brightest. From the known value of the inductance (L) of the wave-meter coil and the capacitance (C) of the condenser, when the circuit is in tune, you can calculate the frequency of the oscillations by the following equation, where F is the frequency and 1 is a constant:

$$F = \frac{1}{2\pi \sqrt{LC}}$$

What you usually want to find, though, is the length of the electric waves which are sent or received, rather than

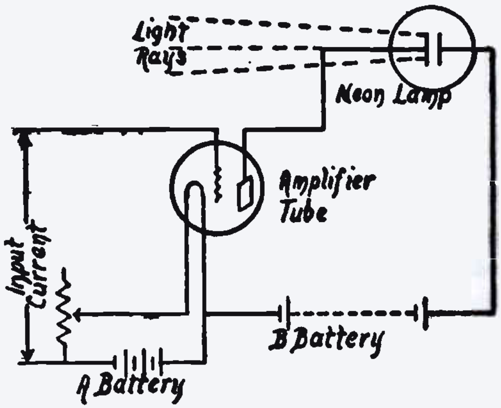


FIG. 112—A Simple Neon Lamp Amplifier Tube Circuit.

the frequency of the oscillations that sets them up. To find the wave length (λ) you must know, however, what the frequency is, because they are fundamentally related, as the following formula shows:

$$\lambda = \frac{V}{F}$$

where V is the velocity of the electric waves in air, and this is 300,000,000 meters per second,[1] and F is the frequency.

[1] This is about 186,500 miles per second.

To find the wave length, you need only to divide the velocity (*V*), which is given above, by the frequency (*F*), which you can get with the wave meter.

Connecting the Neon Lamp with the Amplifier Tube.—You can connect the neon lamp to the output of the last amplifier tube in any one of several different ways, but it is usually done by means of a resistor, an *impedance coil*, or *choke coil*, as it is commonly called, or by an *audio-frequency transformer*.

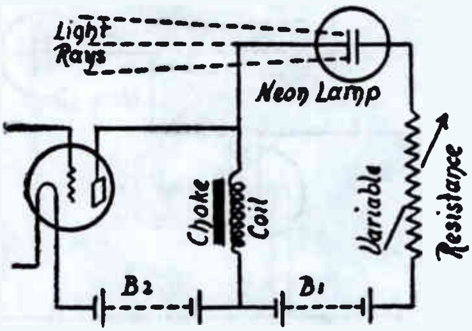


FIG. 113—A Neon Lamp Amplifier-Tube Circuit with a Choke Coil.

(1) The simplest way is to connect the anode of the neon lamp directly to the plate of the last (or output) amplifier tube, then the cathode of the lamp to the negative pole of the battery and the positive pole of this to the filament of the amplifier tube, as shown in Fig. 112. In using this circuit, you must see to it that the plate voltage of the amplifier tube is a little higher than the striking voltage of the neon tube.

(2) Another way is to connect the cathode of the neon lamp with the plate of the amplifier tube, the anode of the lamp with one post of a 1000-ohm variable resistance,

the other post of this with the positive pole of the battery marked B1 and the negative pole of this with the filament of the tube. Now connect a choke coil between the plate and the positive pole of the battery marked B2 and the negative pole of this to the filament of the tube, as shown in Fig. 113.

(3) Still another way is to use two choke coils, and for this circuit, connect the cathode of the neon lamp with one terminal of a choke coil, the other terminal of this with the

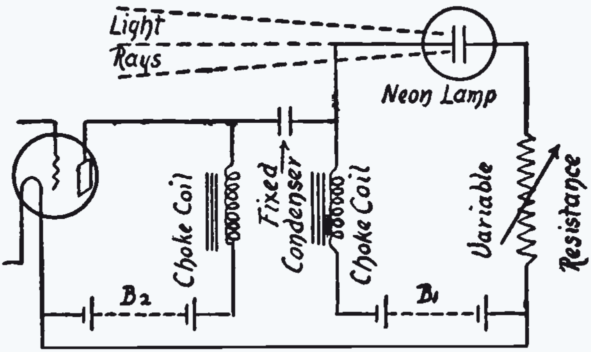


FIG. 114—A Neon Lamp Amplifier-Tube Circuit with Two Choke Coils.

negative pole of the battery marked B1, and the positive pole of this with the anode of the tube. Next connect the plate of the last or output amplifier tube to one post of the second choke coil, and the other terminal of this with the positive pole of a battery marked B2, and the negative pole of this with the filament of the amplifier tube. Connect the plate of the amplifier tube to one side of a fixed condenser and the other side of this with the cathode of the neon tube. Finally connect the negative pole of battery B2 with the positive pole of the battery B1 as shown in Fig. 114.

(4) A fourth way is to use an audio-frequency transformer, as shown in Fig. 115. To do this, connect the plate of the amplifier tube to one terminal of the primary coil of the transformer, the other terminal of this to the positive pole of the battery, and the negative pole of this to the filament of the tube. The next step is to connect the cathode of the neon tube to one terminal of the secondary coil of the transformer, and the other terminal of this to the filament of the

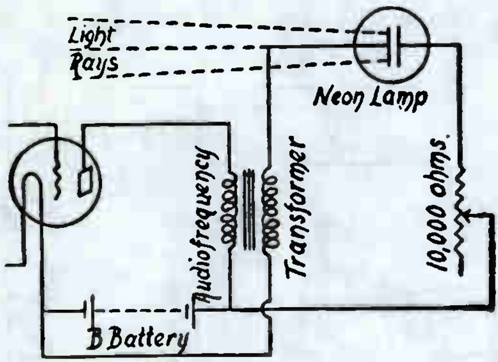


FIG. 115—A Neon Lamp Amplifier-Tube Circuit with an Audio-Frequency Transformer.

amplifier tube. Finally connect the anode of the lamp with one post of a variable resistance, and the other post of this with the positive pole of the battery, when the set-up is ready to use.

Experiments with the Neon Lamp and Scanning Disk.—In the *television receiver*, the scanning disk is placed between the neon lamp and the eye of the observer. As explained in Chapter III, the scanning disk is used in the receiver to keep the eye of the observer on a given point which corresponds to the current impulse that represents, in turn, the picture element which is being transmitted at that particular instant. When the scanning disk at the transmitter is rotating, and the outside hole traverses the upper edge of the field of view, the outside hole of the receiver likewise moves across the upper edge of the plate on the neon lamp at exactly the same instant. The result of this synchronous action is that the various intensities of the light which are reflected from the object onto the photo-electric cell vary proportionately the current that is sent out, and these impulse currents, or

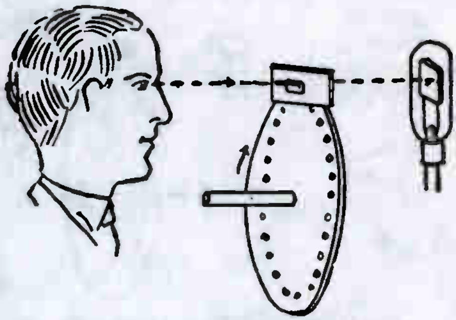


FIG. 116—An Experiment with a Neon Lamp Scanning Disk.

picture signals, as they are called, set up like variations in the intensity of the light given out by the neon lamp.

The Neon Lamp and the Scanning Disk.—To demonstrate how the scanning disk breaks up the light on the plate of a neon lamp into lines, mount the lamp on one side of, and close to, the disk. Have the cathode plate face the disk and exactly parallel with it, and see that the center of it is in an axial line with the holes and the eye that is to view the image it produces, as shown in Fig. 116.

Connect the lamp as pictured in Fig. 96, when you are all ready to make the first experiment. To do this, turn on the light, then look at it through the top outer hole in the reproducer disk. (*a*) Now turn the disk slowly round and look at the light through the outer hole and then through each successive one, and when you reach the inner hole you will have seen every part of the plate.

(*b*) Next revolve the disk at a high speed, and this you can do by securing it to the shaft of an electric motor. You will not be able to see the holes but, as a result of the persistence

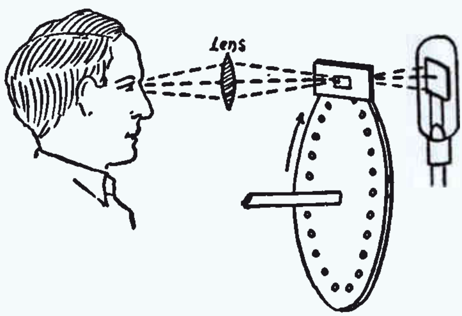


FIG. 117—How to Magnify the Image.

of vision, you will apparently see the whole of the illuminated plate just as though the disk were not there, except that the light will not be nearly as intense. In making this and other experiments, it is a good scheme to have the neon lamp and the upper part of the disk mounted in a box, in order to shut out all outside light. If you do this, cut a 1-inch hole in the end of the box, in a line with the scanning area and the lamp, so that you can look at the lamp through it.

Magnifying the Image.—To see an enlarged view of the plate of the neon lamp, which is the equivalent of seeing an enlarged image of the televised subject, mount a convex lens with a diameter of 3 or 4 inches, and focal length of about 6 inches, on the near side of the reproducing disk, in the position shown in Fig. 117.

Magnifying and Reflecting the Image.—Use the same set-up as in the above experiment, but in this case, instead of having a hole in the end of the box, cut a hole about 3 by 4 inches in the top of it. Mount a 4- by 5-inch mirror at an angle of 45 degrees in front of the disk, and another mirror of the

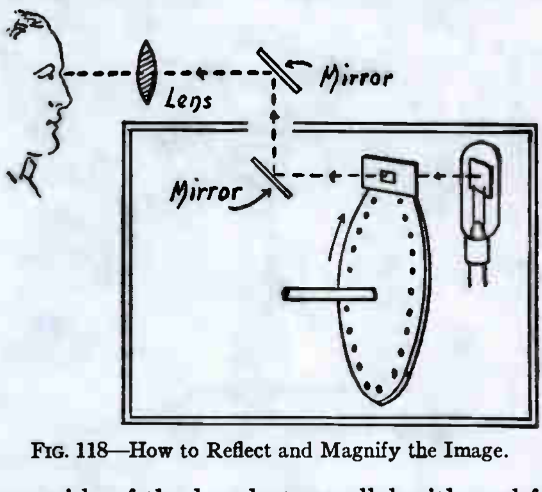
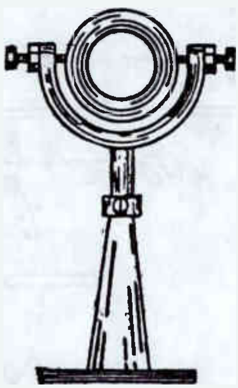


FIG. 118—How to Reflect and Magnify the Image.

same size outside of the box but parallel with and facing the first one. Now mount a lens in front of the outside mirror, as shown in Fig. 118, and you will be able to see the magnified image to still better advantage.

How to Make a Demonstration Television Set.—To make a transmitting and receiving television set is a comparatively simple undertaking, and here is the way to do it. It consists of three chief parts, namely: (1) the mechanical equipment, (2) the motor drive, and (3) the electrical apparatus. The transmitting and receiving disks are mounted on the same shaft, and it follows that they must run synchronously. The transmitting and receiving electrical devices are connected by a wire circuit, and the only thing that is left to the imagination is the element of distance.

The Mechanical Equipment.—Get a steel rod 3/8 of an inch in diameter and 6 inches long and fix on it a pulley, 1 inch in diameter, 1 3/4 inches from one end. Next make or, better,

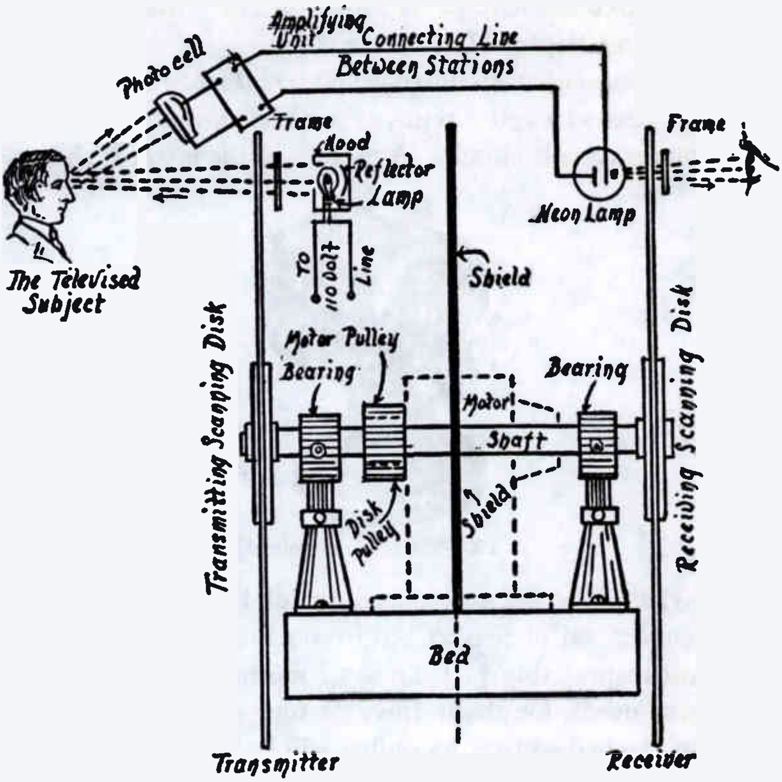


A. FIG. 119—A Self-Alignment Shaft Support.

buy, two scanning disks of the same size, 12 inches in diameter and with the same number of holes in each one, and fix these on the ends of the shaft in the way I described in Chapter III, and be sure that their corresponding holes are ***exactly in a line*** with each other, as this is highly important.

Mount the shaft in the bearings of adjustable self-alignment supports, see *A* in Fig. 119, so that they will be on the inner sides of the disks, and then bolt the bases of the supports to a thick board, as shown at *B*. The disk at the left of the diagram is for the transmitter and the one at the right is for the receiver.

The Motor Drive.—To drive the disks at a speed high



B. FIG. 119—A Simple Demonstration Television Set.

enough for television purposes, *i.e.*, about 1000 or 1200 revolutions per minute, you will need an electric motor that will develop not less than 1/30 of a horse power, and one a little more powerful will give even better results. The speed of these small motors is generally from 1800 to 2000 revolutions per minute, but you can make them run at any desired lower speed by connecting a rheostat in series with the motor and the source of current, as shown in the wiring diagram in Fig. 37, in Chapter III.

You can use either an *alternating-current motor* that works on a 60-cycle, 110-volt circuit, or a *direct-current motor* that works on a 110-volt circuit. A picture of the latter is shown

FIG. 120—The Electric Motor.

in Fig. 120. The list price of either of these motors is in the neighborhood of $20.00, but if you live in a city of any size you can probably pick up a second-hand one that will serve your needs, for about three or four dollars. Bolt the motor to the bed so that its pulley will be in a line with the pulley on the disk shaft, and then bolt them together.

The Electrical System.—Back of the transmitting disk, close to it, and in a line with the holes in the disk, mount a 200-watt incandescent lamp, which must be enclosed in a hood or box that is light-tight except for an opening to let the light pass out and through the holes. In front of the disk and close to it, fix a frame, the purpose of which I explained in Chapter III.

The rays of light from the lamp will then pass through each hole in the scanning disk in succession, thence through the frame and, finally they will fall on the object that is being televised. Lastly mount the photo-electric cell just

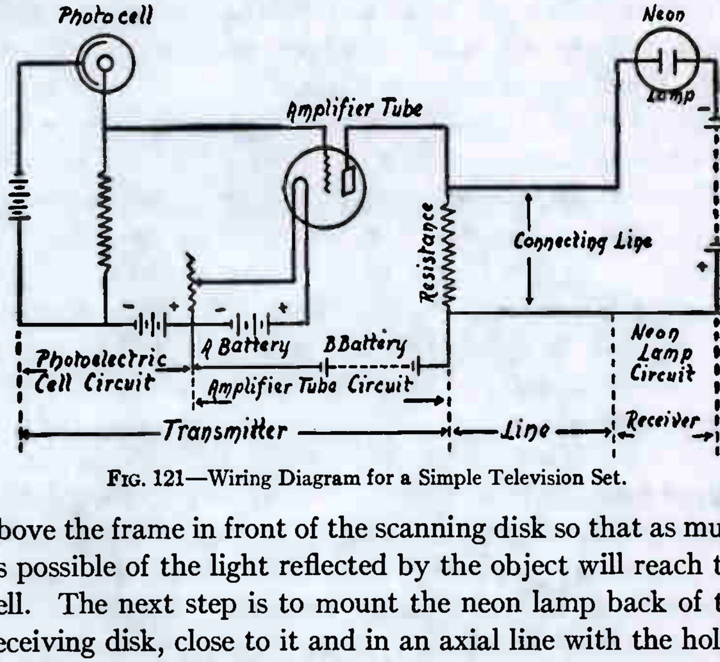


FIG. 121—Wiring Diagram for a Simple Television Set.

above the frame in front of the scanning disk so that as much as possible of the light reflected by the object will reach the cell. The next step is to mount the neon lamp back of the receiving disk, close to it and in an axial line with the holes. In front of the disk and close to it fix a frame, the purpose of which was also explained in Chapter III.

The last thing to do is to connect the photo-electric cell of the transmitter with the neon lamp of the receiver. This will be a simple matter if you have made the experiments with the amplifier tubes as explained in the preceding chapter. Begin by connecting the photo-electric cell with a one-stage amplifier. Connect the plate of this with one post of a resistance and the other post of the latter with the positive pole of the *B* battery. Connect the plate of the amplifier tube also with one end of one of the line wires, and the other end of this to the anode of the neon tube. The cathode is connected with the negative pole of the lamp battery, the positive pole of which leads to the positive pole of the *B* battery, as shown in Fig. 121.

To Operate the Television Set.—The first step in operating the set is to start the motor by moving the rheostat arm until the scanning disks begin to revolve. Then gradually cut out the resistance of the rheostat until the motor is running at full speed, and test the speed of the disks with a speed indicator, as shown in Chapter III. With the rheostat, regulate the speed of the motor until the disks run at a speed between 1000 and 1200 revolutions per minute.

Now close the circuit which includes the photo-electric cell of the transmitter and the neon lamp of the receiver. Place the subject to be televised in front of the transmitting scanning disk, then take a look at the neon lamp through the disk of the reproducer, when you will see an image of the object that is being televised. The quality of the reproduction will depend on several very important factors, the chief of which are the accuracy with which the scanning disks are made and the precision with which they run.

CHAPTER VII

EXPERIMENTS WITH ELECTRIC WAVES

The electric impulses that are set up by a television transmitter can be sent over short or long distances, either (1) by a wire circuit, or (2) by wireless, that is, by electric waves in the ether. Where a wire circuit is used, all you need to do is to connect the last stage of the transmitting amplifier to one end of the line, and the first stage of the receiving amplifier to the other end.

Where the picture impulses are to be sent by radio, then you must connect the last stage of amplification from the photo-electric cell with the oscillator tube, this with the first stage of oscillation amplifier, and the last stage of the latter with the aerial and ground wires. The aerial and ground wires of the distant receiving station are connected with the detector of the short wave or other receiver, this with the first stage of the television amplifier, and the last stage of this with the neon lamp. While all of this may sound somewhat complicated, the experiments that follow will provide a clear understanding of the whole system.

What Electric Waves Are.—What we call *light waves* are really very short electric waves in the ether, that act on the eye, which, in turn, produces the sensation of light in the brain. The shortest waves that the eye can sense produce the sensation of violet. The longest waves that it can sense produce the sensation of red.

There are, however, shorter waves beyond the violet end of the spectrum which are called *ultra-violet waves*, and these are so short that the eye cannot sense them, but they act very vigorously on certain chemicals, as, for example, the silver salts used to sensitize photographic plates and films. Again, beyond the ultra-violet waves are still shorter ones, and these are set up by the X-ray tube and radium. And, finally, still beyond these, according to some authorities, are exceedingly short waves which form what Milliken calls *cosmic rays*.

At the other end of the visible spectrum, or the band including all of those light waves that the eye can sense, are waves a little longer than those that form red light. These are called *infra-red waves*. While they do not affect the eye, they do act on the thermal nerves of the body, and produce the sensation of heat. Beyond the heat waves are those just a trifle longer, called *micro-waves*, and, finally, there are other and longer waves that range from an inch or less to a mile or more in length; these set up high frequency currents, or electric oscillations, as they are called, in both open and closed circuits. These oscillations manifest themselves to our senses by various devices which go by the generic name of *detectors*. While all the foregoing waves are electro-magnetic in character, these long waves are called *electric waves*, *wireless waves*, and *radio waves*.

The Discovery of Electric Waves.—The first indication of the existence of electric waves was made by Joseph Henry, of Washington, D. C., in 1860. With the aid of a frictional machine, which gave electric sparks, he was able to magnetize needles that were placed some 30 feet away. Silvanus

Thompson, of England, set up electric waves in 1870 with a spark coil, but he did not know that the energy it radiated was in the nature of electric waves. In 1880, Professor Fitzgerald, of Dublin, believed that electric waves were set up by the action of a spark coil or by the discharge of a con-

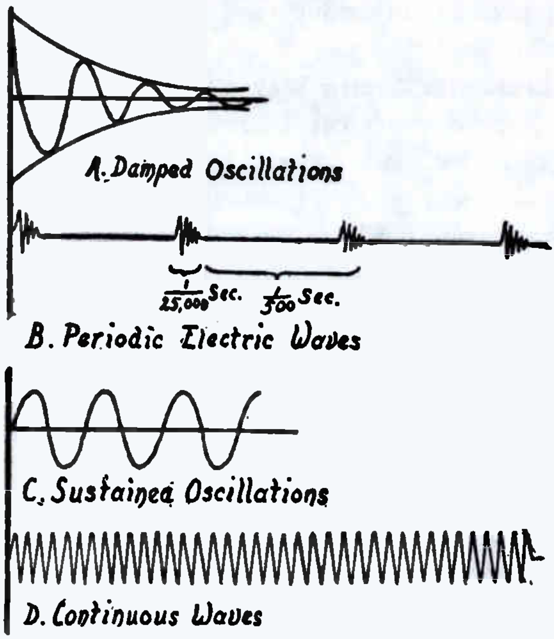


Fig. 122—Kinds of Electric Oscillations.

denser, but he was not able to prove the existence of such waves.

It remained for Heinrich Hertz, of Karlsruhe, Germany, to discover, in 1888, not only the elusive electric waves, but to devise a means for sending them out, a detector to make their energy visible and to measure their wave lengths. Thus it was that he made known their real nature, which other physicists had merely speculated upon. His experimental researches were analyzed by such great mathematical physicists as Lodge, Poynting, Heaviside, J. J. Thompson, and Fleming. Marconi first used electric waves for wireless telegraphy, the present author for wireless telephony, and Baird for television.

Experiments with Electric Waves.—There are several ways by which electric waves can be set up, but the two chief ones are (1) with a spark coil and (2) with an electron tube. The *spark coil* sets up *damped oscillations*, with the result that the waves produced are *periodic*, as shown at *A* and *B* in Fig. 122, while the *electron tube* sets up *sustained oscillations*, resulting in *continuous waves*, as pictured at *C* and *D*. For all telegraphic, telephonic, and televisionic transmission, the government permits only the use of the latter kind of wave.

Experiments with the Spark Coil.—*The Hertz Apparatus.*—To reproduce Hertz's classic experiments of setting up oscillations, sending out waves, and receiving the waves which, in turn, set up oscillations, you will need (1) a spark coil and a battery to energize it, (2) an oscillator to set-up the oscillations, and (3) a ring detector. You can use any kind of *spark coil*, but, naturally, the larger it is the more intense will be the waves that it sends out.

To make the *oscillator*, get a pair of sheet zinc or copper plates 4 or 5 inches on the sides, and, to the middle of one edge of each one solder one end of a thin brass rod about 6 inches long.[1] Now slip the rods through the binding

[1] This is the right length for a 1-inch spark coil. The length of the rod should vary according to the capacity of the coil.

posts of the spark coil until the adjacent ends are close enough together to make a spark gap ½ inch in length, as shown at *A* in Fig. 123. This done, connect a battery and a key or a switch in circuit with the primary of the spark coil,

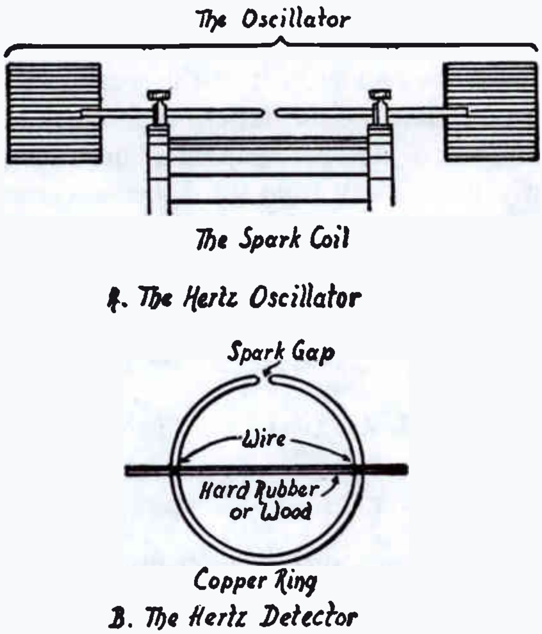


Fig. 123—The Hertz Electric Wave Apparatus.

when you are ready to set up damped oscillations and send out periodic waves.

Before you do so, however, you must have a *detector* to receive and detect them. The original Hertz detector, which he called a *resonator*, consisted of a ring made of copper wire, about 14 inches in diameter, with the ends terminating in a pair of small brass balls which were brought close together to form a minute spark gap. You can make a detector of this kind by taking a piece of copper wire ⅛ of an inch in diameter and 25 inches long, and bending it into a ring. To make it hold its shape, fasten it to a strip of dry hard wood with fine wire, as shown at *B*.

The Hertz Experiments.—To set up the oscillations which surge through the oscillator, start the spark coil, and to detect the waves that the oscillations send out, hold the ring detector in front of the spark gap, in a horizontal plane, and then slowly move away from it. When a certain point is

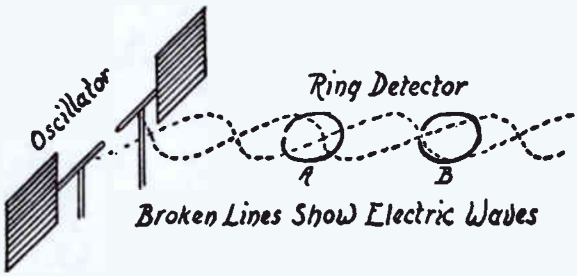


Fig. 124—The Hertz Electric Wave Apparatus.

reached, you will see a succession of bright little sparks fill the minute gap of the ring detector, and when this takes place you will know that you have struck the crest of an electric wave, as shown at *A* in Fig. 124.

Now move a little farther away to a point where there will be no sparks set up in the gap of the ring. By this token you will know that the detector is in a *node*, or valley, between two electric waves, as pictured at *B* in Fig. 124. At a point farther back, sparks will again fill the gap of the ring, indicating that you have struck another wave crest. By making note of the positions of the crests and nodes, you can easily determine the length of the waves that are being sent out.

The Marconi Apparatus.—To duplicate Marconi's first wireless telegraph experiments, connect one of the wires of the spark gap of the spark coil to a piece of copper wire about 6 feet long, make a loop in the free end and hang it on a nail in the wall. Connect another wire about 4 feet long to the other side of the spark gap and let the free end lay on the

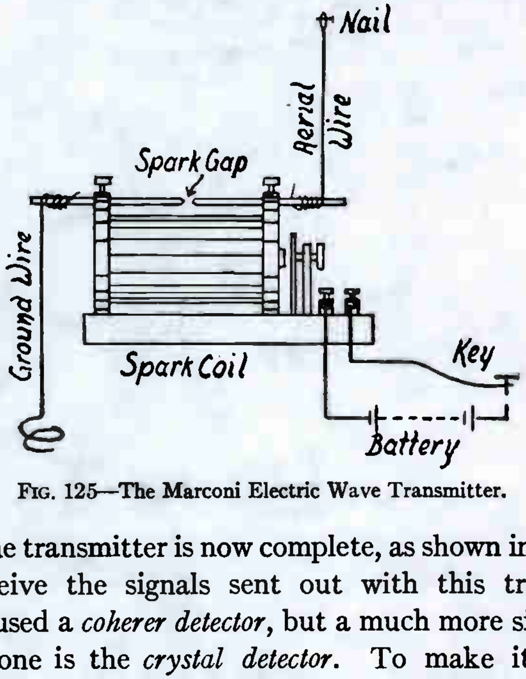


FIG. 125—The Marconi Electric Wave Transmitter.

floor.[1] The transmitter is now complete, as shown in Fig. 125.

To receive the signals sent out with this transmitter Marconi used a *coherer detector*, but a much more simple and sensitive one is the *crystal detector*. To make it, screw a binding post near one end of a block of wood ½ inch thick, 2 inches wide, and 3 inches long, then scrape one end of a piece of copper wire clean, make a loop of it, slip it around

[1] In the later Marconi apparatus this wire was connected with a copper plate buried in the ground.

the screw and then screw the binding-post up tight. This done, get a fine brass wire 2½ inches long, slip one end into the binding-post, and screw it up tight.[1]

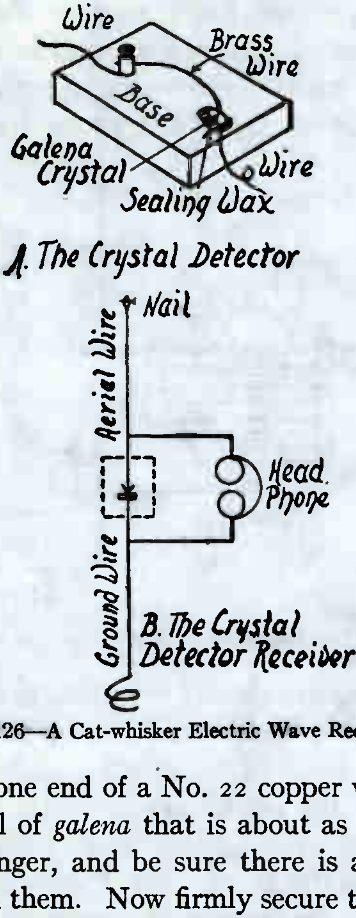


FIG. 126—A Cat-whisker Electric Wave Receiver.

Scrape clean one end of a No. 22 copper wire and twist it around a crystal of *galena* that is about as large as the end of your little finger, and be sure there is a good electrical contact between them. Now firmly secure the crystal to the base, about 2 inches from the binding-post, with sealing wax,

[1] In the early days of radio this wire was called a *cat-whisker*.

and finally adjust the free end of the fine brass wire so that it will rest very gently on the surface of the crystal. You will then have what is known as a *cat-whisker detector*, as pictured at *A*, Fig. 126.

The way that the detector is connected to the head-phone, the aerial, and ground wires, is shown at *B*, and you will observe that a dry cell is not included in the circuit. This is because the galena crystal *rectifies* the oscillations that are set up in the aerial wire and which surge through it (the crystal); in other words, it changes the oscillations into a pulsating direct current and it is this which operates the telephone receiver.

Experiments in Tuning.—In music, the word *tuning* is applied to a series of tones, made by the voice or an instrument, that are symmetrical and which have the proper pitch. By extension, the term is used in physics to mean a series of harmonious and symmetrical impulses of any kind, occurring in a vibrating body. In electricity, the word also applies to oscillating currents that surge in either an open or a closed circuit.

In a wireless transmitter, the closed oscillation circuit, which includes the source of the oscillations, and the open circuit, which includes the aerial and ground wires, must be tuned to each other so that the frequency of the oscillations set up in the former will be identical with that of the latter. Likewise, in a wireless receiver, the open or aerial wire circuit and the closed oscillation circuit must be tuned to the same frequency of oscillation. Finally, the transmitting and receiving circuits must be tuned to each other, that is to say, whatever the frequency of the oscillations set up by the transmitter (for on this depends the length of the waves), so also must be the frequency of the oscillations set up in the receiving circuits.

A Pendulum Analogue of Tuning.—Here are a couple of unusually pretty little experiments that will give you a clear idea of how open and closed circuits act on each other when oscillations are surging through them. Take two pieces

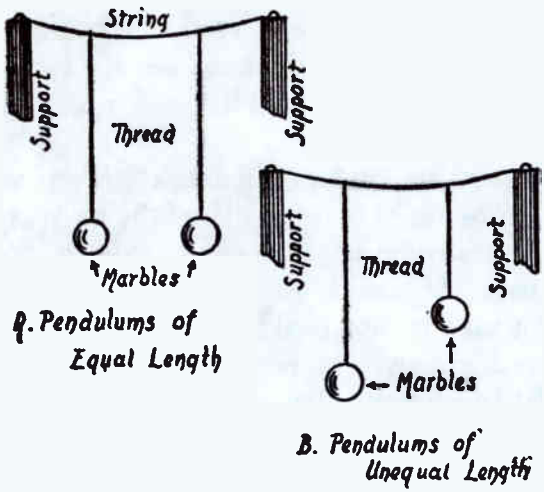


Fig. 127—Pendulums Showing the Principle of Tuning.

of thread about a foot long and fix a marble to one end of each one, which you can do with a drop of sealing wax.

The next step is to tie a string about two feet long to the backs of two chairs, or other supports, and set them close enough together so that there will be a little slack in it. This done, tie the free ends of the threads to the string so that they will be about 18 inches apart, as shown at *A* in Fig. 127.

(1) Now give one of the pendulums a good swing at right angles to the supporting string. In a few moments, the energy of it will be transmitted along the string to the other pendulum, which will begin to swing in unison with the first one.

(2) To show how the lengths of the threads affect the tuning of the pendulums, make one of them considerably shorter than the other, as shown at *B*. Now give one of the pendulums a good swing and you will see that it will have little or no effect on the other one. This is because they are not in tune with each other.

Mechanical and Electrical Tuning.—There is a very marked similarity between *mechanical vibrating bodies*, such as a steel spring, or a tuning fork, and the way they set up *sound waves in the air*, and *electric oscillating currents* and the way they set up *electric waves in the ether*. After you have made the tuned pendulum experiments described in the foregoing paragraphs, you will see at once that mechanical vibrations and sound waves behave in a similar manner and, finally, that electric oscillations and electric waves behave in an analogous manner.

Damped Mechanical Vibrations and Periodic Sound Waves. —Get a piece of the mainspring of a clock and straighten it out so that it will be perfectly flat. Grip one end of it firmly in a vise, as shown at *A* in Fig. 128. Now pull the free end over and let it go, when it will vibrate forth and back with *decreasing amplitude* until it comes to rest, as shown by the curve drawn at *B*.

The action that takes place in this experiment is this: when you pull the spring over, you store up energy in it, and when you let it go, the potential energy in it is changed into the kinetic energy of motion. In striving to restore its equilibrium, the spring shoots past the point where it is without tension, first on one side and then on the other side, or *vibrates*, as we say, until all of the energy that was stored

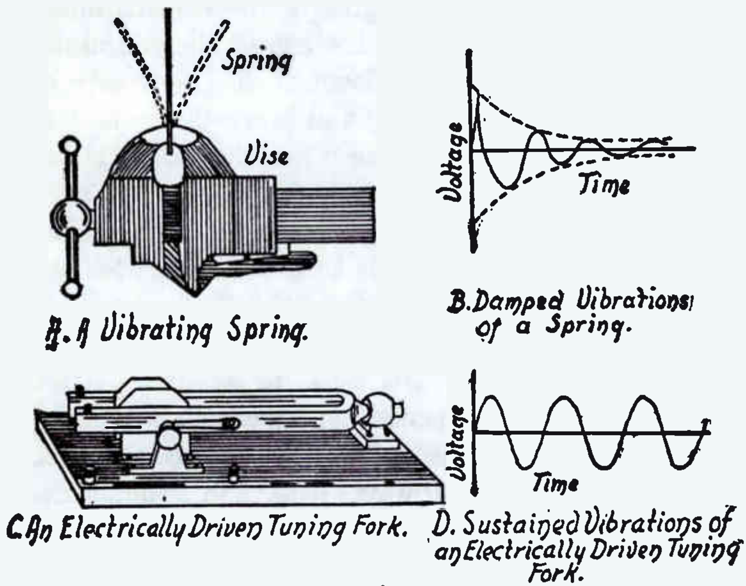


Fig. 128—Damped and Sustained Mechanical Vibrations.

up in it is spent in overcoming the air pressure and other resistances.

If you placed the spring in a perfect vacuum and there were no internal frictional losses, once it was started vibrating, it would keep up its motion for a very long period, if not, indeed, to the end of time. But when it vibrates in the air it sets this into motion in the form of waves, which are called *sound waves*, and as this action uses up the energy that you imparted to the spring, it soon comes to rest.

Sustained Mechanical Vibrations and Continuous Sound Waves.—There is a method by which one can make a spring vibrate without stopping and, consequently, keep the amplitude of its vibrations constant. That method is to drive it by means of an electro-magnet. To do this, you need only to get a buzzer, or an electric bell with the hammer and gong removed. A better way, however, is to use an *electrically driven tuning fork*, as shown at *C* in Fig. 128.

This apparatus consists of an electro-magnet with an interrupter to make and break the current in the same way that it does in an electric bell. This device is fixed between the prongs of a tuning fork. When the magnet is energized by a current, it makes the prongs of the fork vibrate, and the amplitude of the vibrations is kept even, as the curve at *D* clearly shows. In other words, the vibrations will be *sustained*, and the waves set up in the air will be *continuous*.

Damped Electric Oscillations and Periodic Electric Waves.—The vibrating steel spring previously described is a very good analogue of the way that *damped oscillations* surging through a circuit set up and send out *periodic electric waves* in the ether. To produce damped oscillations in a circuit, connect a *condenser* (a small Leyden jar will do) and an *inductance coil* (which consists of a few turns of copper wire with each turn separated a little from the next one to it) in series with the *spark gap* of your spark coil, as shown at *A* in Fig. 129.

Now when you energize the spark coil by means of the battery, sparks will pass between the electrodes of the spark gap and these set up in the circuit electric oscillations, the frequency of which depends on the value of the capacitance [1] of the condenser and the inductance [2] of the inductance coil. They are damped out by the resistance of the circuit and the radiation of the energy by it in the form of electric waves,

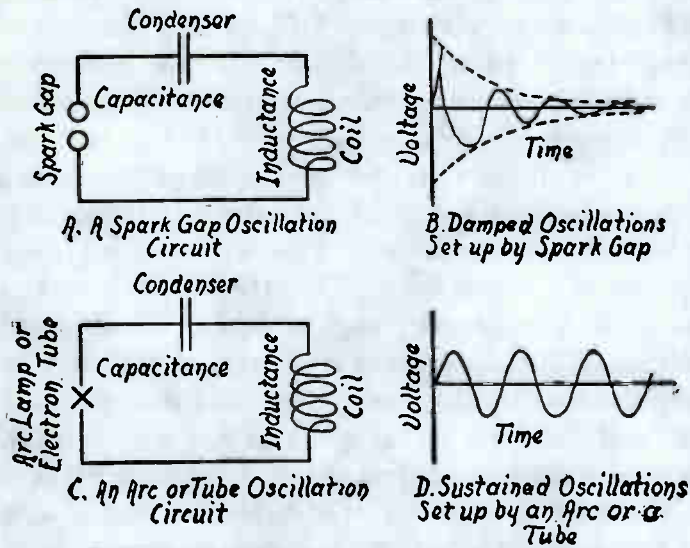


FIG. 129—Damped and Sustained Electric Oscillations.

as shown at *B*, very much in the same way that the vibrations of a spring are damped out by the sum of the resistances it has to overcome.

Sustained Electric Oscillations and Continuous Electric Waves.—There are two chief ways by which one can set up *sustained electric oscillations* in a circuit. The energy of these oscillations will be radiated in the form of *continuous*

[1] This is measured in *microfarads*. [2] This is measured in *millihenries*.

electric waves. These methods are (1) by an arc lamp, and (2) by an electron tube. In the early days of wireless telephony, or *radio,* as it is now called, the arc lamp was the only known means for setting up sustained oscillations, but when it was discovered that the three-electrode tube could be used as an oscillator, it supplanted the former because it was more simple and less expensive.

(1) To set up sustained oscillations with an *arc lamp,* you must connect an inductance coil and a condenser in series with the lamp as shown at *C* in Fig. 129, and energize it with a 500-volt direct current. In this case the amplitude of the oscillations will be kept up as shown by the curve at *D* and, naturally, the waves which it sends out in the ether will be continuous.

(2) To set up sustained oscillations with an electron tube is an easy thing to do—so easy, in fact, that in the early types of radio receivers it was almost impossible to keep the tubes from setting up oscillations, with the unhappy result that *howls* were of frequent occurrence. A little farther on I shall tell you how to connect up a tube with which one can produce sustained oscillations of any frequency within reasonable limits, to send out electric waves of corresponding lengths.

Experiments in Acoustic Resonance.—In physics the word *resonance* is used to designate that property of a vibrating body which enables it to increase the strength of sound waves, or to prolong them in duration. There are two kinds of resonance, namely, (1) simple resonance, and (2) sympathetic resonance. By *simple acoustic resonance* is meant that the sound waves set up by a vibrating body are made to set up like vibrations in another body that is close to the first, and which, in turn, acts on the original sound waves and reinforces them. The term *sympathetic acoustic resonance* means the action of the sound waves which are set up and sent out by a vibrating body, causing vibration of another body at a distance from the first one.

Experiments in Simple Resonance.—(1) Set a quart milk-bottle on the table and then, with your mouth on a line with

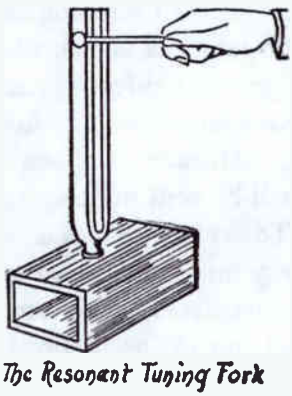


FIG. 130—Experiments in Simple Acoustic Tuning.

the rim of the neck, whistle at a low pitch across it, as shown at *A* in Fig. 130. Now raise the pitch of your whistle, note by note, until you reach one whose sound waves will set the air contained in the bottle into vibration. This will, in turn, reinforce the waves of your whistle and, consequently, the strength of it.

(2) Another experiment in simple resonance is to mount the handle of a tuning fork on a box made of thin wood—a cigar box will do—from which you have removed the ends, as pictured at *B*. This done, strike one of the prongs with

a felt or rubber hammer, to set the fork into vibration. You will be surprised to find how much louder the sound is when the handle of vibrating fork is set in the box than when held in your hand. This is due to the fact that the vibrations of the fork set the box into vibration and this, in turn, causes the air in the box to vibrate, and the waves set up by the box and the air within it will reinforce those produced by the tuning fork.

Experiments in Sympathetic Resonance.—Having made the above experiments in simple resonance, you are ready now to make a far more interesting one in sympathetic resonance. To do this you will need two tuning forks that are made with adjustable weights on their prongs, the purpose of which is to enable you to change the frequency of vibration and so be able to tune them to exactly the same frequency of vibration.[1]

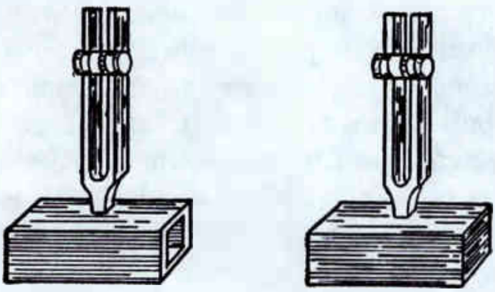
The next thing to do is to make two tubes of wood, each 3 inches high, 3 inches wide, and 5 inches long. Get two blocks of wood, each one ½ inch thick, ¾ of an inch wide, and 1 inch long, and bore in each one a hole of such size that the handle of one of the forks will fit firmly in it. Glue a block in the center of the top of each of the tubes.

To make the experiment, adjust one of the forks so that its frequency of vibration will be about 80 per second and then adjust the other one to vibrate at a frequency of 88 or 90 per second. Next set the tubes so that the open ends will be in a line with each other and their adjacent ends

[1] The law for tuning forks is that (1) with a rectangular cross-section the frequency varies inversely with the square of the length and directly as the thickness, and (2) with a circular cross-section the frequency varies inversely with the square of the length and directly as the radius.

will be 3 or 4 inches apart, as shown in Fig. 131. (1) Now strike one of the forks with your rubber hammer, and you will find that the second fork will not respond. The reason it does not do so is because the rates of vibration for the two forks are different, or, in other words, they are *out of tune.*

(2) Adjust both forks so they will vibrate with the same frequency, for example, 90 per second. Set the tuning forks



A. The Sender B. The Receiver

Fig. 131—An Experiment in Sympathetic Acoustic Tuning.

a foot apart, then strike one of them with your hammer. The vibrations of it will set up waves in the air, and when these strike the second fork, the successive impulses set it into vibration and you have the phenomenon of mechanical sympathetic resonance.

Experiments in Electric Resonance.—Just as there are two kinds of acoustic resonance, so also are there two kinds of *electric resonance*, namely (1) simple electric resonance, and (2) sympathetic electric resonance. By *simple electric resonance* is meant that the inductance and capacitance of a circuit are given such values that the frequency of the oscillations which surge in it will be in tune with it. When this condition prevails the voltage will rise until it is considerably higher than its normal value.

The term *sympathetic electric resonance* applies to the effect obtained when the electric oscillations which surge in a circuit send out electric waves of a given length and these strike a second circuit that is tuned to exactly the same frequency as the first one, so that electric oscillations will be set up in it.

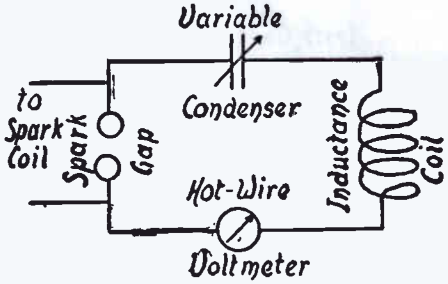


FIG. 132—An Experiment in Simple Electric Tuning.

(1) To make an experiment which shows how *simple electric resonance* takes place, you need only to connect an inductance coil, a variable condenser and a *hot-wire* voltmeter in circuit with the spark gap of your spark coil or other source of electric oscillations, as shown in Fig. 132. Now start up your spark coil and adjust the condenser until the voltmeter shows the highest reading, which indicates that the resonant point has been reached.

(2) To demonstrate *sympathetic electric resonance*, make two circuits, one for setting up oscillations and sending out electric waves, and the other for receiving the electric waves and converting them into electric oscillations. The first

thing to do is to get, or make, two pint Leyden jars of exactly the same size so that they will have precisely the same capacitance. Next get a piece of copper wire 1/8 of an inch thick and 36 inches in length, then wrap one end of it around the lower end of one jar and twist it tight so that a good contact will be made between them. Bend the wire into a rectangular shape and bring the free end of it over until it comes to within 1/16 of an inch of the wire that projects through the cork of the jar, thus forming a spark gap, as

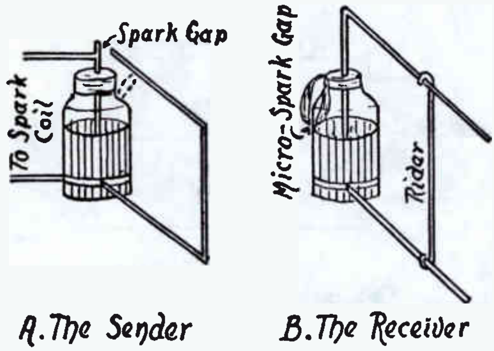


Fig. 133—An Experiment in Sympathetic Electric Tuning.

shown at *A* in Fig. 133. You will have to brace the free end of the wire forming the loop, which you can do by heating the ends of a stick of sealing wax and fixing one end to the cover of the jar and the other to the wire, as shown by the broken lines in the picture. Finally connect the outside of the jar and the wire that projects through the cork with the binding posts of the secondary of the spark coil, and this completes the transmitter.

Now take the cork out of the other Leyden jar and glue a strip of tin-foil to the tin-foil coating inside of the jar;

bring the strip out and over the neck and glue it to the outside of the jar so that the free end of it will come to within 1/64 of an inch of the outer coating. A minute spark gap will thus be formed. Next cut off a piece of copper wire ⅛ of an inch thick and about 20 inches long, then wrap one end around the lower part of the jar and twist it tight. This will leave a length of the wire projecting out about 10 inches.

Take out the wire that passes through the cork, and which is connected with the chain, and then cut off another piece of wire about 14 inches long, bend one end over about 4 inches and push the short end through the cork. Push the cork down tight in the jar and turn the upper wire around until it is parallel with the lower one. Finally, cut off a piece of wire, bend over the ends and slip it over the parallel wires, and your receiver is now ready to use, as shown at *B*.

To show the sympathetic resonance effect between the two circuits, set the jars 2 or 3 feet apart, with the rectangular loops of wire parallel with each other. Now charge the transmitting jar by starting up the spark coil. If the transmitting and receiving circuits are exactly in tune with each other when the spark occurs in the former, oscillating currents will be set up in the latter, and these will make sparks pass across the minute spark gap. If sparks do not pass, it is because the circuits are not in tune, but you can easily tune the receiver to the transmitter by sliding the short wire rider forth and back on the parallel wires.

Experiments with the Electron Tube Oscillator.—As previously pointed out, it is not a difficult matter to set up oscillations with an electron tube but, rather, the hard thing is to prevent oscillations when using it as a detector or an amplifier. Thus it is possible to set up sustained oscillations with any kind of electron tube, be it a detector, an amplifier, or an oscillator tube. A tube made especially to be used as an oscillator is, of course, the best kind for setting up oscillations and, therefore, its use is recommended for the following experiments.[1]

To Set Up Sustained Oscillations.—To make this experiment you will need the following components: (1) a 5-watt

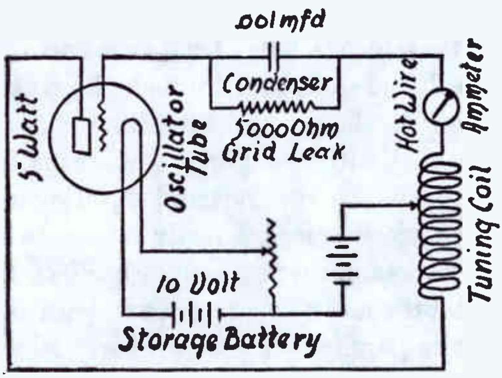


FIG. 134—A Set-up for Producing Sustained Electric Oscillations.

electron tube oscillator and socket, (2) a filament rheostat, (3), a 10-volt *A* (storage) battery, (4) a 100-volt *B* (or dry) battery, (5) a 5000-ohm grid-leak resistor, (6) two .001 microfarad fixed condensers, (7) a two-clip tuning coil, and (8) a hot-wire ammeter.

To hook up the above parts, connect the negative pole of the 10-volt storage battery to one of the taps of the filament of the oscillator tube. Next connect the other tap of

[1] You can use a power amplifier tube instead of the 5-watt oscillator tube to set up the oscillations, but it will give less than 1 watt output with a storage battery to heat the filament. A 171-tube will serve the purpose.

this to one of the posts of the rheostat, and the other post of this to the positive pole of the *A* battery. Connect the grid of the tube to one side of the condenser, the other side of this to one post of the ammeter, the other post of this to one end of the tuning coil, and then shunt the grid leak around the grid condenser. Connect the plate of the tube to the clip at the opposite end of the tuning coil, the negative *B* battery terminal to the positive pole of the *A* battery, and

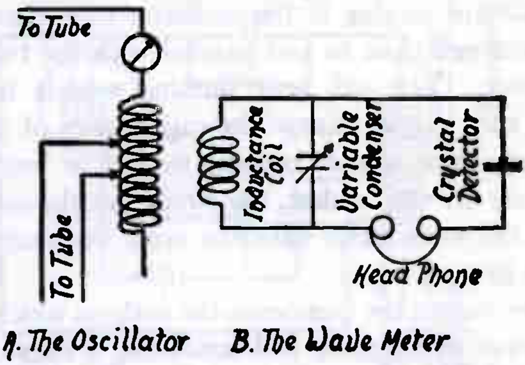


FIG. 135—A Set-up for Finding the Frequency of the Oscillations.

the positive *B* battery lead to one of the clips of the tuning coil, as shown in the diagram in Fig. 134.

How to Tune the Oscillator Circuits.—To tune the circuits of the oscillator, adjust the rheostat until the filament is heated to *brilliancy*, that is, red-hot, then adjust the tuning coil clips until the ammeter shows the highest reading, that is, when the *throw* of the needle is the greatest, and this will show you when the oscillations which are surging in the circuit are the most intense.

How to Find the Frequency of the Oscillations.—To find the frequency of the oscillations that surge in the circuit, your experimental quest for radio knowledge, if you are a novice in the art, so I'll tell you how it is put together.

How to Detect Oscillations.—To make such a receiver, the following components are needed: (1) a simple single-layer tuning coil, (2) a .00025 microfarad variable condenser, (3) a pair of head-phones, (4) a *201A* electron tube detector[1] and

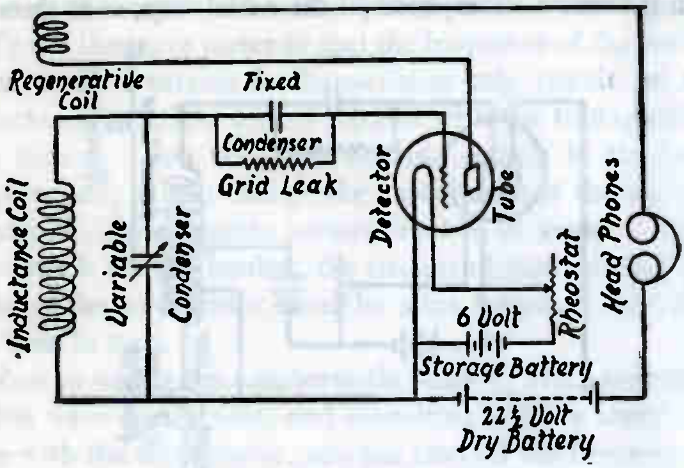


FIG. 137—A Receiver for Detecting Sustained Oscillations.

socket, (5) a 6-volt storage battery, (6) a filament rheostat, and (7) a 45-volt dry battery.

To hook up the above parts, connect one of the posts of the coil with one of the posts of a variable condenser, and the other post of this with the other post of the condenser. Next connect one of the posts of the latter with the post of the detector tube socket which is connected with the grid of the tube; then connect the terminals of the filament of

[1] Use an *Eveready Raytheon*, a *Radio Corporation* tube, or one of equivalent proven high quality.

this to one of the posts of the rheostat, and the other post of this to the positive pole of the *A* battery. Connect the grid of the tube to one side of the condenser, the other side of this to one post of the ammeter, the other post of this to one end of the tuning coil, and then shunt the grid leak around the grid condenser. Connect the plate of the tube to the clip at the opposite end of the tuning coil, the negative *B* battery terminal to the positive pole of the *A* battery, and

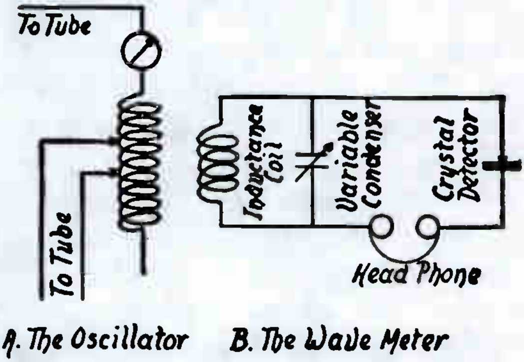


FIG. 135—A Set-up for Finding the Frequency of the Oscillations.

the positive *B* battery lead to one of the clips of the tuning coil, as shown in the diagram in Fig. 134.

How to Tune the Oscillator Circuits.—To tune the circuits of the oscillator, adjust the rheostat until the filament is heated to *brilliancy*, that is, red-hot, then adjust the tuning coil clips until the ammeter shows the highest reading, that is, when the *throw* of the needle is the greatest, and this will show you when the oscillations which are surging in the circuit are the most intense.

How to Find the Frequency of the Oscillations.—To find the frequency of the oscillations that surge in the circuit, you will need a *wave meter*, which is really a *frequency meter*. This you can either make or buy.[1] A wave meter consists of an inductance coil of fixed value whose inductance in millihenries is known, a variable condenser whose capacitance in microfarads is known, and these are connected together. Shunted around the condenser is a crystal detector in series with a pair of head-telephones as shown in Fig. 135.

To use the wave meter to find the frequency of the oscillations that are surging in the oscillator-tube circuit, set the inductance coil close to and parallel with the tuning coil of the former. You will hear buzzing sounds in the headphones, and, as you change the capacitance of the variable condenser, these sounds become weaker or louder. When the sounds are the loudest, the circuits of the oscillator and those of the wave meter have the same frequency, and they are then in tune.

Now by noting the number on the scale on which the needle of the wave meter rests, and consulting a curve sheet that goes with the wave meter, you can read off the frequency of the oscillations which are surging in the circuit, directly in seconds. You can get any frequency desired, and hence, any wave-length, by simply using an inductance coil with a smaller or a large number of turns in it and a condenser with a lesser or greater number of plates in it.

A Simple Continuous-Wave Transmitter.—To make a short-range radio transmitter for either telegraphy, telephony or television, you need only to add an aerial wire and a ground wire to the above-described oscillator set-up. To do this, cut the hot-wire ammeter out of the grid circuit and

[1] Wave meters are sold by dealers in radio parts and apparatus.

connect the aerial wire to the post of the tuning coil; connect the third clip of the latter to one post of the ammeter, the other post of this to one side of a .001 microfarad condenser and the other side of this to the ground plate, all of which is shown in Fig. 136.

To make a wireless telephone transmitter out of it you can connect a microphone in the aerial wire, as is shown in

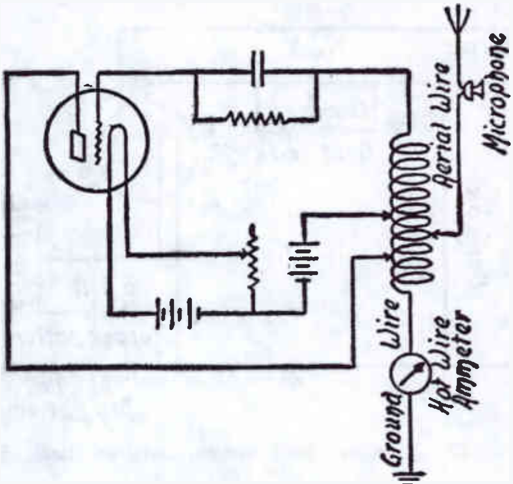


FIG. 136—A Simple Oscillator-Tube Transmitter.

the diagram. The way to connect a photo-electric cell with an oscillator tube to form the electrical set-up of a television transmitter is described in Chapter IX.

Experiments with an Electron-Tube Detector.—To make a simple single tube receiver for detecting electric oscillations that are set up in it, either by conduction, electromagnetism, or electric waves, is a simple undertaking, but such a circuit has many faults. Still, it will serve you in your experimental quest for radio knowledge, if you are a novice in the art, so I'll tell you how it is put together.

How to Detect Oscillations.—To make such a receiver, the following components are needed: (1) a simple single-layer tuning coil, (2) a .00025 microfarad variable condenser, (3) a pair of head-phones, (4) a *201A* electron tube detector[1] and

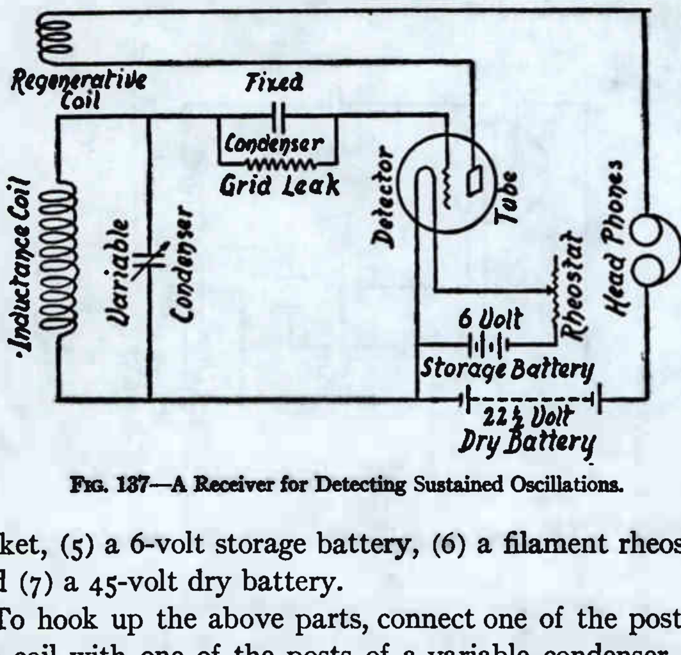


Fig. 137—A Receiver for Detecting Sustained Oscillations.

socket, (5) a 6-volt storage battery, (6) a filament rheostat, and (7) a 45-volt dry battery.

To hook up the above parts, connect one of the posts of the coil with one of the posts of a variable condenser, and the other post of this with the other post of the condenser. Next connect one of the posts of the latter with the post of the detector tube socket which is connected with the grid of the tube; then connect the terminals of the filament of

[1] Use an *Eveready Raytheon*, a *Radio Corporation* tube, or one of equivalent proven high quality.

the tube with the rheostat and the negative pole of the storage battery in *series*, that is, one after the other.

Connect the other side of the condenser with the positive pole of the storage battery, and then connect this pole with the negative terminal of the dry battery, and the positive terminal of this with one of the head-phone leads. Finally, connect the other phone connection with the plate of the

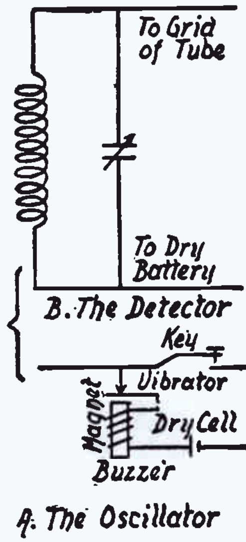


FIG. 138—How to Set Up and Detect Feeble Oscillations.

tube detector. A fixed condenser of about .002 microfarads capacity should be connected across the phones. Fig. 137 shows this circuit with a grid condenser and leak and a regenerative plate coil added.

To Detect Conductive Oscillations.—A buzzer or an electric bell with the hammer and gong removed will set up feeble damped oscillations, and you can use this for your first experiment. To do so, connect up the buzzer or bell in series with a dry cell and a key or a push-button. Now connect a wire from the fixed contact point of the vibrator to one end of your tuning coil, as shown in Fig. 138.

Before setting up the oscillations with the buzzer and detecting them with the receiver, you must adjust the components of the latter so that you can tune it. To do this, slide the contact point of the tuning coil half way between the ends of the coil, and then turn the knob of the variable con-

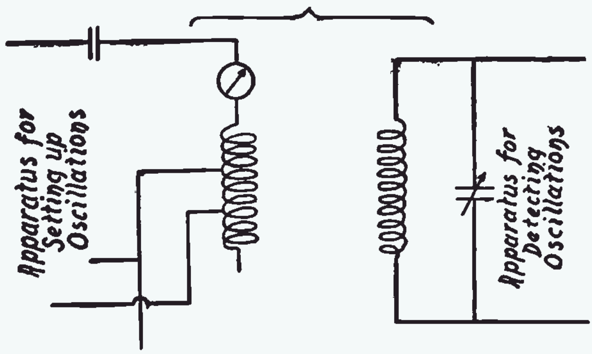


FIG. 139—To Detect Oscillations by Electromagnetic Induction.

denser until the movable plates are midway between the fixed plates. This done, put on your head-phones and heat the filament of the detector tube to brilliancy.

Now press the key or button of the buzzer circuit, and minute sparks between the fixed and vibrating contacts will set up oscillations that are about as strong as if a station 25 or 50 miles away were producing them. This done, slide the contact of the tuning coil to and fro until the loudest hum is heard, then turn the knob of the variable condenser forth and back until the sounds are still louder, and, finally, carefully adjust the rheostat until the filament is heated to its *critical temperature*, when you will hear the sound of the oscillations that are set up in the receiver.

To Detect Oscillations by Electromagnetic Induction.—To set up the oscillations for this experiment, you can use the electron-tube oscillator previously described. Place its tuning coil close to and parallel with the tuning coil of the receiver, as shown in Fig. 139. When you set up oscillations

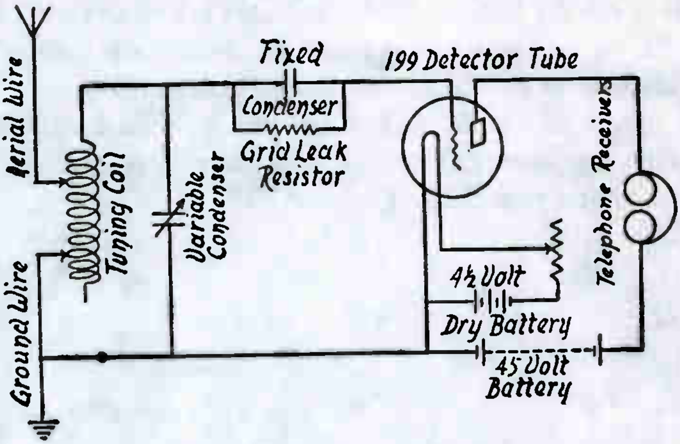


FIG. 140—A Simple Detector-Tube Receiver.

by the former device, they will surge through its tuning coil and their energy will set up oscillations in the tuning coil of the receiver, by electromagnetic induction.

To Receive and Detect Electric Waves.—To make this experiment you need only to connect an aerial wire to one end of your tuning coil and a ground wire to the slider,[1] as shown in Fig. 140. Now heat the filament of the detector

[1] You can make a much better receiver of it by using a loose-coupled tuning coil, as shown in Fig. 136.

tube to brilliancy, put on your head-phones, and adjust the tuning coil and the condenser until you hear a distant station as clear and as loud as possible.

In this case, as I explained in one of the earlier chapters, the energy of the oscillations that are set up in the aerial wire at the transmitting station is converted into electric waves. When these strike the aerial wire of your receiver they are converted back again into electric oscillations. The receiver detects the *oscillations* that are set up in it, not the electric waves, though it is called an electric wave detector rather than an oscillation detector, which it really is. The way to connect a detector tube with a neon lamp, thus forming the electrical set-up of a television receiver, is described and pictured in Chapter X.

CHAPTER VIII

EXPERIMENTS IN SYNCHRONISM

There are two fine technical words in the English language that have become especially important since the art of television has developed, and these are (1) *isochronism* (pronounced *i-sok'-ro-nism*), and (2) *synchronism* (pronounced *sin'-kro-nism*). We get the word *isochronism* from the Greek terms *iso*, meaning *equal*, plus *kronos*, meaning *time*. When these are compounded they signify *equal in time*, or performed in *equal time*. The word *synchronism* comes from the Greek root *sun*,[1] which means *with*, plus *kronos*, meaning *time*, and together they mean *occurring at the same time*, or having the *same period and phase*.

Analogues of Isochronism and Synchronism.—*With Swinging Pendulums.*—You can get a clear understanding of what these two words mean, and the difference between them when applied to television, by making the two following experiments. Cut off two pieces of thread exactly the same length, say 12 inches. Next fix a marble to one end of each thread with sealing wax and tie them to a rigid horizontal support.

(1) Pull the marbles back and then let one go, so that it will swing to and fro. When it has travelled half the length of its first swing, release the other marble. Now the speed at which both of these pendulums swing is exactly the same,

[1] There is no "*y*" in the Greek alphabet.

assuming that their lengths are identical, but they are not swinging together, or, as the technician would say, they are *out of step*, or *out of phase*, as shown at *A* in Fig. 141. Since,

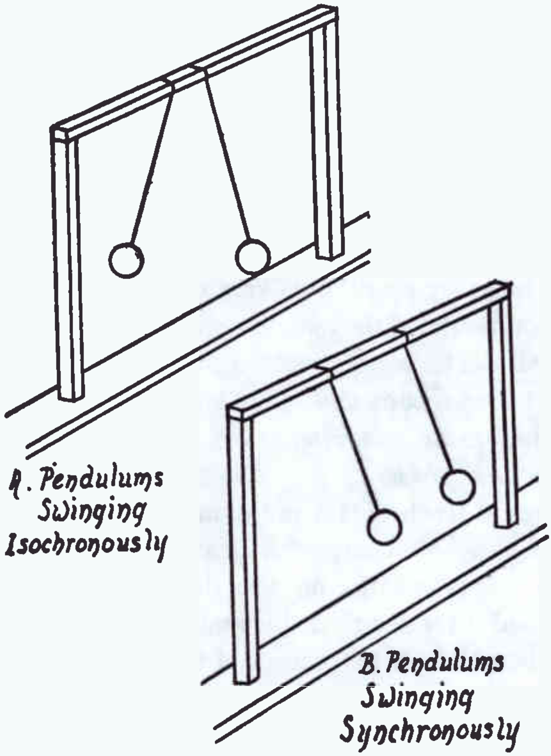


FIG. 141—Pendulum Analogues of Isochronism and Synchronism.

however, their *time periods* are the same, they are said to be in *isochronism.*

(2) Having made the above experiment, pull both of the marbles back the same distance and let go of them at the same time. In this case they will not only swing to and fro

in exactly the same time but they will also swing exactly together; in other words, their time periods are not only the same, but they are also in step, or in phase, see *B*, and they are now said to be in *synchronism.*

With Rotating Disks.—Isochronism and synchronism can take place in rotating bodies as well as in swinging bodies. Fix two disks of cardboard on a shaft and mount the latter

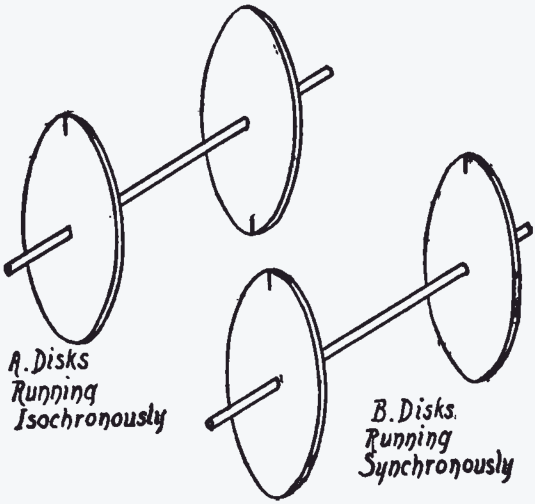


FIG. 142—Disk Analogues of Isochronism and Synchronism.

in bearings so that you can revolve it. Make a heavy black mark at any point on the edge of one disk, and another at a point diametrically opposite the first mark, on the other disk, as shown at *A* in Fig. 142.

(1) Now when you revolve the disks they will, perforce, turn at exactly the same speed and will be in isochronism; but the marks on the edges of the disks will be 180 degrees apart, not in step or phase, and hence not in synchronism.

(2) Fix the disks on the shaft so that the marks will be exactly even with each other, as pictured at *B*. Now when you revolve them, they will not only run at the same speed, but the marks will keep together, so they are in synchronism. This is precisely the state of affairs that must prevail between the scanning disk of the transmitter and the reproducing disk of the receiver of the television set.

Synchronism is one of the toughest problems in television today. I shall tell you how it has been approached, and how it is handled at the present time. If you can invent some kind of simple and precise method by which the disk of a transmitter and that of a receiver can be made to run at identically the same speed, and so that the corresponding holes in them will keep exactly even, that is, in step or phase, without any connection between them, your fortune will be made.

Kinds of Synchronization Schemes.—The scanning disk of a transmitter and the reproducing disk of a receiver can be synchronized by three chief methods, and these are (1) mechanical, (2) electro-mechanical and (3) electrical. To keep two rotating disks exactly in phase by any purely mechanical method, when they are separated by any great distance, is practically impossible, and whatever device is used must of necessity be very crude, yet it may serve your first experimental needs.

For more practical purposes, an electro-mechanical device, such as the magnetic toothed-wheel synchronizer, offers about the best solution of the problem to date, especially where the transmitter and the receiver are located in the same power station zone, when their motors can be run from the same source of alternating current, in which case the frequency of the alternations in the line circuit is exactly the same. The ever increasing use of electric clocks has a tendency to standardize the current supply in this respect.

Experiments with Mechanical Synchronizers.—All of the following mechanical schemes work independently of the

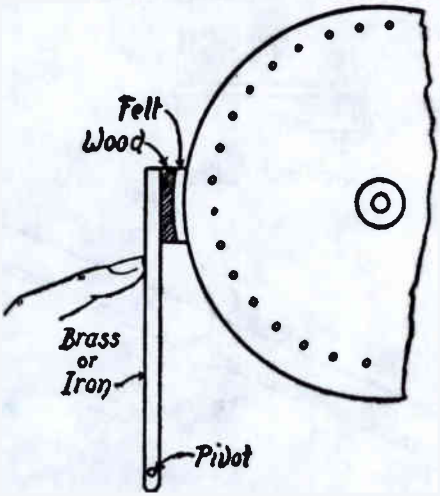
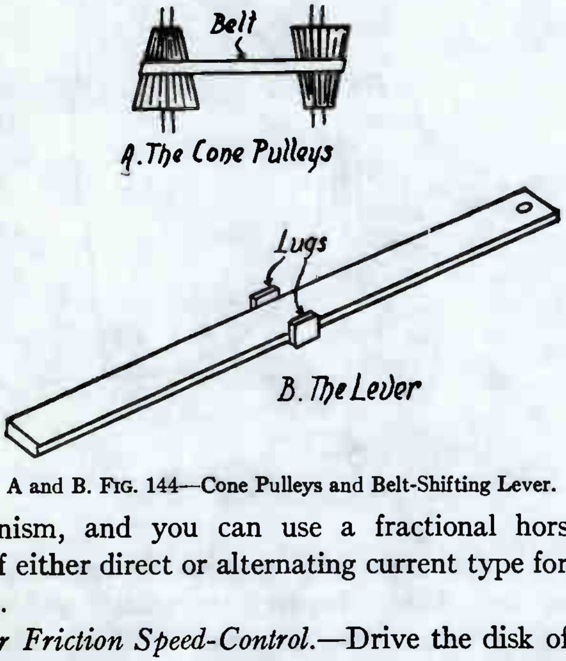


FIG. 143—A Friction-Brake Control.

transmitter and, consequently, they do not require a special wire or wireless channel between transmitter and receiver. Synchronizing devices that are purely mechanical in operation are usually manually controlled, that is to say, they are controlled by the hand of the operator.

If you will experiment a little with any of the devices which follow, you will soon be able to control the speed of your reproducing disk so that you can keep it running in phase with the transmitting disk, albeit the synchronism will be far from perfect.

While the use of a hand-controlled synchronizing device is interesting enough, the results are far from satisfactory when you are trying to receive a *telecasted* program, as the broadcasting of television events is called. The following are the simplest manually controlled mechanical means for effecting

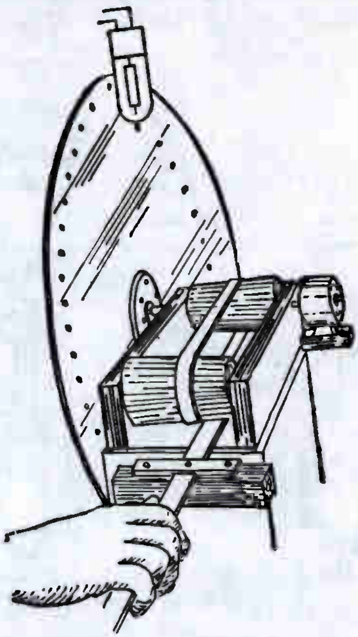


A and B. Fig. 144—Cone Pulleys and Belt-Shifting Lever.

synchronism, and you can use a fractional horse-power motor of either direct or alternating current type for driving the disk.

Finger Friction Speed-Control.—Drive the disk of the receiver at a little higher speed than that at which the disk of the transmitter is being driven, and press your finger on the surface of the former, close to the hub. By varying the pressure you can keep it roughly in synchronism with the transmitting disk.

Friction-Brake Speed-Control.—Cut a piece of hard wood ½ inch thick, ¾ inch wide, and about 5 inches long. Hollow out one end of it to fit nicely on the edge of the disk, then pivot the other end at the base that supports the bearings of the disk, as shown in Fig. 143. Now, by pressing, or by



C. Fig. 144—The Cone Pulleys in Operation.

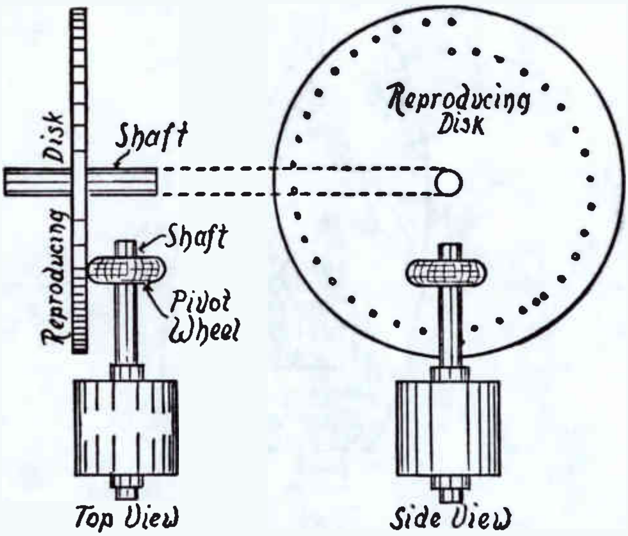
easing up, on the opposite end of the lever, you can control the speed of the disk to a much better advantage than with your finger alone.

Cone Pulley Speed-Control.—Cone pulleys are used in various machines where a small and flexible speed-control is needed.[1] The principle of cone pulleys is shown at *A* in

[1] This type of control is used in paper mill machinery.

Fig. 144, and it is obvious that when you shift the belt from one end of the cone to the other, the speed of the one on which is fixed the disk is varied proportionately, and it will run either faster or slower depending on which way the belt is shifted.

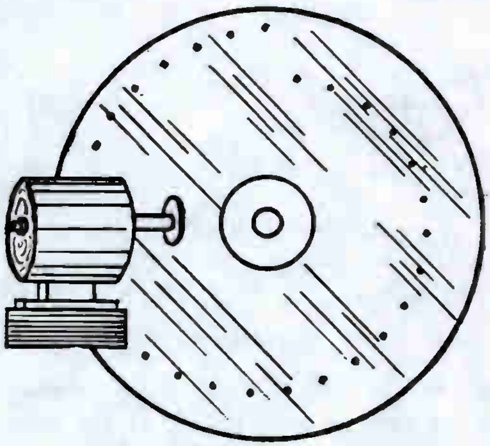
To make a cone pulley speed-control, have two cones



A. Fig. 145—The Friction-Drive Speed-Control.

turned up of hard wood, each one tapering from 1 inch in diameter at the apex to 3 inches in diameter at the base, and 5 inches long. Have a ¼-inch hole bored through each one exactly in the center, and force in a ¼-inch steel rod for the shaft. Mount the cones about 12 inches apart in a rigid frame and couple them together with a leather belt ½ inch wide.

The next thing is to make a lever of a strip of brass or iron ⅛ inch thick and 15 inches long; then solder two lugs to it at a point about 6 inches from one end, and have them just far enough apart so that the belt will run between them as shown at *B*. Now pivot one end of the lever to the end of the frame that supports the cone on whose shaft the disk is fixed, all of which is shown at *C*. If the driving motor is turning over 1000 times per minute, then the speed of the disk may be varied from 400 to 2800 revolutions per minute.



B. Fig. 145—The Friction-Drive Speed-Control.

Friction-Drive Speed-Control.—A far better manually adjusted mechanical control than the cone pulley just described is the friction-drive speed-control. In this device the television disk must be ⅛ of an inch thick, or, if it is thinner than this, it must be strengthened by a smaller and comparatively thick disk secured to its inner surface.

In the friction-drive speed-control, one end of the shaft of the motor carries a small leather-faced wheel, which is made to press against the reproducing disk, as shown at *A* in Fig. 145. In this drawing the shafts are shown at right angles to each other, but in the television transmitter or receiver they are set at an angle of about 35 degrees, in order to make room for the motor.

The motor is pivoted to a sliding base, so that it can be turned slightly and moved forward or backward in order to keep the driving wheel in contact with the disk. This latter movement is controlled by means of a handle fixed to a screw gear, as shown at *B* in Fig. 145. When the driving

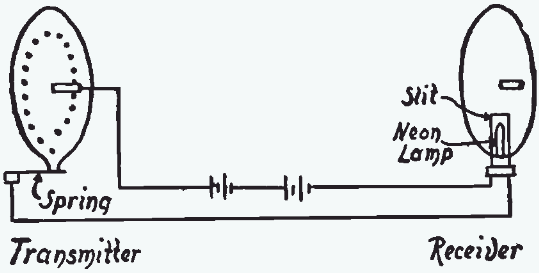


FIG. 146—A Simple Synchronism Indicator.

wheel is nearest the center of the driven disk, the latter will revolve at its highest speed, but as the former is moved toward the circumference, the speed of the disk is gradually reduced.

Experiments with Electro-Mechanical Synchronizers.—*A Simple Synchronism Indicator.*—A simple and effective way to tell when the reproducing disk of the receiver is in synchronism with the scanning disk of the transmitter is to cut a slot ¼ inch wide and ½ inch long in the former and have a projecting point on the circumference of the latter so that they will be exactly in the same relative positions with respect to the spiral holes, as shown in Fig. 146.

Now fix one end of a flat copper spring, or brush, as it is called, to one end of a block and secure this to a support so that the free end of it will press on the shaft; next fix one end of another brush to a block and this to a support so that when the disk revolves the projection will make contact with the brush. Now directly back of the reproducing disk and in a line with the slot in it, mount a neon lamp with the cathode (luminous) surface of the plate toward the slot.

This done, connect the brush that makes contact with the shaft of the scanning disk with one terminal of the neon lamp, then connect the brush that makes contact with the projecting point of the scanning disk with one pole of a 180-volt dry-cell battery, and the other pole of this with the other terminal of the neon lamp.

Every time the projecting point on the scanning disk makes contact with the brush, the circuit is closed and the neon lamp lights up, and conversely, the instant the contact is broken, the light goes out. If the reproducing disk and the scanning disk are in synchronism, you will be able to see the light through the slot, but if the receiving disk is out of step with the transmitting disk, the slot will then be either ahead of or lag behind the light, so that you cannot see it.

About Electromagnetic Synchronizers.—Electromagnetic speed-control devices, or *synchronizers*, as they are called, are of two general types, namely, (1) manually operated devices, and (2) automatically controlled devices. *Manually operated electromagnetic speed-control devices* are a very considerable improvement over the manually operated mechanical speed-control devices just described, but either kind is a joy while you are experimenting with them, but a joykiller when you want to look-in for entertainment purposes only.

The Electromagnetic Lever-Brake.—With this speed-control device you can control the speed of a disk while seated in front of the receiver. To make it, get an iron lever 1/16

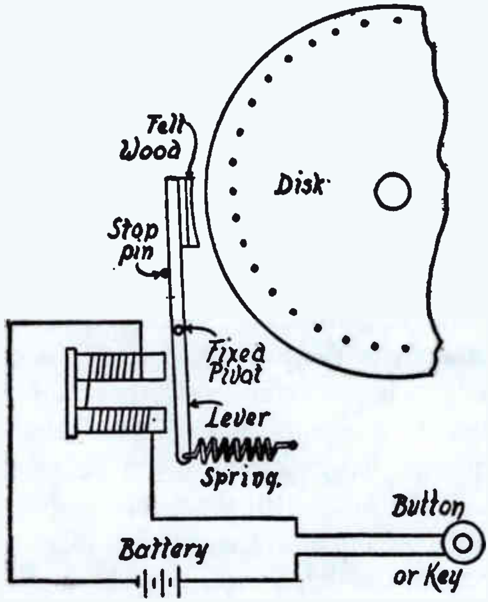
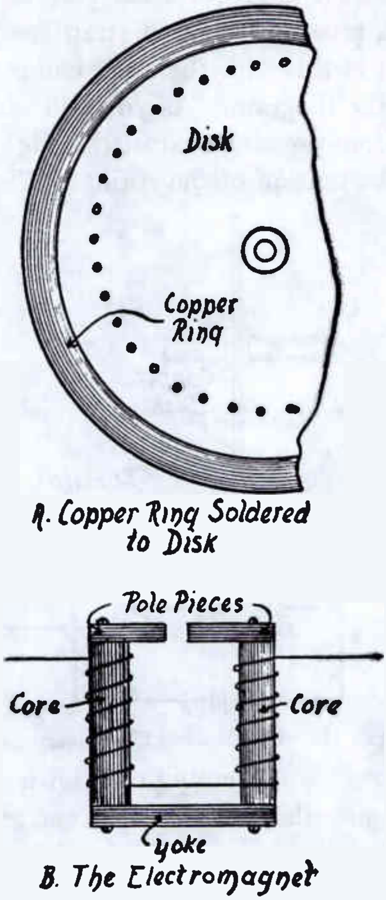


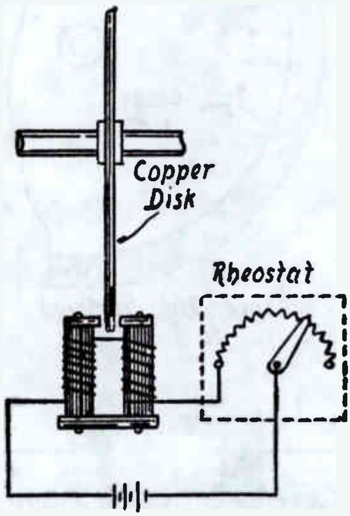
FIG. 147—An Electromagnetic Brake Speed-Control.

of an inch thick, 3/8 of an inch wide, and 4 inches long, and fix a hollowed-out brake-shoe made of wood, which has a piece of thick felt glued to it, as shown in Fig. 147. At a distance of 1¼ inches from the other end, pivot the lever to a support that is fixed to the base on which the disk is mounted, and to the right-hand end of the lower part secure one end of a spiral spring, the other end of which is held by a pin fixed in the base.



A. FIG. 148—The Disk and Electromagnet Control.

Near the other side of the lever mount a small electromagnet that has a resistance of about 4 ohms—a telegraph sounder magnet will serve the purpose admirably. Now connect one end of the magnet coil with one of the poles of a 3- or 4-cell battery, and the other pole of this with one of the posts of a push button or a strap key; finally, connect the other post of this with the other end of the magnet coil, as shown in the diagram. As you will observe, the brake-shoe is kept from pressing against the edge of the reproducing disk by the tension of the spring. When you want the



B. FIG. 148—The Disk and Electromagnet Control.

disk to run slower, you simply press down on the key which closes the circuit, the current then energizes the magnet; this attracts the lever and pulls the shoe against the disk, retarding the speed of the latter.

The Electromagnetic Disk Brake.—It was the great Faraday who discovered that when a copper disk is made to revolve in a magnetic field it is slowed down by the magnetic flux. You can employ this phenomenon to control the speed of your reproducing disk. For this method of control you will have to use a copper disk, or else secure a copper ring to the edge of the disk you are using, as shown at *A* in Fig. 148. The magnet must have pole pieces screwed to the ends of the usual polar projections, as pictured at *B*.

Mount the magnet so that the rim of the disk will run between the ends of the adjacent pole pieces, as shown at *C*. Connect one terminal of the magnet with one pole of a battery, the other end of this with one of the posts of a rheostat, and the other post of this with the other terminal of the magnet coil. To adjust the speed of the disk, you need only to throw in or cut out some of the resistance, by moving the lever of the rheostat toward the right or the left. Once adjusted so that the reproducing disk is running synchronously with the scanning disk of the transmitter, the speed should remain correct for at least a minute or two.

The Push-button Resistance Control.—You do not need an alternating current synchronous motor to drive the reproducer disk, but can use any kind of small motor that draws its current from the commercial 110-volt service line. This motor must, of course, have a higher speed than that of the motor which drives the transmitting scanning disk.

To make the push-button control, you will need a rheostat with a pair of contact points and with a resistance of about 20 ohms. Now connect one of the posts of the motor with one of the lines that leads to the source of current. Connect the other post of the motor with the contact arm of the rheostat, and the post at one end of the resistance coil to the other line wire as well as to one terminal of a push button, and, finally, the other terminal of this to the second contact point of the rheostat, as shown in Fig. 149.

The Automatic Relay Synchronizer.—All of the experimental synchronizers previously described were either operated or actuated manually, but with the relay synchronizer we come to the kind which are controlled automatically, whereby the speed of the disk of the receiver is kept constant, at least theoretically, without any hand manipulation. This is done in the case of the relay synchronizer by cutting in

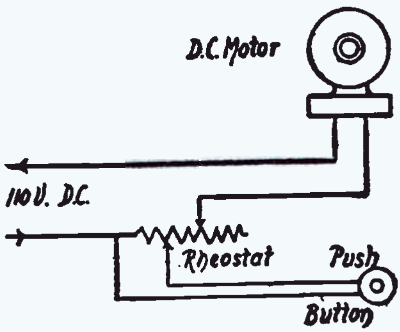


FIG. 149—A Push-Button Resistance-Control.

and out a part of the resistance of the magnet field-coils, and in this way varying the speed of the motor.

By a look at Fig. 150, you will see that the rheostat and the fixed resistance are connected in series with the stator, or field coil, and the brushes of the rotor of the alternating current motor. The armature of the relay, which carries the movable contact, and the stationary contact are shunted around the fixed resistance. One terminal of the relay magnet-coil is connected with the negative pole of the battery, and the positive pole of this with one of the filament terminals of the last amplifier tube. The other terminal of the magnet-coil leads to the positive electrode of the neon tube, and the negative electrode of this to the plate of the amplifier tube.

Next you must make or buy a commutator[1] which has as many segments in it as there are holes in the reproducing disk, and this commutator you mount on the free end of the motor shaft, by which is meant the end opposite the one which carries the disk.[2] Each of the terminals of the

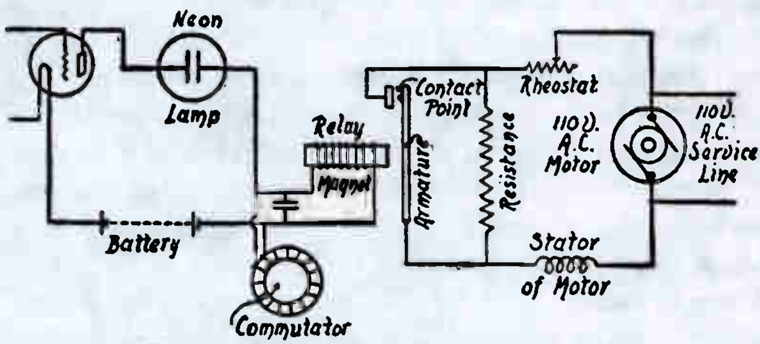


FIG. 150—An Automatic Relay Synchronizer.

magnet coil is connected to a copper or bronze brush, one of which sets a little ahead of the other on the commutator. Lastly, connect a condenser across the copper brushes.

Now when the receiver is in operation, the picture impulse currents that are set up in the circuits by the distant transmitter are not only impressed on the neon lamp, but on the magnet coil as well, at regular intervals, and at the same time. These intervals depend on the speed that the repro-

[1] A *commutator* consists of a ring formed of transverse copper segments insulated from one another by insulating strips.

[2] In the diagram the commutator is shown separated from the motor shaft in order to make the connections clearer.

ducing disk is making. When the disk is rotating at exactly the proper speed, the relay coil does not get enough current to energize it sufficiently to pull the lever into contact and close the stator-and-resistance circuit.

But when the speed of the receiver motor is faster than that of the transmitter motor, and, hence the disk of the receiver gets out of phase with the one of the transmitter, a larger amount of current flows through the magnet coils, the magnet is energized and draws the lever to it, bringing the points into contact; this short circuits the fixed resistance, that is, it cuts out the latter, and when this takes place the current in the field coil of the stator is increased, with the result that the speed of the rotor is retarded. As soon as the motor is again running at its normal speed, the current in the magnet coil gets weaker, the spring on the lever pulls it back, and the contact is broken.

The Automatic Tuning-Fork Synchronizer.—The electromagnetic tuning-fork synchronizer is used in the Ranger system of transmitting and reproducing pictures at a distance, either over wires or without wires. While this form of synchronizer can be employed for television, it is so cumbersome and costly that it is not likely to become popular in home receivers. Perhaps you can simplify it and make it more compact and less expensive, and so I will tell you how the original one is made.

It consists of (1) a tuning fork about 12 or 15 inches long, mounted on a brass frame with an electromagnet between the prongs, (2) a small correcting electromagnet which is energized periodically by (3) the pendulum of a very accurate clock, (4) an electron tube oscillator for maintaining a constant vibration of the fork, (5) an audio-frequency transformer, (6) an electron-tube amplifier, (7) a variable condenser, (8) a double-pole, double-throw switch, and (9) a pair of head-phones.

To wire up these components, begin by connecting one terminal of the electromagnet with the middle post *A* of the double-pole, double-throw switch, the middle post *B* of

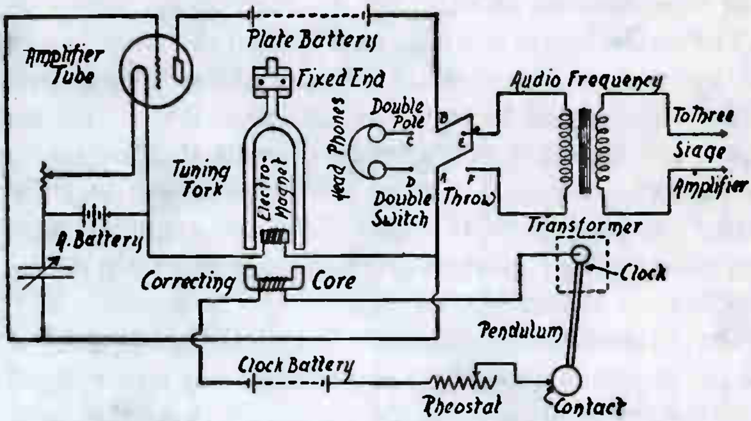


FIG. 151—A Tuning-Fork Synchronizer.

this with the negative pole of a battery, the positive pole of this with the plate of the oscillator tube, and then connect the grid of this with the same terminal of the magnet.

Next connect the other terminal of the magnet with the negative post of the *A*, or storage, battery, then connect a variable condenser between the grid circuit and the negative pole of the storage battery; now connect the rheostat between the positive pole of the clock battery and the point that makes contact with the pendulum of the clock. Connect the negative end of the clock battery through the winding of the correcting-core to the top of the pendulum, which must be a good electrical conductor.

Connect the *C* and *D* posts of the switch with the pair of head-phones and the *E* and *F* posts with the primary coil of an audio-frequency transformer. Lastly, connect the secondary coil of this with the first audio-frequency amplifier stage, and the last stage with the alternating current lines that are connected with the motor. See Fig. 151.

The oscillations of the tube tend to hold the vibrations of the tuning fork to a constant frequency,[1] and this counteracts the changes in the speed of the motor that drives the disk. The high-frequency impulse currents that are set up by the fork are passed through the transformer, the alternating currents from this pass into the amplifier tube, and the amplified currents from this are impressed on the synchronous motor.

The purpose of the clock is to further check the frequency of the tuning fork, and so whatever variation may be developed in either the oscillator tube, the vibrating fork, or the clock, the effect of each unit is stabilized by the influence of the others. In this complicated way, then, it is possible to overcome the variations of the current that are set up in the motor, causing a tendency to make it run faster, or *hunt*, as it is called.

Experiments with Synchronous Electric Motors.—Synchronous motors are used for synchronizing the scanning

[1] In order to eliminate the variations in the time period of the vibrations of the fork, caused by the expansion and contraction of its metal, it must be enclosed in a *constant temperature box*, that is, a box that has a filament lamp to heat it when the temperature drops below a certain point. The current is automatically cut off from the lamp by a thermostat when a critical temperature is reached.

disk of the transmitter and the reproducing disk of the receiver when these are run (1) from the same alternating current service line, and (2) from separate and distinct lines that supply the alternating current.

Power-line Synchronous Motors.—Where commercial alternating current service lines supply power over a large area, or *interline transmission*, as it is called, as they do in many cities, the transmitting and receiving synchronous motors

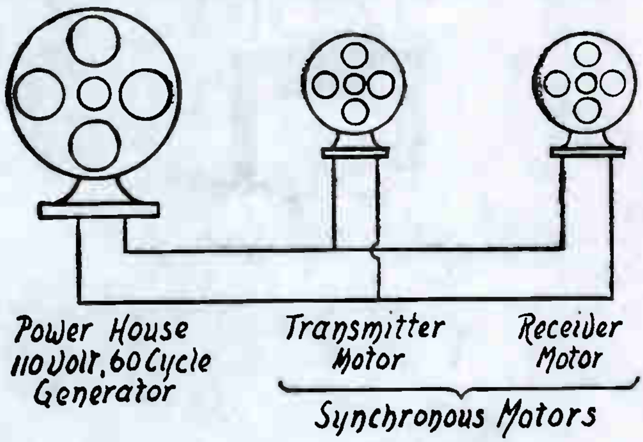


FIG. 152—Transmitting and Receiving Synchronous Motors. (*Connected in Parallel with a 60-Cycle Service Line.*)

can be connected in parallel with them, as shown in Fig. 152, while television picture impulses are transmitted over telephone lines or, more often, by electric waves, *i.e.*, by radio.

While synchronous motors can be used without any accessory controlling means, still far better results can be had when the latter are used with them because when the voltage of the line increases, the phase angle decreases. When these variations take place in lines that carry industrial loads, there is a sufficient variation in the speed of the transmitting and receiving motors to prevent perfect synchronization.

How a Simple Synchronous Motor Is Made.—The simplest type of synchronous motor is known as the *toothed-wheel* or

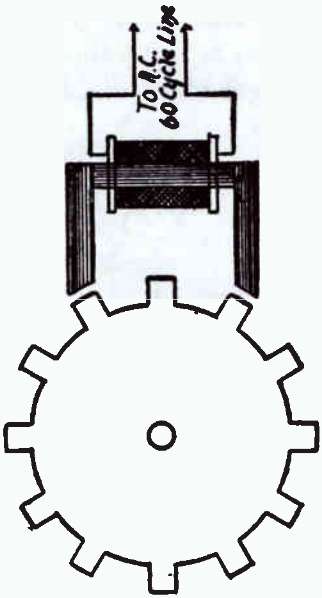


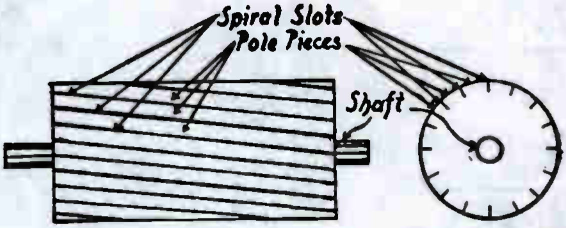
FIG. 153—How the Magnetic Toothed-Wheel Synchronous Motor is Made.

phonic-wheel motor. The *rotor* is formed of a disk of iron,[1] on the circumference of which are cut a number of teeth. The *stator* consists of an electromagnet, the polar projections of which just barely clear the teeth of the rotor as shown in Fig. 153.

When an alternating or a periodic direct current flows

[1] This is usually built up of disks of soft sheet iron so that it will magnetize and demagnetize quickly.

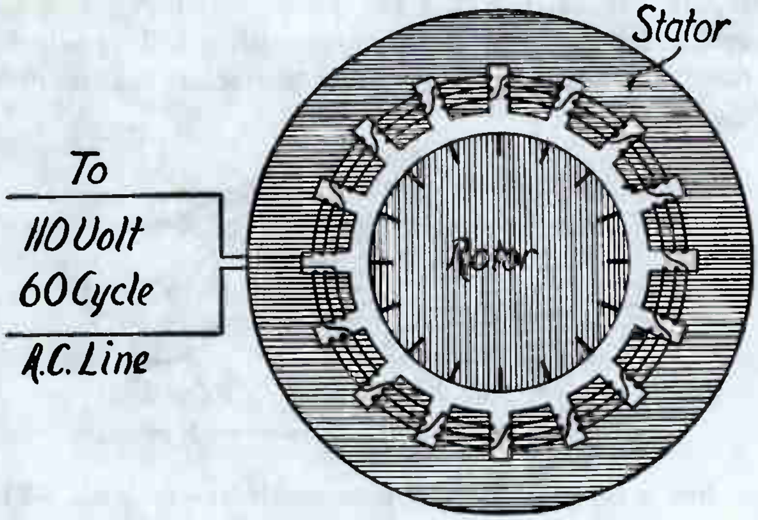
through the coils of the stator the latter is energized, and this tends, if the rotor is at rest, to hold the teeth of it to the pole-pieces of the former, so that there is a magnetic pull on them. If, however, you give the rotor a spin, it will then be continuously pulled around by the stator, and when it is running in step with the impulses of the current it will develop power. The phonic-wheel motor is not used in television to drive the transmitting and reproducing disks, but to control the speed of the motors that do drive them.



A. Fig. 154—The Rotor of a Synchronous Motor.

How a Constant-Speed Synchronous Motor Is Made.—The principle of the synchronous motor used for driving the scanning and reproducing disks is practically the same as that of the phonic-wheel motor just described, the chief difference between them is that the stator of the driving motor is in the form of a cylinder, instead of an electromagnet, as in the phonic wheel, and the rotor of the former is a cylinder instead of a disk, as in the latter.

The rotor has 60 or more slots cut spirally on its outside surface as shown at *A* in Fig. 154, so that an equal number of polar projections are formed, while the stator is slotted horizontally across its inside surface so that it has as many pole pieces as there are projections on the rotor. Each pole of the stator has a coil of wire wound on it, see *B* in Fig. 154, and these are all connected in series except the first terminal of the first one and the last terminal of the last one, which are used as the leads for connection with the supply lines.

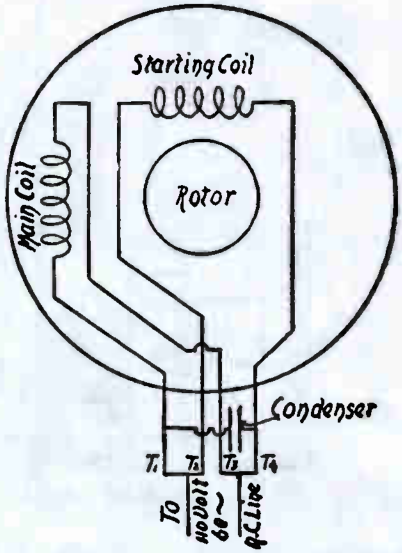


B. Fig. 154—Wiring Diagram for a Synchronous Motor.

If you connect one of these motors to the supply lines of a single-phase alternating-current generator, it will run synchronously with the cyclic changes of the current developed. This is the reason it is called a *constant-speed motor*, and it will serve very well for driving the scanning disk of your experimental transmitter and receiver.

How a Variable-Speed Induction Motor Is Made.—What is called a *variable-speed induction motor* is made very much like the constant-speed motor just described, only it will run at a higher speed than that at which the scanning or reproducing disk runs and it is connected with a rheostat.

The normal speed of the variable speed motor is 1750 revolutions per minute, but by means of the rheostat this is reduced to 1200 r.p.m., or until the television image is held steady in the frame. While this method gives fairly

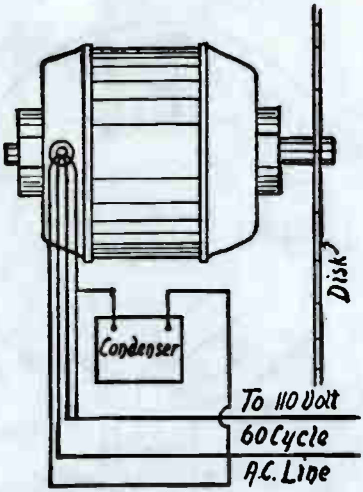


A. FIG. 155—Connections of the Condenser Type of Synchronous Motor.

good results it is not good enough for the practical reception of television images. For this reason, H. S. Baird employed the phonic wheel method of controlling the speed of the driving motor, and this will be described presently.

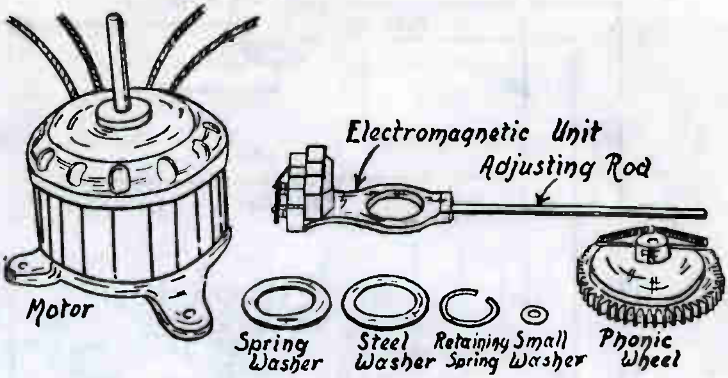
The Self-Starting Synchronous Motor.—As I explained under the caption of *How a Simple Synchronous Motor Is*

Made, a motor of this type will not start by itself when it is energized by an electric current. To make such a motor self-starting, several different schemes have been resorted to. In the larger synchronous motors an extra coil, called a *starting coil*, is wound on the stator, and a *centrifugal switch* is connected across this coil between the supply line and the winding designed for synchronous operation.

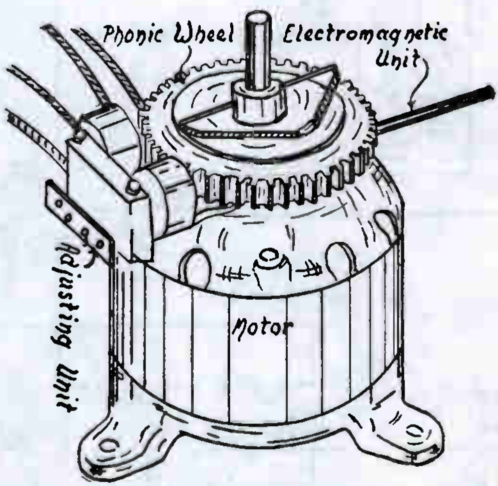


B. Fig. 155—Connections of the Condenser Type of Synchronous Motor.

When the current is passed through the stator, the starting coil starts up the motor, and when the speed gets nearly up to its synchronous rate, a switch is closed by a pair of centrifugal balls, that spread apart like the flyballs of an engine governor, and this cuts the starting coil out of the circuit. A starting coil is also used in the smaller synchronous motors, such as those used for running television disks, but in this case, one terminal of it is connected to one



A. FIG. 156—Motor, Magnet, and Phonic-Wheel Assembly.



B. FIG. 156—Motor with Phonic-Wheel and Synchronizing Magnet Mounted on it.

end of a 2.5 microfarad condenser, the other end of which is connected with the proper terminal of the main coil, as shown at *A* in Fig. 155.

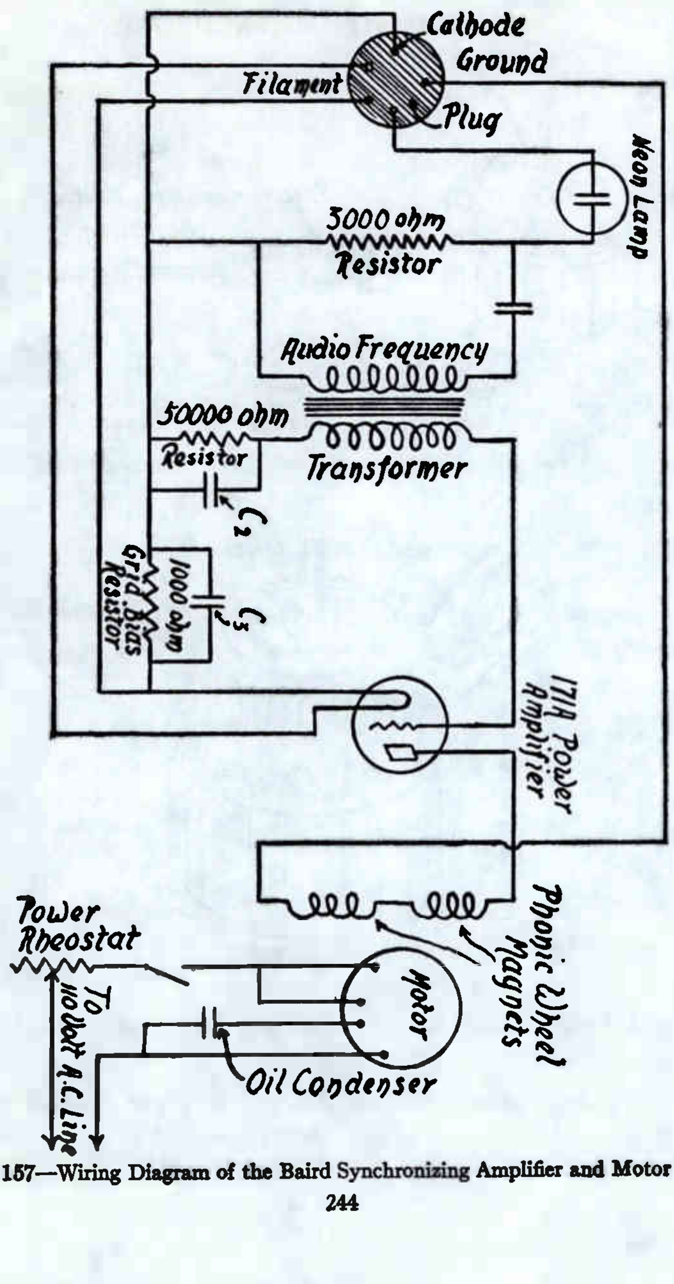


Fig. 157—Wiring Diagram of the Baird Synchronizing Amplifier and Motor Unit.

The connections as here shown will make the rotor run in a counter-clockwise direction, but if you want it to run clockwise you need only to reverse the connections of the terminals T_1 and T_3. The terminals, as they come from the motor, are connected with the condenser and the service lines as pictured at *B*. The condenser not only helps along the starting, but it gives a better power factor[1] and, it follows, a higher efficiency. The connections of the condenser type of motor are shown also at *B*.

The Phonic-Wheel Control of the Driving Motor.—The way the phonic-wheel motor is applied to the variable-speed motor is this. The phonic wheel, with its electromagnet and assembly parts, see *A* in Fig. 156, are fitted together and then mounted on the driving motor as pictured at *B*. The terminals of the stator coils are then connected with the alternating current service line, using a condenser having a large capacitance, as shown in Fig. 157.

Next the reproducing disk is secured to the shaft of the motor, to which the phonic wheel is also keyed, when the device is all ready to run, except for connecting in the electromagnet of the phonic-wheel motor. The way this is done is shown in the wiring diagram in Fig. 157. One of the terminals from the electromagnet is connected with the plate of the amplifier of the television synchronizing unit, and the other leads to the pin marked *ground*, on the plug shown on the left-hand side of the diagram.

When this plug is pushed into the socket shown on the lower right-hand side of the wiring diagram of the Baird

[1] The term *power factor* means the ratio of electric power in watts to the apparent power in volt-amperes, in an alternating current circuit or apparatus.

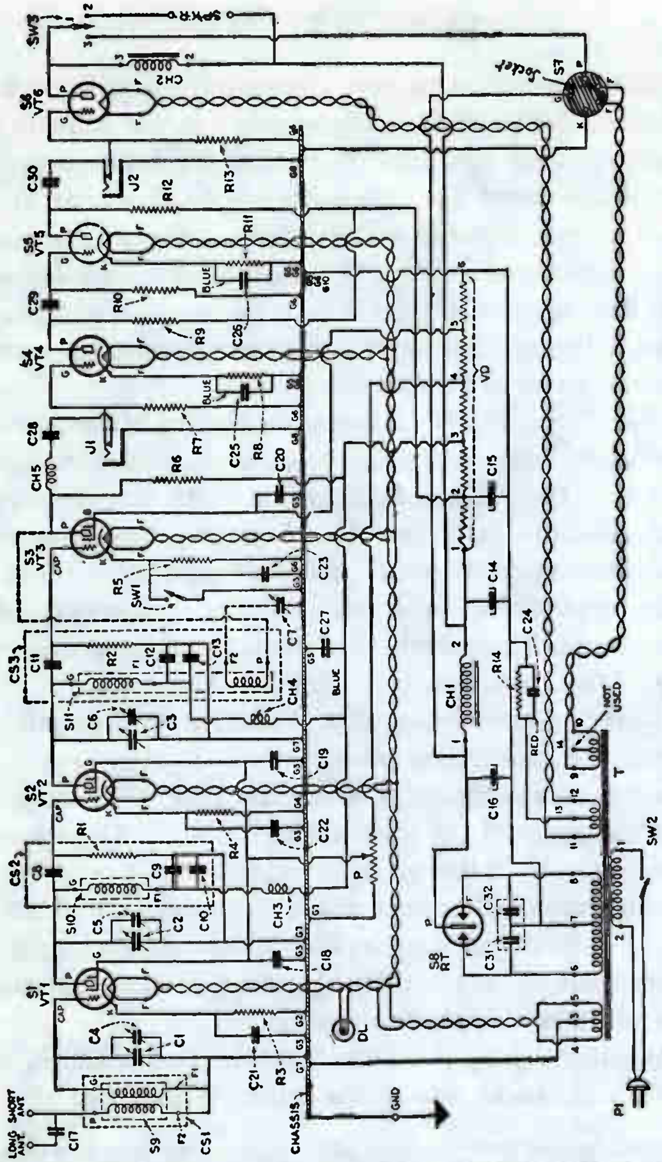


FIG. 158—Wiring Diagram of the Baird Universal Short-wave Receiver.

universal short wave receiver[1], see Fig. 158, the terminal of the electromagnet will be grounded to the chassis of the receiver. When you have done this, you are all ready to look-in on the telecast images from various short-wave stations all over the world.

How the Phonic Wheel Control Operates.—Each spot of light that is sent by the neon tube of a television receiving unit through a hole in the reproducing disk forms a line across the area of the image that is being built up and which you see in the frame. Now after each line of the image, a synchronizing signal current, which is set up by the break in the continuity of the image, is impressed on the amplifier tube, and the amplified current then flows through the electromagnet which operates the phonic wheel.

The teeth of the phonic wheel can, of course, move freely across the polar projections of the electromagnet only when there is no current flowing through it, therefore when the synchronizing signal current energizes the electromagnet it will accelerate the speed of the phonic wheel and, consequently, the speed of the rotor of the driving motor, the rheostat of which is so adjusted that it will run a little slower than that of the rotor of the motor which is driving the scanning disk of the transmitter. The result is that, at the end of every line of light which forms the image on the plate of the neon lamp, the phonic wheel speeds up the rotor of the driving motor and brings it into step with the one at the transmitting end.

[1] If you are interested in *short-wave receivers* and television receivers, and will write to the *Baird Shortwave and Television Corporation*, Boston, Mass., U. S. A., the Chief Engineer will send constructional manuals and working blue prints of the wiring, free of charge.

How to Synchronize Heavy Disks.—Where the transmitter motor and the receiver motor are operated from the same alternating current power line you will have no trouble in keeping a light-weight reproducing disk in synchronism with the scanning disk, but when a relatively heavy disk is used the motor will not get into step very easily. There are two simple ways by which this objectionable feature can be overcome, and these are by using (1) a push button control, and (2) a synchronizing coupling.

The Push-Button Control.—In this method the stator of the motor is wound for a voltage that is lower than normal and is connected in series with a resistance unit which prevents the motor from heating up. This scheme to speed up the motor until it gets into step is very effective but, being manually operated, it will not pull the disk into synchronism as well as the following method.

The Synchronizing Coupling.—Some time ago the Baldor Electric Company, of St. Louis, Mo., developed a *synchronizing coupling* that will automatically pull a heavy disk into step and is therefore preferable to the push-button control just described. It consists of a coupling that is mounted on the shaft of a synchronous motor, the coupling flange of which is secured to the reproducing disk.

Types and Prices of Motors.—The types of television motors listed at the end of this chapter are all ball bearing, with a winding of the condenser type, which eliminates centrifugal starting-switches and hum; they can be operated either in a vertical or a horizontal position and, finally, by interchanging the terminal connections, the direction of rotation of the motor may be reversed.

The list prices of the different motors which have been described above do not include the condensers or push-button control. These are usually worked into the television cabinet and, hence, are handled separately from the motor proper.

Type B.—Frame M2C, 1/15 horse power, single phase, 60 cycle, variable speed motor, 1700 r.p.m., and requires a 2 microfarad condenser. The list price is $14.00.

Type C.—Frame M3CN, 1/30 horse power, single phase, 110 volts, 60 cycle motor, 1200 r.p.m., synchronous push-button type. Requires a 3 microfarad condenser and push-button control. The list price is $16.00.

Type D,—Frame M3CN, 1/30 horse power, single phase, 110 volt, 60 cycle motor, 1200 r.p.m., synchronous coupling type. Requires a 3 microfarad condenser which is included. The list price is $17.00.

CHAPTER IX

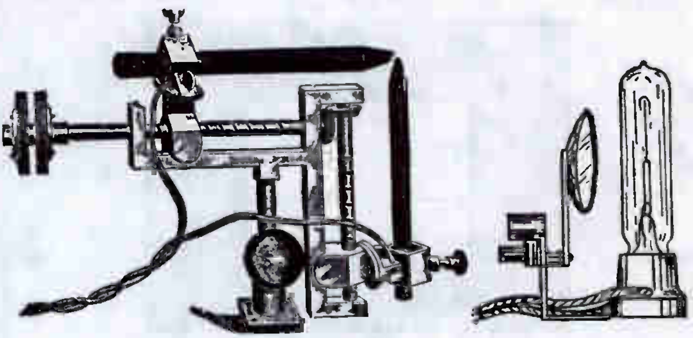
HOW TO MAKE A TELEVISION TRANSMITTER

It is beyond the scope of this book to tell how to build, install, and operate a television broadcasting transmitter, since the apparatus for such a station costs several thousands of dollars, is subject to the strictest governmental regulations, and its design and construction require a high degree of technical skill. If you want to put up a real telecasting station, the thing to do is to get the equipment from one of the big radio manufacturing companies, such as the Radio Corporation of America, of Camden, N. J., or the Western Electric Company of Chicago, Ill.

How to Make a Simple Radio Television Transmitter.—What I propose to do is to explain how to make a simple radio television transmitter that can be used indoors for either experimental, demonstration, or lecture purposes. To make such a transmitter you will need the components for (1) the television units, and (2) the radio units.

The Television Transmitting Unit.—The components for the television transmitting unit include (1) a source of light, (2) a scanning disk, (3) a synchronous motor, (4) a photoelectric cell, (5) three amplifier tubes, (6) four high resistances, or *resistors* as they are called, (7) three filament rheostats, (8) a filament, or *A*, storage battery, (9) three plate or *B* batteries, and (10) three grid, or *C*, dry cells.

For the source of light you can use either a 90-degree hand-feed arc lamp, such as is used for projecting magic lantern pictures, see *A* in Fig. 159, or a 500- or 1,000-watt incandescent lamp. If you use the latter kind, you should place it in the focus of a parabolic reflector, see *B*, so that all of the rays of light will be concentrated in a beam. Either type of lamp must be enclosed in a sheet-iron hood, with holes in the sides near the bottom, and on top, for ventila-



A. A 90° Hand-Feed Arc Lamp

B. An Incandescent Lamp and Parabolic Reflector

FIG. 159—The Sources of Light.

tion. The front of the hood is provided with a tube to hold a 2- or 2½-inch convex lens, which has a focus of about 8 inches. The arc or incandescent lamp can be energized with a 110-volt direct current or a 120-volt alternating current.

The scanning disk for this transmitter should be 15 inches in diameter and have 60 holes in it. I would suggest that you buy this disk, and not try to make it, unless you are fairly well skilled in the use of machine tools, for it must be accurate in every respect. Having the disk, mount it on one end of the shaft of a 1/15 horsepower, 60-cycle, single phase condenser type of motor. The speed developed by this motor is 1750 revolutions per minute, but by using a rheostat you can reduce it to 1200 revolutions per minute.

This motor is of the alternating current constant-speed type, that is, the rotor is built up of iron segments, or pole

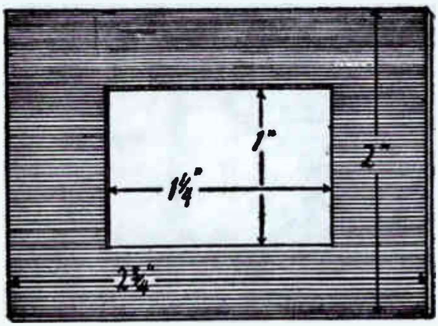


FIG. 160—The Mask for the Scanning and Reproducing Disks.

pieces, and, therefore, it requires neither slip rings nor brushes. The stator has four field coils connected together with a microfarad condenser, as shown in Fig. 155[1].

The next thing you will need is a frame for the scanning disk. You can make this of a piece of sheet brass that is 1/32 of an inch thick. Cut out a rectangle that is 2 inches wide and 2¾ inches long and cut a hole in the center of it that is 1 inch wide and 1¼ inches long, as shown in Fig. 160. This done, mount it in front of the scanning disk, at the upper edge of the latter, so that the upper edge of the hole will just clear the first or upper hole in the disk, and the

[1] See Chapter VIII.

lower edge will just clear the last or lower hole in the disk. The size of the aperture, or hole, is marked 1 by 1¼ inches, but the exact measurements of it will depend on the radial

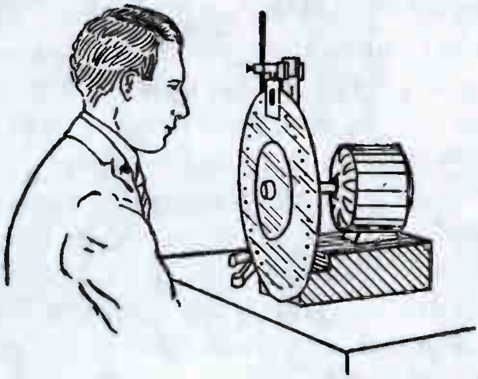


FIG. 161—A Simple Way to Mount a Photocell and Mask.

distance between the first and last holes and circumferential distance between any two adjacent holes.

You must mount this frame in such a way that you can

FIG. 162—An Easily Made Hood for a Photocell.

adjust its position relative to that of the holes in the scanning disk with alacrity and dispatch. A quick and easy way, though it is by no means the best way, is to use a laboratory tripod base with a support rod screwed into it.

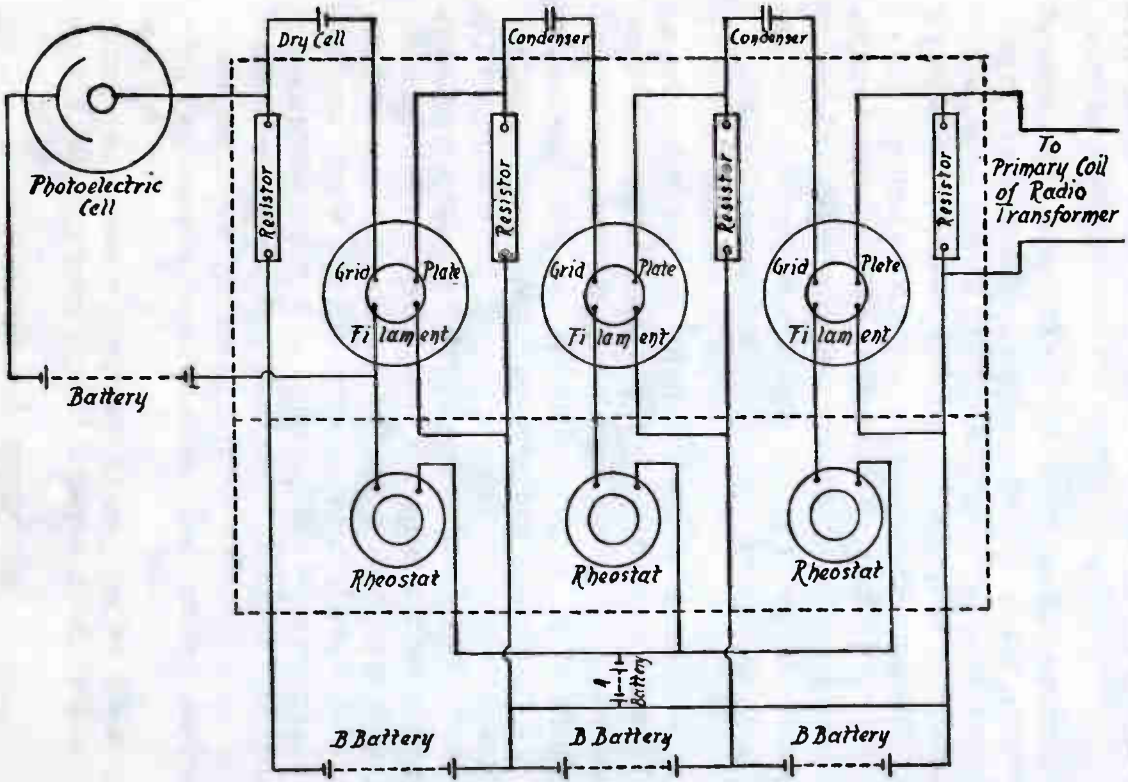
This must be fitted with an adjustable right-angle clamp, so that it can be moved up and down on the rod in order to obtain the height that is needed. The frame is secured to the free end of the rod so that it is in a vertical position. Now fix another clamp, above the one that holds the frame, to hold the photo-electric cell, as shown in Fig. 161.

You can use any one of the various makes of photo-electric cells that are now sold in the open market but, for convenience, let us assume that it is a *Visitron* cell. Make a little sheet metal hood, or case, for it and in one side cut a hole about 2 inches in diameter; now make a short tube 2¼ inches in diameter and 1½ inches long, and open at both ends; next solder one end over the hole in the hood, so that it will look like Fig. 162.

This done, fix the base of the photocell to the bottom of the hood, and have it set in such a position that when the cell is pushed into the base the sensitive area directly faces the open end of the tube. The purpose of the hood is, of course, to keep out the light from every direction except that which is reflected from the subject's face and passes through the tube of the hood to the cell.

The last thing to do in connection with the television unit is to make the amplifier stages. Three stages are needed, the first and second of which use 201A amplifier tubes[1] and the third a 171A power amplifier tube. Mount the sockets of these tubes on a bakelite base with about 3 inches between centers, and mount three filament control rheostats

[1] Use either the UX-201A made by the *Radio Corporation of America* or the ER-201A made by the *National Carbon Company* and sold under the name of the *Eveready Raytheon 4-Pillar Tubes.*



A. Fig. 163—Schematic Layout for a Demonstration Television-Transmitting Unit.

on a panel, with their centers 3 inches apart. Likewise mount four 10-megohm resistors on the base, as shown at *A* in Fig. 163.

All that remains to be done now is to connect up the photo-electric cell, the amplifier tubes, the resistors and the rheostats and the batteries, and these connections are shown in the wiring diagram at *B*. This will give you a multi-stage amplifier with a single *A* battery[1] for supplying current to the filaments of all three tubes, and separate *B* batteries[2] for energizing the plates. Where a direct current is used, the grids are given a negative bias by connecting a single dry cell between each one and its complementary resistor.

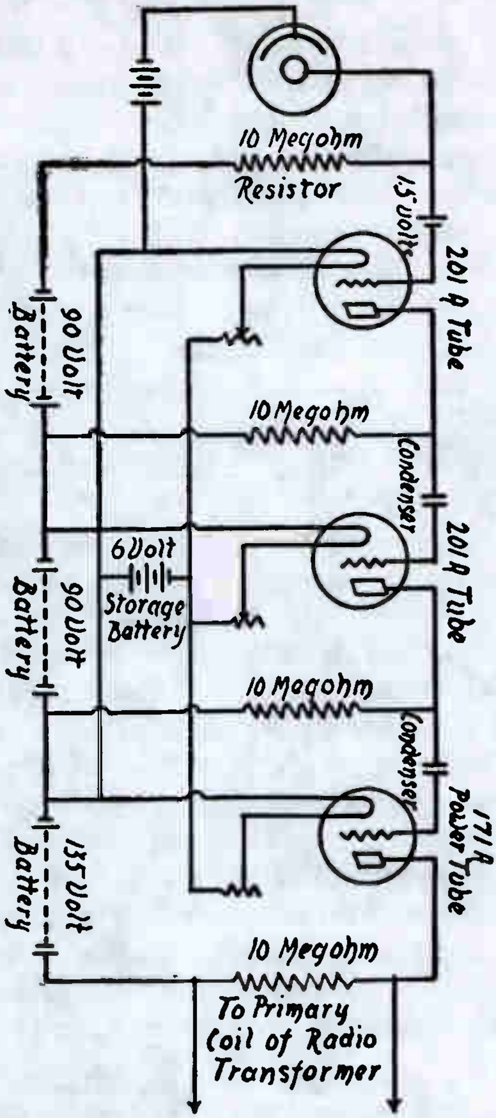
When you have built this television transmitting unit and experimented with it enough to know "all about it," you can then build up the amplifier, using a 110-volt direct current supply, as shown in Fig. 87 (Chapter IV), or a 105- to 120-volt alternating current supply, as shown at *A*, in Fig. 88, in the same chapter.

The Radio Transmitting Unit.—The components for the radio transmitting unit consist of (1) a radio frequency transformer, (2) an oscillator electron tube, (3) a filament rheostat, (4) two fixed condensers, (5) a grid leak, (6) a tuning inductance coil, (7) a radio-frequency ammeter, (8) a filament, or *A* storage, battery and (9) a plate, or *B*, battery.

The *radio-frequency transformer* is the same kind that is used in a radio-frequency stage of a receiver, to wit, it has a primary coil, a secondary coil and an *air core*, which means

[1] Use a 6-volt storage battery for all of the tubes.

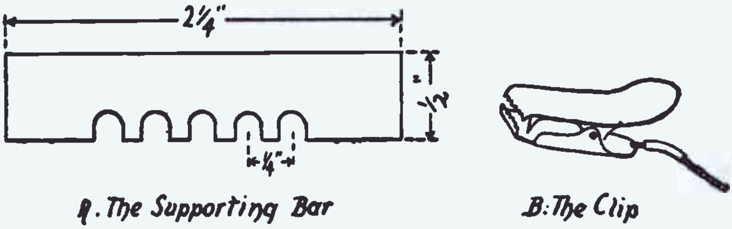
[2] Use 90-volt dry batteries for the first two amplifier tubes, and a 135-volt dry battery for the power tube.



B. FIG. 163—Wiring Diagram for a Demonstration Television Transmitting Unit.

there is no iron in it. Now while the electrical impulses that are fed into it from the amplifier are of audio frequency, an audio frequency transformer cannot be used because the radio frequency oscillations which are set up by the oscillator tube surge through the plate circuit, and this includes the secondary coil of the transformer.

You can use any kind of an amplifier tube for setting up the oscillations, but a *5-watt oscillator tube*[1], which is made



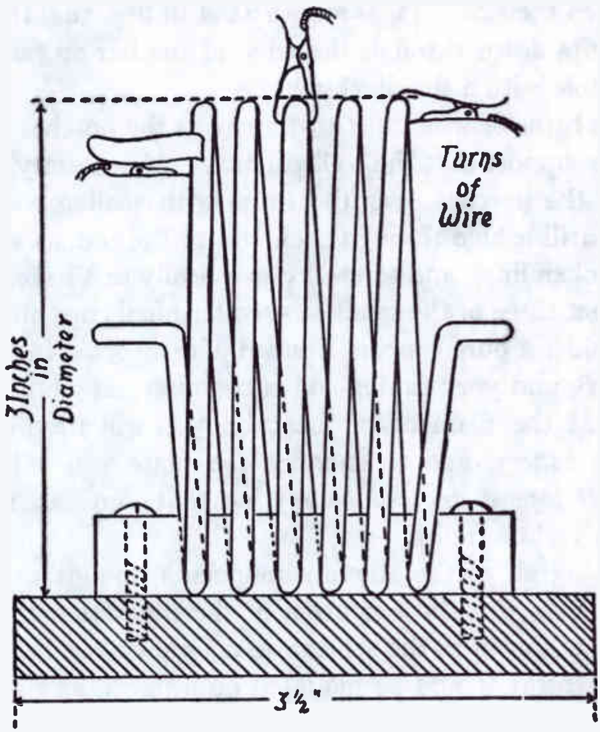
A and B. FIG. 164—Parts of a Transmitting Tuning Coil.

for the purpose, will give a larger output, since it takes more current to heat the filament, *i.e.*, about 2 amperes at 7.5 volts, and will stand a plate potential of 350 to 450 volts, while the maximum plate current is 55 milliamperes.

The *rheostat* for controlling the *A* battery current can be of the same type that is used for amplifier tubes but it must be large enough to take care of 2 amperes without heating. The *fixed condensers* that are used must be of the mica type, and each should have a capacitance of .001 microfarad and a breakdown potential of 3000 *volts*. The grid-leak resistor is a high resistance unit having a resistance of 2 megohms,

[1] This is made by the Radio Corporation of America, Camden, N. J. You can use a UX or an ER250 power amplifier tube for the oscillator as this will provide about 4½ watts.

and with a mid-tap so that you can use half of it if necessary. It is used in the radio transmitter to keep the voltage of the grid of the tube at a constant value, and in this way it controls the output of the aerial, with which it is also connected.



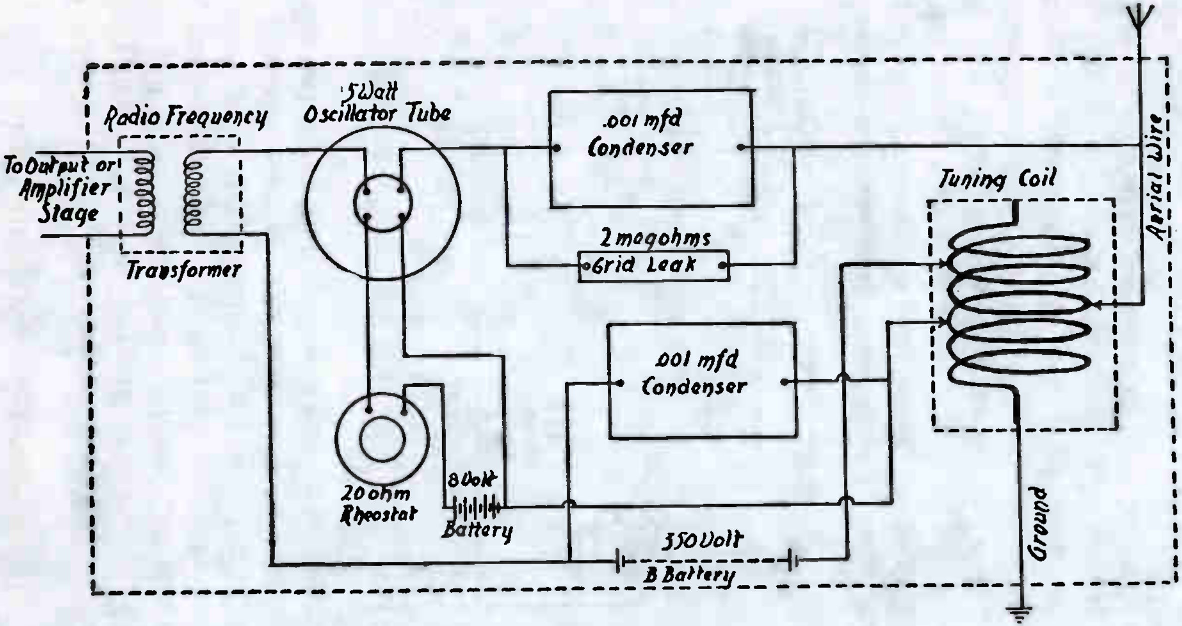
C. Fig. 164—The Tuning Coil Complete.

You can make the *tuning inductance coil* of a piece of pure annealed copper wire ⅛ of an inch in diameter and about 50 feet long. Wind it up in a coil of 5 turns spaced ⅛ of an inch apart, and give it a diameter of 3 inches. You can easily do this by using a wooden cylinder or a short length of iron pipe to wind it on. To hold the turns of the wire in place, mount the coil in a bar of bakelite that is 3/8 of an inch thick, 1/2 of an inch wide and 2 1/2 inches long. To notch it, drill six 1/8-inch holes in a line, and with 1/4 of an inch between their centers, as shown at *A* in Fig. 164, then make two cuts down through the edge of the bar on each side of each hole with a fine hacksaw.

The turns of wire must fit tightly in the notches as this is all the support that the coil will have. If necessary, you can fill in the notches over the turns with sealing wax. This done, drill a hole through each end of the rod, as shown by the broken lines, and screw it down firmly to a bakelite base. Now get three of the smallest sized terminal clips obtainable, and solder a pure copper-stranded wire or braid to each one, as at *B*, and your tuning coil is complete, as pictured at *C*. To heat the filament of the tube, you will need an 8-*volt storage battery*, and to energize the plate you will need a 350-*volt tapped dry cell battery*, so that you can adjust it within certain limits.

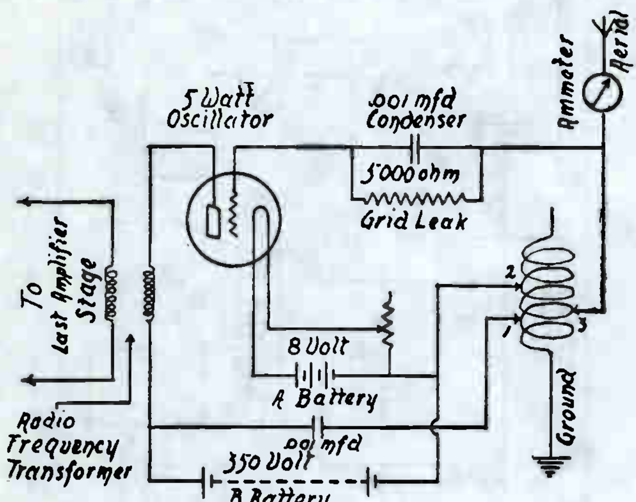
Having all of the above components, mount them on a baseboard, with the exception of the rheostat and the batteries, as shown in the schematic diagram at *A* in Fig. 165. The rheostat should be mounted on a panel, as should also a radio-frequency ammeter, which is shown connected with the aerial wire. Be sure to mount the radio frequency transformer and the tuning coil so that their turns of wire are at right angles to each other, for otherwise there may be an inductive action set up between them.

When you have all of the parts of the radio unit suitably mounted, connect them together, as shown in the diagrams



A. FIG. 165—Schematic Layout of a Demonstration Radio Transmitting Unit.

at *A* and *B*. This done, connect the plate of the last amplifier tube of the television unit to one terminal of the primary coil of the radio transformer, and the other end of this to the positive pole of the *B* battery, with the secondary coil connected to the oscillator circuit as shown at *B*, Fig. 165. Finally connect the synchronous motor that runs the scanning disk to the leads of a 120-volt, 60-cycle lighting cir-



B. Fig. 165—Wiring Diagram for a Demonstration Transmitting Unit.

cuit, and your transmitter is complete and ready to send out television picture waves.

How the Radio Television Transmitter Works.—*The Television Unit.*—When you start up the motor, and the scanning disk which it drives gets up to operating speed, that is, 1200 revolutions per minute, and this you can check with a speed indicator,[1] the beam of light from the arc or

[1] See Chapter III.

incandescent lamp passes through the successive holes and falls in progressive sequence on the subject's face, these rays, or at least a part of them, are reflected so that they fall upon the photo-electric cell. The light makes the cell more or less conductive to the current that is passing through it, and thus the strength of the latter is varied accordingly.

The infinitely minute modulated current that flows through the photocell then passes into the first of the amplifier stages, the amplifier current passes into the second amplifier stage, and, finally, this amplified current reaches the power amplifier stage, where the current is sufficiently amplified to measurably impress its modulations on the oscillating currents that are set up by the oscillation tube of the radio unit.

The Radio Unit.—The above result is obtained by means of the radio-frequency transformer. The audio-frequency picture impulses, which range from 10 to 20,000 per second, that pass through the primary of the transformer, are impressed upon the radio frequency currents which are set up by the oscillator tube, and which surge through the secondary of the transformer, and modulate the latter currents accordingly.

In the radio transmitter shown at *A* and *B* in Fig. 165, the positive potential of the 350-volt *B* battery energizes the plate of the oscillation tube, while the negative terminal is connected to the filament of it, hence there is a difference of potential of 350 volts between the plate and the filament. Now, when you switch on the *A* battery current, the filament is heated to brilliancy, and throws off electrons which form a conducting path between it and the plate; when this takes place, the 350-volt current then flows from the latter to the former just as though they were connected with a wire, but with this difference, that the grid, which is energized by the modulated current from the television amplifier stages, controls the intensity of the former.

Now follow the connections from the plate of the oscillator over to the blocking condenser, thence to clip *1* of the tuning coil, through the turns of the latter to clip *2* and over to the filament and, when the latter is heated, you have a *closed oscillation circuit.* The oscillations surging in the latter set up other like oscillations in the tuning coil between the end *3* and the clip *2*, and these surge through the circuit formed by this portion of the coil, the grid condenser and the filament; this forms an amplifying circuit which corresponds to the regenerative circuit of a receiving set.

When the modulated picture impulses are impressed on the grid, it is charged alternately to the positive and negative signs. These reversals of the voltage vary the strength of the oscillations in the plate circuit, but this effect does not vary their frequency. These modulated sustained oscillations surge not only in the closed circuits but run to and fro also in the aerial wire system, and their energy is radiated in the form of electric waves.

In order to calculate the frequency of the oscillations in kilocycles and, hence, the wave length in meters, radiated by your television transmitting aerial, you must measure the former with a wave meter, as explained in Chapter III.

CHAPTER X

HOW TO MAKE A TELEVISION RECEIVER

In this chapter I shall tell you about two kinds of television receivers, and these are (1) a simple experimental one and (2) a practical one for receiving television programs that are sent out by the various telecasting stations. You can easily make a receiver of the first kind, but for the second you will find it far more satisfactory to either (*a*) buy one that is ready to use, or (*b*)—and this is the better way, if you are experimentally minded—buy a kit and put it together yourself. There are several makes of television receivers on the market, but if you get one of the Shortwave and Television Co., 70 Brookline Avenue, Boston, Mass., you can't go wrong.

How to Make a Simple Radio Television Receiver.—The radio television transmitter which I shall tell you how to make is designed to be used in conjunction with the simple radio television transmitter described in the last chapter. For this receiver, you will need the components for (1) the radio unit and (2) the television unit.

The Radio Receiving Unit.—The components for the radio receiving unit include (1) a tuning inductance coil, (2) a variable condenser, (3) an electron detector tube, (4) two amplifier tubes, (5) three filament rheostats, (6) three fixed condensers, (7) a grid leak resistor, (8) four coupling resistors, (9) an *A*, or filament, storage battery, (10) two *B*, or plate, batteries, (11) a neon lamp, and (12) a neon lamp battery.

For the tuning coil you can use a *green octocoil*[1] which, with

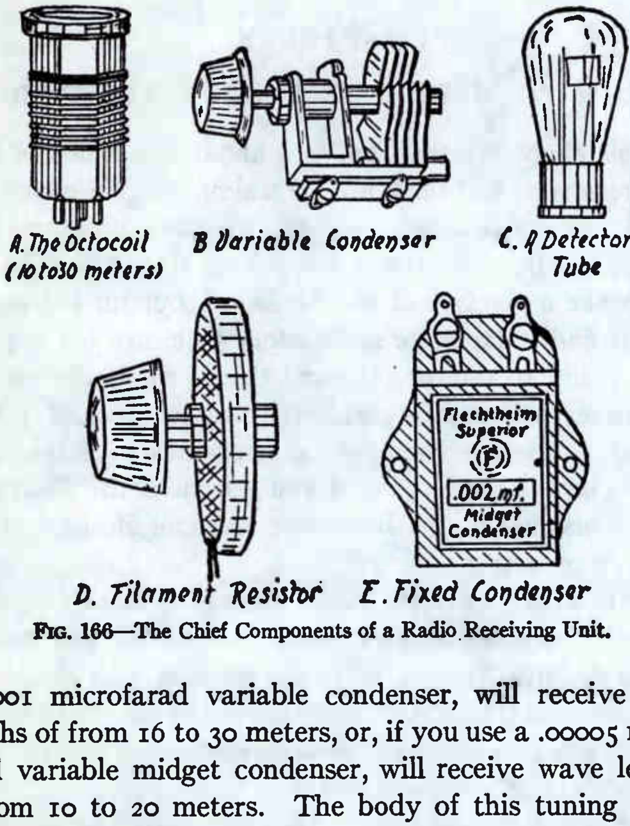


Fig. 166—The Chief Components of a Radio Receiving Unit.

a .0001 microfarad variable condenser, will receive wave lengths of from 16 to 30 meters, or, if you use a .00005 microfarad variable midget condenser, will receive wave lengths of from 10 to 20 meters. The body of this tuning coil is made of bakelite, has a diameter of 1 7/8 inches, a height of

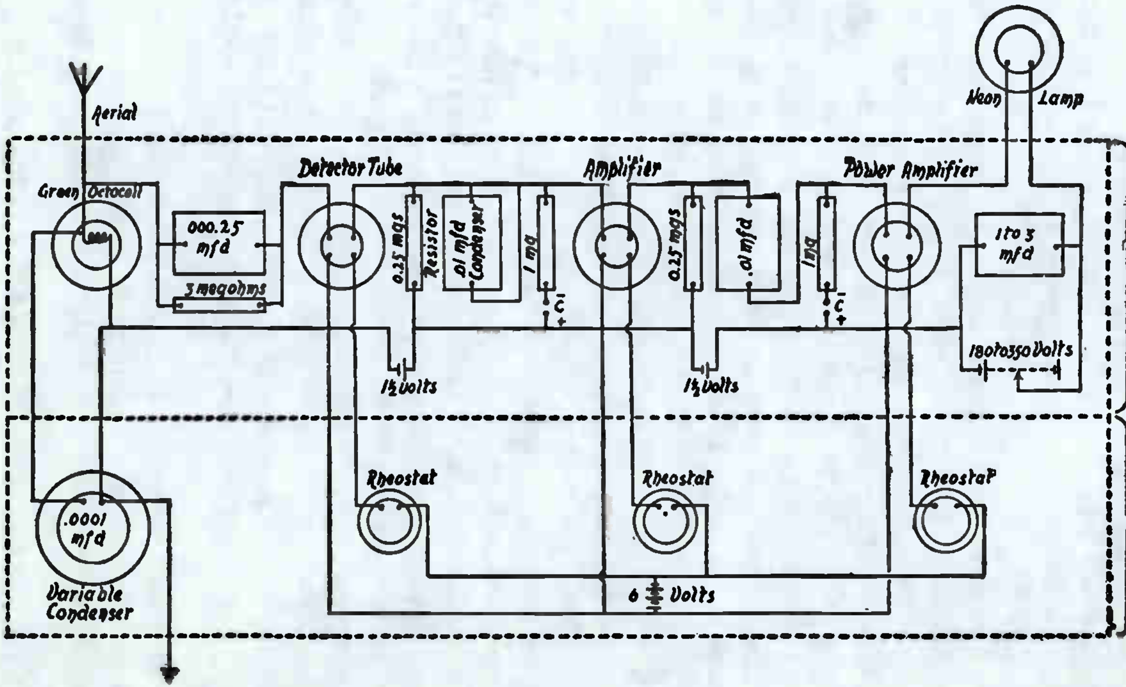
[1] This is made by the Shortwave and Television Corporation of Boston, Mass. It is so-called to differentiate it from coils wound for other wave lengths and which are known as brown, blue, and red.

3⅝ inches, and is wound with six turns of No. 12, enamelled copper wire. It is made so that you can plug it into an ordinary detector or amplifier-tube socket, as shown at *A* in Fig. 166.

The *variable condenser*, which is shown at *B*, is of the usual rotary type, that is to say, it is formed of a set of fixed semicircular metal plates which are slightly separated from each other; between them a like set of rotatable plates is made to interleave, and these are secured to a shaft, on the upper end of which is a knob. By turning this, the rotatable leaves are caused to move in or out from between the fixed leaves, and to vary the capacitance of the condenser, and, hence, of the circuit with which it is connected. As stated before, you can tune the circuit to receive wave lengths of from 10 to 20 meters if you use a .00005 microfarad condenser, or a wave length of from 16 to 30 meters if you use a .0001 microfarad condenser.

The *detector tube* has, as you know, a third electrode, or *grid*, placed between the wire filament and the metal plate. This arrangement allows the current flowing between the two latter electrodes to be increased or decreased, by the oscillations that are set up by the incoming waves, to a very considerable extent. The kind of detector to use is a 201A, shown at *C*. It takes 5 volts at ¼ of an ampere to heat the filament, and 45 volts to energize the plate of it.

The *amplifier tube* of the first stage is made in practically the same way as the detector tube, and the best kind for this purpose is a 112A tube. It takes 5 volts at ¼ of an ampere to heat the filament, and 90 volts to energize the plate.



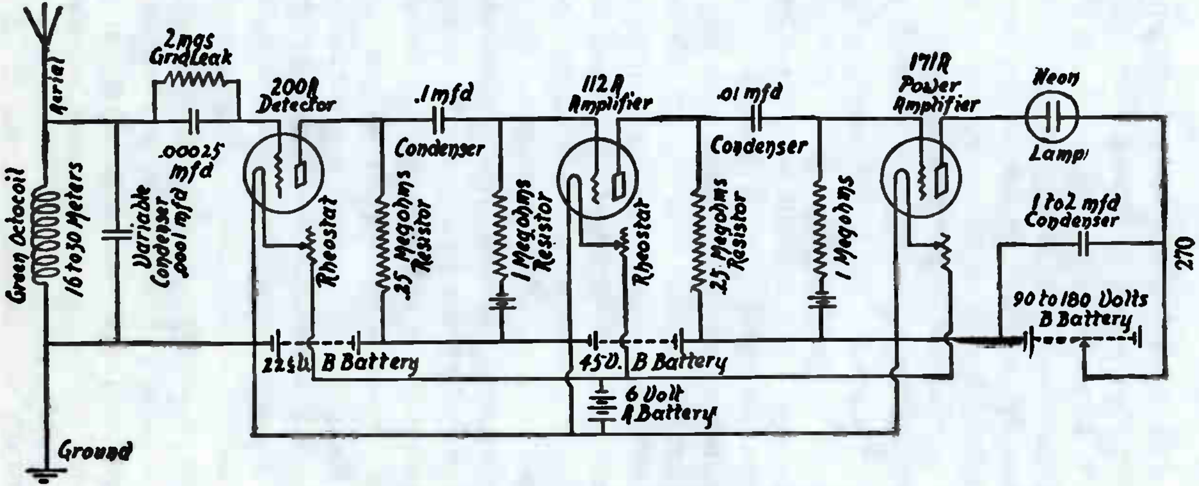
A. FIG. 167—Schematic Layout of a Radio Receiving-Unit.

The *power amplifier tube* is made like the tubes described above, but it is larger and more rugged. It takes the same filament current, and from 90 to 180 volts to energize the plate. This power amplifier tube is known as a 171A tube.

To heat the filaments of the detector and amplifier tubes, you will need a *6-volt storage battery*, called the *A battery*. Since all of the filaments are connected in parallel, a single battery will serve for all of them. To regulate the filament current, you will need three *rheostats*—one for each tube. Each rheostat, see *D*, consists of an adjustable resistance formed of an insulating ring on which is wound a number of turns of resistance wire. The rotatable contact arm, which slides over and presses on the turns of wire, is secured to the knob on top of the casing.

To energize the plates of the detector and amplifier tubes, you will need three *dry cell batteries*, called the *B batteries*. The one for the detector must develop 45 volts, that for the first amplifier stage must develop 90 volts, and the one for the power amplifier should deliver 180 volts, and this also supplies the voltage for the neon tube, which is connected in series with it.

The *grid condensers* are all of fixed value, and of the mica type, that is, the insulating sheets between the leaves of tin foil are made of mica. The one used in the detector circuit has a capacitance of .00025 microfarads, while each of those used in the amplifier circuits has a value of 0.01 microfarads. The condenser that is connected across the battery of the power amplifier plate and the neon tube circuit should have a value of 1 to 3 microfarads. A condenser of the former type is pictured at *E*.



B. Fig. 167—Wiring Diagram of a Radio Receiving-Unit.

The *grid leak* has a resistance of 2 megohms; the *first resistor*, that is, the one between the plate of the detector and the 22½-volt *B* terminal, has a resistance of 0.25 megohms, the *second resistor* a resistance of 1 megohm, the *third* a resistance of 0.25 megohms and, finally, the fourth, and *last resistor*, a resistance of 1 megohm.

The way in which these components are placed on the base and the panel is pictured at *A* in Fig. 167, and the way they are connected up is shown in the wiring diagram at *B*. The panel stands upright, at right angles to the base, or you can mount the components in a box and have the variable condenser and the rheostats on the inside of the front of it, while the knobs are mounted on the outside.

The components need not be arranged on the base as shown, but you can arrange them any way you like. I have strung them along in a line so that you can follow the wiring with the least trouble. By placing the octocoil, the detector, and the amplifier tubes in a row near the front edge of the base, and the fixed condensers and resistors in front of them, you can make a much more compact unit, and one that will work just as well.

The Television Receiving Unit.—The components of the television receiving unit include (1) a neon lamp, (2) a reproducing disk, (3) an optical system, and (4) a synchronous motor. You can use any of the different makes of neon lamps that are sold in the open market for television reception, but, to be specific, an example of this type is the *Raytheon Kino lamp.*[1]

In the wiring diagram given at *A* in Fig. 168, and in the

[1] This is made by the National Carbon Company, New York City.

layout at *B*, the neon lamp is shown connected in the circuit with the radio receiving unit; the lamp, however, is not properly a component of the radio unit, but it is a separate and distinct part which belongs to the television unit. As I have indicated in the foregoing diagrams, it is illuminated by the same current whose voltage energizes the power amplifier tube.

The reproducing disk must be of the same size, have the same number of holes, and run at exactly the same speed as the scanning disk of the transmitter; that is, it should be 15 to 16 inches in diameter, have 60 holes, and run at a speed of 1200 revolutions per minute. The motor for running the disk must be of the same type and power as the one which you use at the transmitting end, namely a single phase alternating-current motor with a condenser connected across the four field coils, as shown at *A* in Fig. 154[1], and it is run from the same 60-cycle power line as the transmitting motor.

It is not absolutely necessary to use the *optical system* to see the image which is formed by the television unit, but as it gives you an enlarged view of it, it is a good scheme to do so. The system consists of two lenses, the first of which is a double convex lens that has a diameter of 1½ inches and a focal length of 1 inch, in which case it will give a magnification of the image of about 10 times. The lens nearest your eye is a concavo-convex lens, 2 inches in diameter. Make a pasteboard tube that has an internal diameter of 1½ inches at one end, 2 inches at the other end, and is 6 inches long. Mount the convex lens in the small end and the concavo-convex lens in the large end.

[1] See Chapter VIII.

Now, assuming that you want to enclose the components, make a strong wooden box with a removable top. The boards should be of hard wood 1 inch thick, and the box 18 inches

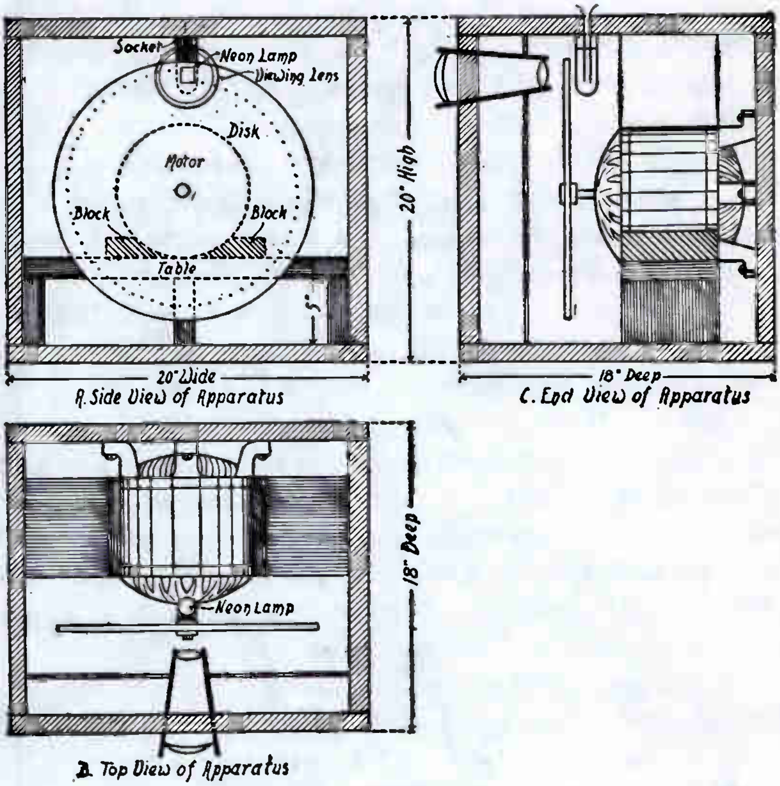


FIG. 168—Assembly of the Television Receiving-Unit.

deep, 20 inches wide, and 20 inches high, outside measurement. Make a stand, or table, 5 inches high[1] and 18 inches long for the motor to rest on, then screw it (the stand) to

[1] The exact height of it will, of course, depend on the diameter of your motor.

the bottom and the sides of the box, and then lay the motor on it, as shown in the front view at *A* in Fig. 168.

Next saw out two blocks of wood and have each one 1 inch thick, 3 inches wide, and 5½ inches long, and screw or, better, bolt, these to the top of the stand, 3 inches apart. Now lay the motor on them as pictured at *A*, and then bolt the legs of the motor to the back of the box, as shown at *B*. Drill a couple of 3/16 inch holes in the back of the box, about 1 inch apart and near the center of it, slip a screw through each one, screw on a large binding post, and connect the terminal wires to the screws.

Having done this, mount the socket of the neon lamp on the inside of the top of the box so that it will be in a line with the center of the disk and just back of it, as shown at *A*, *B* and *C*. Now when you push the lamp into the socket, the center of the plate of the former must be in a line with the point on the disk that is between the first and last holes of the latter, as shown at *A*. Drill a ⅛ inch hole through the top of the box on each side of the socket, slip a screw through each one, screw on a binding post and then connect the terminal wires of the neon tube to the screws.

If you are going to use the receiver without the lens system, cut a hole 1 inch wide and 1¼ inches long in the front part of the box so that its center is in a line with the center of the plate of the lamp; in this case you view the image by looking directly at the luminous plate through the holes in the reproducing disk. On the other hand, if you want to magnify the image, then you must use the lens system.

To do this, cut a circular hole in the middle of the front end of the box so that its center, and, it follows, the optic axis of the lenses, will be in a line with the center of the plate of the lamp, next, glue the tube in the hole, and a good scheme to keep it in perfect alignment is to support the front end of it. This you can do by cutting a hole in the middle of a strip of wood, ½ inch thick, 3 inches wide, and 18 inches long, slipping this over the small end of the tube and gluing the ends to the sides of the box, as shown at *B* and *C*.

Finally, connect the posts of the motor with the leads of a 60-cycle alternating current, and the posts of the neon lamp with the radio receiver, then you are all set to see the images sent by the transmitter described in the preceding chapter. If you want a closer synchronization than is possible with the synchronous motor above, you can use any one of the several schemes described in Chapter IX.

How the Radio Television Receiver Works.—*The Radio Unit.*—When the electric waves sent out by the aerial wire of your television transmitter strike the aerial wire of your receiver, their energy is converted into electric oscillations, that surge through the inductance coil, which is connected between the aerial and the ground wire. These oscillations also surge in the variable condenser that is connected across the coil, thus forming a tuned circuit, and, by varying the capacitance of the condenser, and, hence, of the circuit, the waves received by the aerial wire will set up the maximum amount of energy in it.

The oscillations then surge through the circuit formed by the filament and the plate of the detector tube, while the action of the grid is varied by the alternate positive and negative voltages that are impressed upon it. It is clear, then, that the *B* battery current which is allowed to flow through the detector, from the plate to the filament, rises and falls in unison with the voltage of the oscillatory currents. Finally, these currents carry the battery current through the tube, which gives it a pulsating character.

The way in which the positive and negative voltages of the oscillations set up by the incoming waves energize the

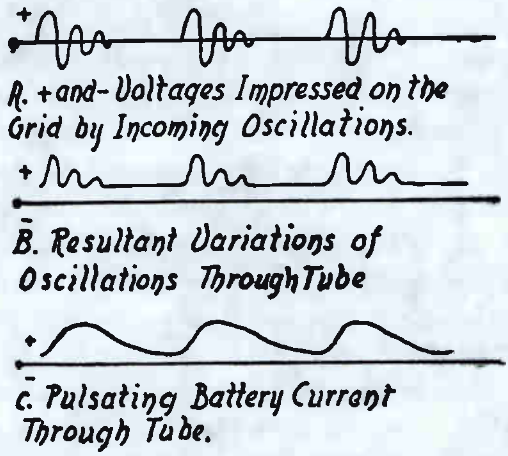
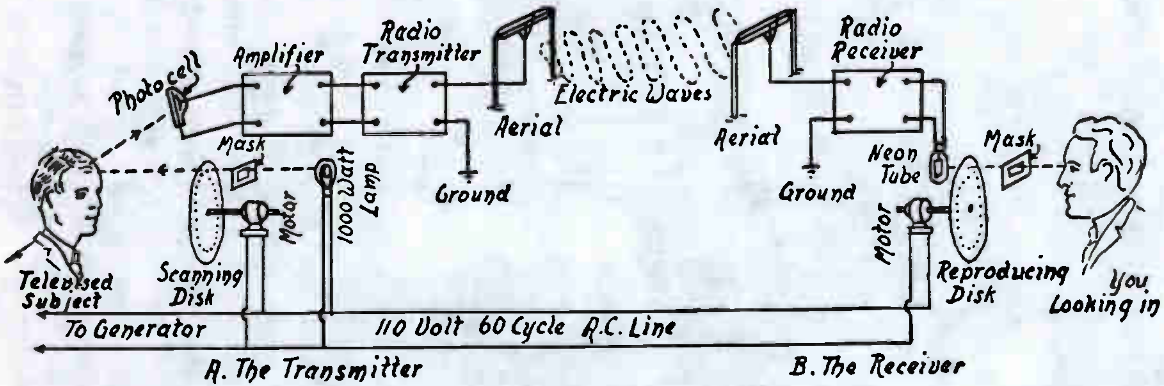


Fig. 169—How the Received Oscillations Control the Flow of the Battery-Current Through the Tube.

grid, how the detector tube clips off the negative parts of them, and how the pulsating direct current is formed by this process, is all shown graphically in Fig. 169. The way these currents rectified by the detector are amplified by the amplifier tubes has already been explained in Chapter VII. The amplified current from the last, or power amplifier tube, is of such voltage and current-strength that it will illuminate the plate of the neon tube.



A. Fig. 170—The Demonstration Television Set in Operation.

The Television Unit.—Now, when you start up the motor which drives the reproducing disk, and it gets up to a speed that is equal to that of the scanning disk of the transmitter, which, let us say, is 1200 r.p.m., and you get it into synchronism with the disk of the latter—which you can do by slowing it down—the light from the neon tube, which is of varying intensity, passes through the successive holes of the disk.

This it does in lines of progressive sequence, and in

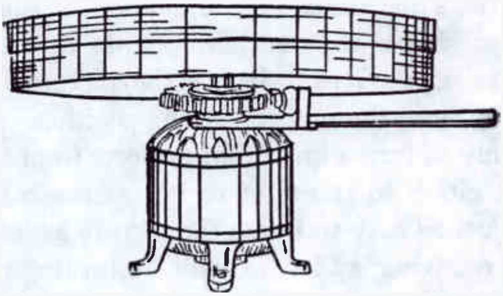
B. Fig. 170—The Baird Home Television Receiver.

this order it falls on the retina of your eye when you are *looking-in.* The persistence of vision makes the light that passes through the first hole in the disk seem to continue until the last hole has passed the scanning area, *i.e.*, one complete revolution of the disk, when you have the illusion of seeing the subject that is being televised at the transmitting end. The way in which the demonstration television transmitter and receiver are connected up is shown at *A* in Fig. 170.

The Baird Shortwave Television Receiver.—If you want to receive telecast pictures you must, of course, have a television receiver, and while I have told you how to make one in the preceding chapter, the easiest, quickest, and surest way is to buy a *television kit* and assemble the parts, which you can do without the slightest difficulty.

There are numerous television receivers on the market, but an especially good one is the *Baird Universal Television Receiver*, as has been proved by first-hand acquaintance.

The receiver that is used for viewing television pictures in



C. FIG. 170—The Baird Television Motor and Scanning-Belt Assembly.

your home is enclosed in a cabinet which measures about 15 inches on the sides, and this is shown at *B* in Fig. 170. Instead of a vertical scanning disk, a steel scanning belt is used, and this is rigidly mounted on a horizontal disk, called a *spider*. This belt has, punched through it, 60 square holes, each of which is 1/100 of an inch on the sides, and these form a spiral line. The spider is mounted on a spindle that is driven by a 1/20 horsepower motor.

As the sheet-steel belt revolves, the neon lamp, which is placed in the center of the space surrounded by belt, projects a spot of light through each hole in succession. The neon lamp actually reproduces 40,000 variations of light per second and, working with the scanning belt, these are assembled into 20 complete pictures per second, thus giving a realistic moving picture of the subject that is being scanned in the studio of the station which transmits them.

The received picture on the plate of the neon tube is about 1 inch on the sides, but this is magnified by a lens so that it looks to be about 4 inches on the sides, and this makes it possible for as many as five or six lookers-in to see the picture at the same time. The operation of tuning in the picture is so simple that a child can do it, and there is an ingenious method of bringing the picture into *frame*, that is to say, into the proper viewing position. To do this you have only to turn a knob that projects from the front of the cabinet either to the right or left as the case may be. Thus it is just as easy to frame the picture as it is to make your radio receiving set low or loud by turning the volume control on it.

To install the television receiver, you need only an electric light outlet and an aerial wire, or you can connect it with the aerial you are using for your receiving set. From this it is evident that you can use the same aerial for receiving television pictures that you do for receiving broadcast programs, and neither one will interfere with the other. For any information you may want on either shortwave broadcast reception or television reception, write to Mr. Hollis S. Baird, Chief Engineer, Shortwave Television Corporation, Boston, Mass.

CHAPTER XI

EXPERIMENTS WITH CATHODE RAYS AND THE OSCILLOGRAPH TUBE

In all the television experiments that have gone before, the *scanning disk* has been employed to send out the picture and receive the image. The scanning-disk method, as you will have gathered from the preceding text, is, nevertheless, subject to many disadvantages, as any method must be that employs mechanically moving parts.

Several schemes have been invented to eliminate the untoward features necessarily inherent in mechanically operated television apparatus, but the one that gives the best promise of supplanting the scanning disk and similar rotating apparatus is the *cathode-ray oscillograph tube*. In this device, the image appears on a fluorescent screen at the end of the tube, and it is produced by a scanning beam of electrons controlled by the intensity of the received electric waves.

And now, before we get down to the working principles of the cathode-ray oscillograph tube as a television receiver, we must understand something about the nature of the cathode rays and make a few experiments, in order to become familiar with them.

The Discovery of Cathode Rays.—What we call *cathode rays* are negative particles of electricity, or *electrons*, which were discovered when scientists began to experiment with vacuum tubes and to learn about the properties of electric currents when these were discharged through rarefied gases. The advances made in this field have been due chiefly to the researches of Geissler, of Germany, who invented the low-vacuum tube, or *Geissler tube* as it is called, Crookes, of England, who made the first high-vacuum tubes, including the cathode-ray tube with which Röntgen, of Germany, discovered the X-rays.

The discovery of the cathode rays by J. J. Thompson, of England, their deflection with a magnet by J. A. Fleming, also of England, and, finally, the researches of Braun and Gaede, of Germany, Ryan, Langmuir, Dushman and Zworykin, of the United States, Knudsen of Denmark, Belin of France, and Dewar and Swinton of England, have been responsible for the development of the oscillograph tube.

Experiments with Cathode Rays.—It is neither an easy nor an inexpensive matter to experiment with cathode rays or to make cathode ray tubes, for to do the former you must have the latter, and to make these you must be skilled in the art of glass blowing. You can, however, buy the various kinds of cathode tubes described in this section from dealers in physical laboratory apparatus.

In making experiments with vacuum tubes, just bear in mind that the path of the cathode rays, *i.e.*, electrons, is visible in a low-vacuum tube and invisible in a high-vacuum tube. This is because in the former the electrons bombard the molecules of the gas which is still in the tube and as this sets the electrons to vibrating, they produce light. In the high-vacuum tube, the gas has been pumped out so thoroughly that there are very few molecules left behind.

To energize any of the tubes used for the following experiments, connect the electrodes with the secondary terminals of an induction coil. You can work a low-vacuum tube on a coil that gives a ½-inch spark or more, but for a high-vacuum tube you will need a coil that gives a 2- to 4-inch spark. For the smallest X-ray tube, a coil giving a 4- to 6-

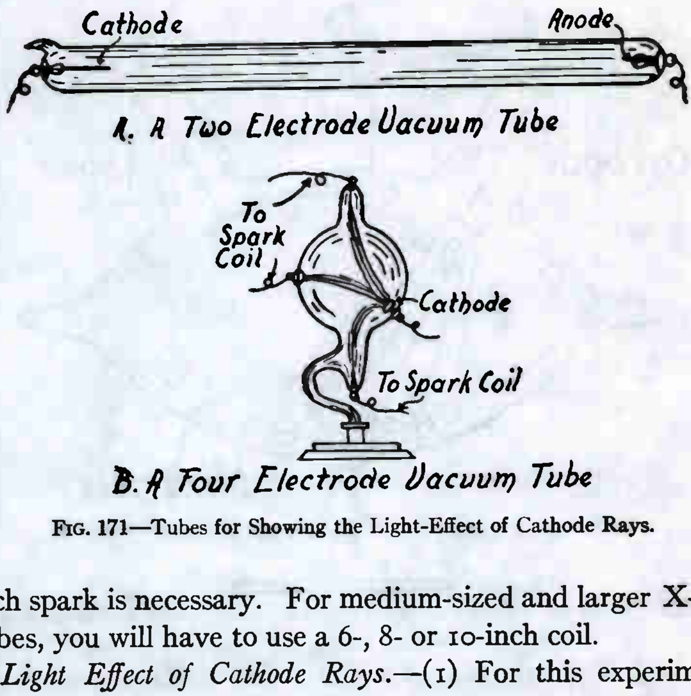


FIG. 171—Tubes for Showing the Light-Effect of Cathode Rays.

inch spark is necessary. For medium-sized and larger X-ray tubes, you will have to use a 6-, 8- or 10-inch coil.

Light Effect of Cathode Rays.—(1) For this experiment you will need a Crookes low-vacuum cathode-ray tube as shown at *A* in Fig. 171. Now when you energize the tube with your induction coil it will be filled with light. (2) By using a tube with four electrodes, as pictured at *B*, you can trace the path of the electrons as they stream across the tube from the cathode to whichever anode is connected with your induction coil, by the colored light they produce.

Fluorescent Effect of Cathode Rays. — You can get a Crookes high-vacuum tube that contains several pieces of different kinds of minerals that are placed on the bottom of it, as shown in Fig. 172. When you energize the tube with

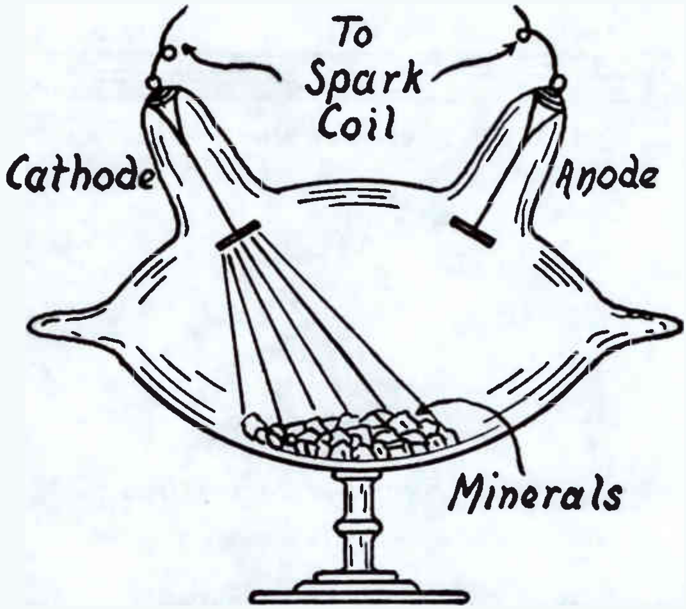


FIG. 172—A Crookes Tube for Showing the Fluorescent Effect of Cathode Rays.

your coil, a stream of cathode rays will strike the minerals and make them fluoresce with various characteristic colors, all of which produces a very pretty effect.

Heating Effect of Cathode Rays.—To show the heating effect of the cathode rays, you must get a Crookes vacuum tube that is made especially for the purpose. Such a tube is shown in Fig. 173. If a bit of glass is placed in the path of the cathode rays, the bombardment of the electrons will

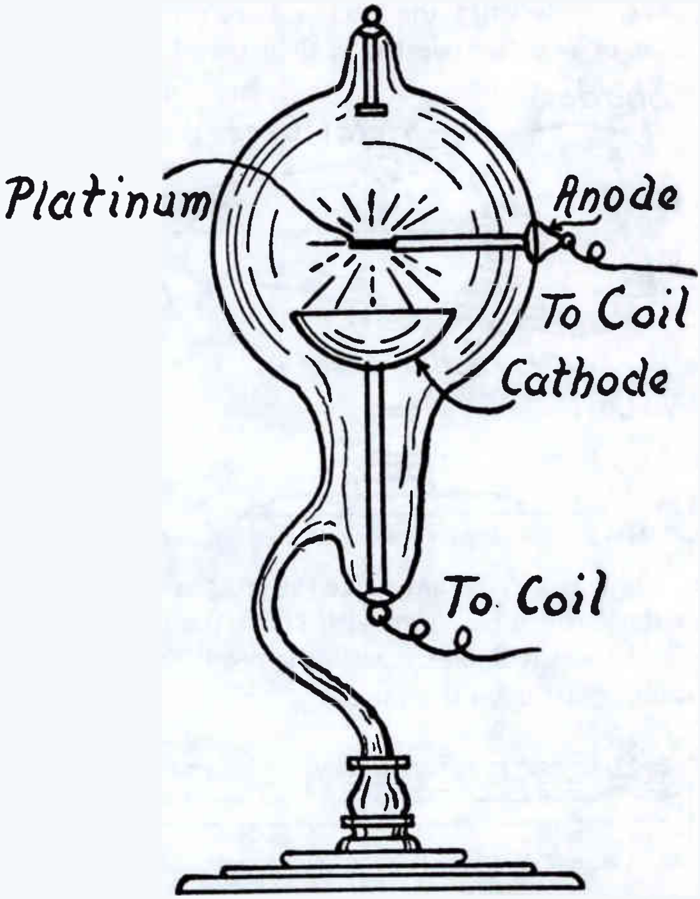


FIG. 173—A Crookes Tube for Showing the Heating Effect of Cathode Rays.

soon melt it, or if a piece of platinum foil is used, it will soon be heated white hot.

Shadow Effect of Cathode Rays.—In this Crookes cathode-ray tube a cross, or other shaped piece of metal, is mounted near the large end, and this forms the anode, as shown in Fig. 174. Now when the electrons are projected from the cathode, or negative electrode, they travel out in straight

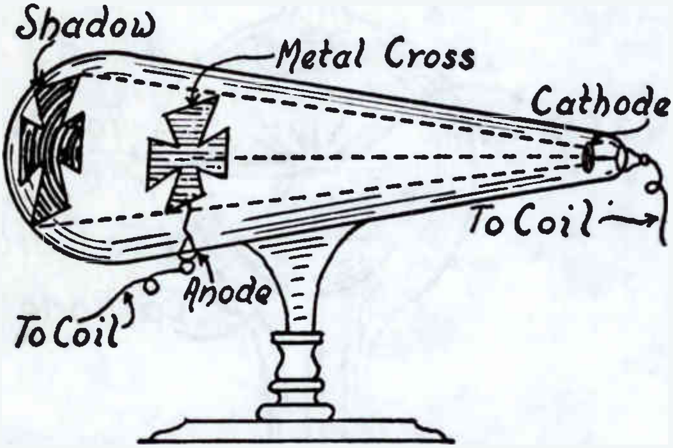


Fig. 174—A Crookes Tube for Showing the Shadow Effect of Cathode Rays.

lines. Those electrons that strike the cross are reflected back, while those which pass around it strike the large end of the tube and make it fluoresce, with the result that a shadow of the cross is cast upon this area.

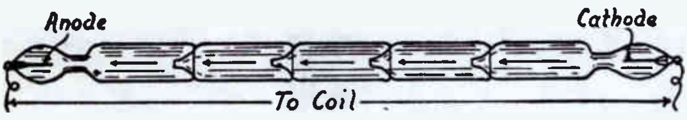


Fig. 175—A Holtz Tube for Showing the Unidirectional Effect of Cathode Rays.

Unidirectional Effect of Cathode Rays.—The tube used for this experiment is built up of a series of funnel-shaped tubes, the small end of each one being sealed in the large end of the next one, as shown in Fig. 175. When the electrode in the end of the tube adjacent to the large end of the funnel is made the cathode, the electrons will pass freely to the anode, but when the electrode in the end of the tube adjacent to the small end of the funnel is made the cathode, the electrons will not pass through.

Magnetic Effect on Cathode Rays.—(1) For this experiment get a Crookes cathode-ray tube that contains a mica screen

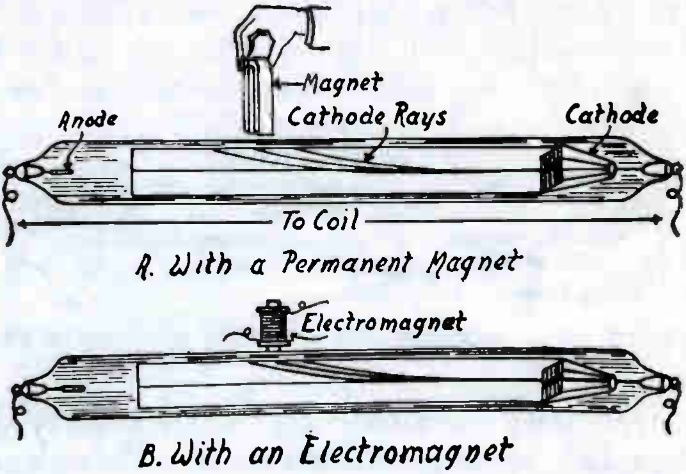


FIG. 176—A Crookes Tube for Showing the Effect of a Magnetic Field on Cathode Rays.

with a slit in it, and mounted near the cathode, as shown in Fig. 176. The purpose of the slit is to allow a definite beam of the cathode rays to pass through it, and the path of these rays can be seen on a fluorescent screen in the tube. Now when you energize the tube with your induction coil and then hold a permanent steel magnet close to the tube, the beam of the cathode rays will be deflected, as you will see by the bending of the fluorescent line represented at *A* in

Fig. 176. (2) Instead of using a permanent steel magnet you can set up a magnetic field with an electromagnet, as pictured at *B*.

Electric Effect on Cathode Rays.—(1) For this experiment you use the same kind of a tube as in the preceding experiment, but, instead of deflecting the ray by means of a magnetic field, you employ an electrostatic field. To set up an electrostatic field, you need only to place a pair of deflecting plates made of small strips of copper, say ½ inch wide by 1 inch long, on opposite sides of the tube, as shown in

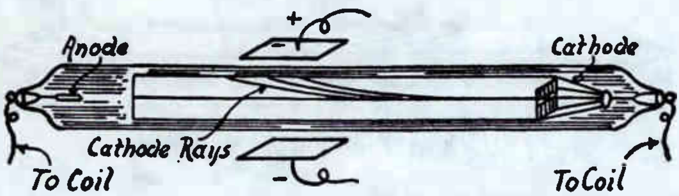


FIG. 177—A Crookes Tube for Showing the Effect of an Electrostatic Field on Cathode Rays.

Fig. 177. Now connect these strips with a source of high-voltage direct current, which you can do by using a radio *B* battery, or a 110-volt direct current, if available on your lighting service lines, or a static electric machine, and the cathode rays will be deflected as in the foregoing experiment.

(2) You can get a very pretty effect by connecting the strips of copper with the secondary terminals of a transformer that will develop 500 volts or more, and then connecting the primary terminals of it with a 60-cycle, 110-volt, alternating current. The cathode rays will move first in one direction and then in the other as the polarity of the deflecting plates is changed.

What the Oscillograph Tube Is.—An *oscillograph tube*, or *oscillograph*, as it is called for short, is a high-vacuum cathode-ray tube that shows visually (1) the wave form of an alternating or an oscillating current, and (2) the image of a transmitted television picture.

The first attempt to use a cathode-ray tube to indicate the wave characteristics of an alternating current was made by Ferdinand Braun, of Germany, in 1897, and it was he who named it the *oscillograph*. Harris J. Ryan, of Cornell University, at Ithaca, N. Y., was the first to make a practical

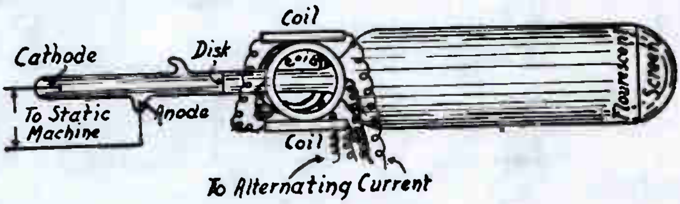


FIG. 178—A Braun-Ryan Oscillograph Tube.

oscillograph tube, and he used it in his researches on high-tension currents.

How the Tube is Made.—His oscillograph was formed of a glass tube 30 inches long, the first half of which was ¾ of an inch in diameter and the last half 5½ inches in diameter. In the small end of the tube a platinum wire was sealed, and this formed the cathode. In a branch nipple, about 6 inches from the end, another platinum wire was sealed, and this formed the anode.

Above the anode there was another branch nipple, and it was through this that the air was pumped out of the tube and sealed off. About 6 inches from these nipples, a glass disk with a small hole in its center was fixed in the tube, and, finally, a fluorescent screen was secured to the inside of the large end, all of which is shown in Fig. 178.

Close to the disk and on the side of it nearest the screen, four coils were mounted with their planes parallel to the axis of the tube; these coils were arranged in two pairs, each pair being connected in series and the pairs in parallel.

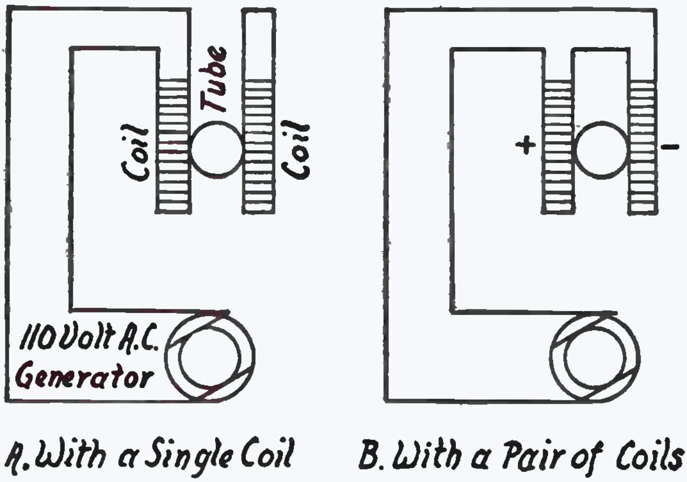


FIG. 179—Experiments with 110-Volt Current.

The axes of both pairs intersected the axis of the tube and, it follows, the axis of the cathode rays which passed through. The tube was mounted on a stand and the cathode rays were set up in it by a current from an 8-plate Wimshurst static machine.

How the Tube Works.—When the tube was energized by the static electric machine, the cathode threw off electrons, and these formed cathode rays. These rays, like rays of light, travel in straight lines and, hence, only those that were in a line with the hole in the disk could pass through it, and, on reaching the fluorescent screen, they struck the center of it and formed a single small bright spot on it.

Experiments with the Oscillograph Tube.—Having your oscillograph tube set up, and the cathode and anode terminals connected with the static machine, you are now ready to make the following experiments: (1) Connect a single coil with a battery, or the service lines of a 110-volt *direct-current* dynamo, as shown in the wiring diagram at *B* in Fig. 179, when a constant magnetic field will be produced, and the beam of the cathode rays that falls on the fluorescent

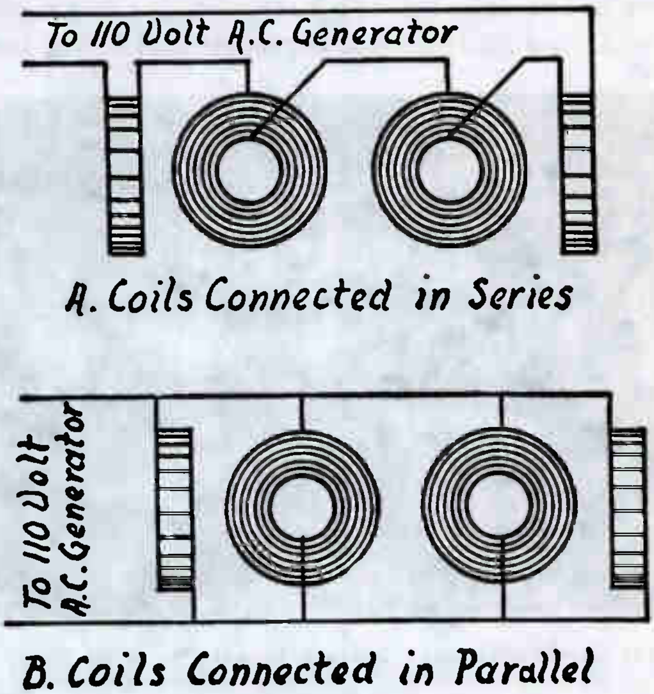


FIG. 180—Experiments with 110-Volt Direct Current.

screen will be displaced, the amount of the displacement being proportional to the strength of the magnetic field.

(2) This done, connect a pair of the coils with a 110-volt source of *alternating current*, as shown at *A*, when the beam of rays will be deflected each instant of time in a direction and with an amplitude that is proportional to the instan-

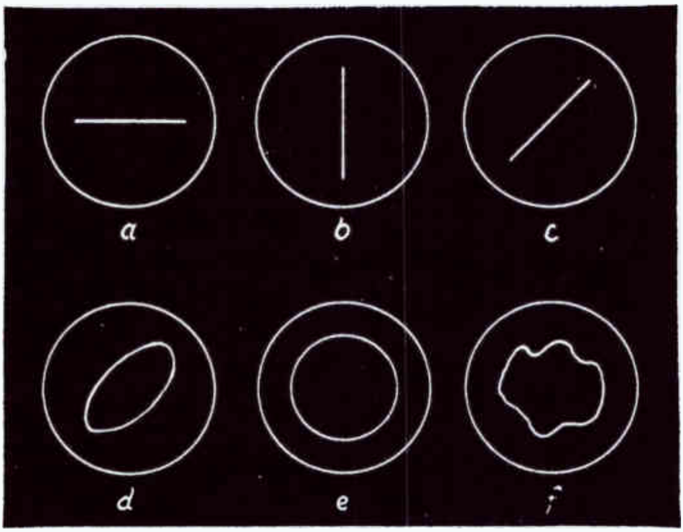


FIG. 181—Lines Traced by Cathode Rays on the Fluorescent Screen.

taneous field that is set up; the bright spot will travel by consecutive points across the fluorescent screen and, due to the persistence of vision, you will see it as a single straight line, as pictured at *a* in Fig. 181.

(3) Now disconnect the pair of coils you used for the last experiment and connect in the other pair of coils. The resultant action will be the same as the one just described, but

the bright spot will produce a line on the fluorescent screen at right angles to the one which the first pair of coils gave as *b* Fig. 181 shows.

(4) For this experiment, connect both pairs of coils in series, as shown at *A* in Fig. 180, when the resultant displacement will give a 45 degree line on the screen, as pictured at *c* in Fig. 181. (5) The same result will be obtained if you connect the coils in parallel, see *b* in Fig. 180, provided they carried a sine wave form of currents which are in the same phase position, but if their relative phase position differs, then the compound displacement will produce an angular ellipse on the fluorescent screen, as indicated at *d* in Fig. 181.

(5) If the currents are equal sine waves in quadrature, the compound displacement will cause the rays to trace a circle on the screen, as shown at *c* Fig. 181. (6) If any two currents whose wave forms are different but which have the same frequency are made to act on the beam of cathode rays, the result will be an irregular curve as, for example, the one pictured at *f* in Fig. 181. Finally (7) if two different wave forms which are of different frequencies are impressed on the beam of rays, the curve traced by it will take on a more complex aspect, but which will, nevertheless, be the resultant of the two component wave forms.

Television with Cathode Rays.—Away back in 1907, the use of the oscillograph tube was suggested by Boris Rosing of Petrograd, Russia, as a possible means of accomplishing television, and the next year his idea was amplified by Campbell Swinton of England. From this it is evident that at that early date the limitations of the scanning disk had been noted, for, being a mechanical device, it necessarily possessed inertia and was, therefore, sluggish in operation. Oppositely disposed, the cathode rays are nearly as tenuous as light rays, and, therefore, extremely well suited for the reception of television images. Systems based on its use were invented by Belin and Douvillier of France, Holwede of Germany, Takayangi of Japan, and others.

The cathode-ray tube has several advantages over the scanning disk as a television receiver, chief among which are that (1) it has no mechanical moving parts and, hence, it is quiet in operation and there is nothing to be adjusted or to get out of order; (2) it is much easier to keep in synchronism with the transmitter; (3) more light is available, and, as a result, the image is brighter; (4) the persistence of fluorescence is added to the persistence of vision, and, therefore, the number of picture images per second can be cut down without the effect becoming jerky; (5) due to the combination of the above factors the number of lines can be increased and, hence, greater detail of the image can be obtained without a corresponding increase in the width of the frequency band; and, finally, (6) incoming waves need not be amplified, as they can be made to act directly on the beam of the cathode rays, provided their strength is above a certain critical value.

From the above encouraging features, it would seem reasonable to suppose that the cathode-ray tube as a television receiver would eliminate the scanning disk, but this is far from being the case at the present time, because it has the disadvantages that (1) it costs something like $500; (2) it has a very short life—in the neighborhood of 200 hours; (3) it is hard to hold the focus of the beam of cathode rays on the fluoroscope screen sharply enough so that the image will remain perfectly clear, and (4) the fluorescent screen as it is now made gives a far from satisfactory image. From this it is evident that the cathode-ray tube as a television receiver has a long road to travel before it will be commercially available for home entertainment.

The Cathode-Ray Television Tube.—An ordinary oscillograph tube such as I have previously described is not acceptable for television reception because, while it is able to scan in two directions, it does not provide a way to vary the strength of the image and, further, not nearly enough light can be had with a tube that is energized with a 110-volt current. To project an image 4 or 5 inches wide on the fluorescent screen, the tube must be energized with a current of 2,000 or 3,000 volts. For this reason the ordinary oscillograph tube had to be very considerably modified to meet these requirements.

Hot Cathode Ray Tubes.—The ordinary oscillograph tube has a *cold cathode*, and, since it is not exhausted to a very high degree, the voltage impressed on the cathode terminal by a static electric machine is quite enough to make it give off a beam of cathode rays.

If the tube is very highly exhausted, then even a high voltage will not make it throw off rays from the cold cathode. If, however, the cathode is made of a filament of wire and this is heated to incandescence by a current from a battery or a 110-volt generator, then it will throw off cathode rays just as it does in a radio tube.

It is easy to understand why a heated filament throws off the electrons which form the cathode rays, if you will but consider the action of hot water in throwing off some of its molecules in an aqueous vapor. In this case the heat sets the molecules of water into violent commotion, and in doing so its surface attraction is overcome, so that the molecules fly off from it; in the former case the heat sets the electrons of the

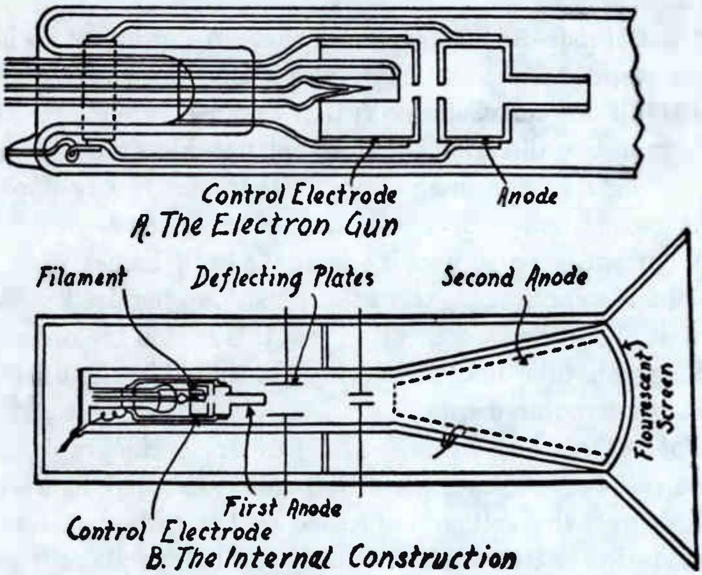
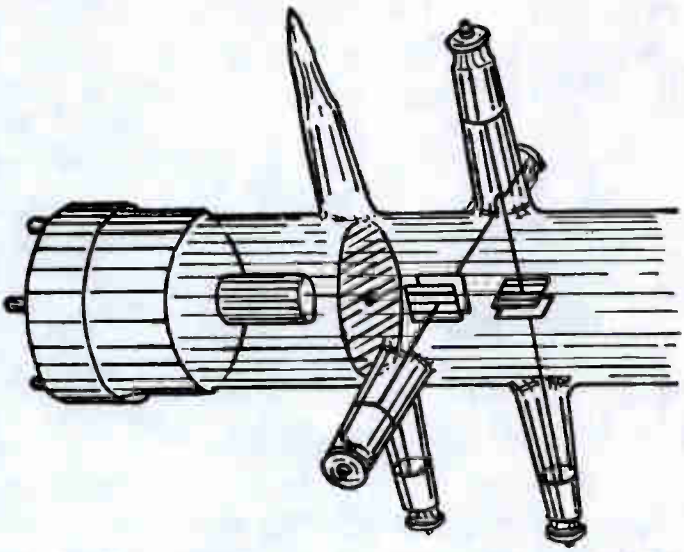


Fig. 182—How a Television Cathode-Ray Tube is Made.

filament into violent agitation so that its surface attraction is overcome in a similar manner and the electrons fly off in the same way. To get the electrons to separate from the filament to the best advantage, it is made of either tungsten or platinum, and this is coated with calcium, barium, or strontium oxide.

The Hot-Cathode Television Tube.—To fulfill the conditions required for television reception, as I have previously pointed out, a new kind of cathode-ray tube, called the *kinescope*, has been devised by Zworykin. In this tube the filament is made of platinum, coated with one of the abovenamed oxides, and this is sealed in the small end of the tube. Directly in front of the filament is a so-called *electron gun*,

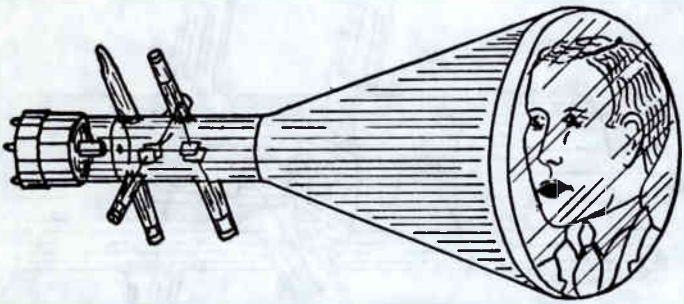


A. Fig. 183—A Close-Up of the Neck of the von Ardenne Cathode Ray Television Receiver.

see *A* in Fig. 182, which consists of a control electrode that has a small hole in it; in front of this electrode is the first anode, which has a like hole in it. The second anode, see *B*, is formed of a metal coating on the inside of the glass bulb.

The fluorescent screen, which is about 7 inches in diameter, is covered with *willemite*,[1] a fluorescent mineral that is slightly conductive. Inside the small end of the tube, and just in front of the electron gun, two pairs of deflecting plates are mounted at right angles to each other, as pictured in Fig. 183, and it is these which give to the beam of cathode rays its vertical and horizontal deflection.

How the Tube Works.—When the filament is heated, it throws off electrons, and these form a beam of cathode rays; the beam then passes through the small hole in the control electrode, and then it goes through the hole in the first anode.



B. FIG. 183—The von Ardenne Cathode Ray Television Tube Complete.

This anode accelerates the speed of the electrons, as it is energized by a positive potential of 300 or 400 volts. As the rays reach the second anode they are again accelerated, since this is energized by a positive potential of 3,000 to 4,000 volts.

The electrons then move at a speed of about one-tenth that of light waves—that is to say, at the rate of about 38,500 miles per second. Not only does the second anode

[1]This is a natural zinc orthosilicate (Zn_2SiO_4). It occurs in the form of hexagonal prisms and also in granular particles, and varies in color from white or greenish-white, to green, reddish, and brown.

increase the velocity of the electrons, but it also helps to focus the beam so that it will fall on the screen in a small point. The slight conductivity of the fluorescent screen is necessary, to permit the electric charges formed on it by the impact of the electrons to leak off.

To deflect the beam of cathode rays, an electrostatic field is preferable to a magnetic field, because the wave form of the incoming current is distorted by the latter, due to its inductive effects. Since the deflector plates are placed in front of the first anode, where the electrons are moving with comparative slowness, the strength of the electrostatic fields set up by the former need not be nearly so great as it would have to be if they were placed in front of the second anode, where the speed of the electrons is enormously increased by the high voltage impressed upon that element.

The degree of brightness of the moving line of light on the fluorescent screen depends on the strength of the negative charge, or *negative bias*, as it is called, that is impressed on the control electrode of the tube. Therefore it is clear that if the varying amplitudes of the wave impulses received from a distant transmitter are impressed on the control electrode of the receiver tube and the cathode beam is deflected in synchromism with the movements of the beam of light of the transmitter as it scans the subject, the image of it will be formed on the fluorescent screen.

The Zworykin Cathode-Ray Television System.—The apostle of the cathode-ray tube television system in this country is V. K. Zworykin, formerly of the *Westinghouse Electric and Machine Company*, East Pittsburgh, Pa., but now of the *Radio Corporation of America*, Camden, N. J.

It would take a chapter as long as this one to describe his transmitter and receiver, but if you want the full details of it you can get them from his article published in *Projection Engineering*, at Albany, N. Y., in the December number of 1929, and from copies of his United States patents.[1] The following brief description of his system is taken from the above-named paper.

The Cathode-Ray Tube Transmitter.—For transmission of the complete picture, three sets of signals (wave impulses)

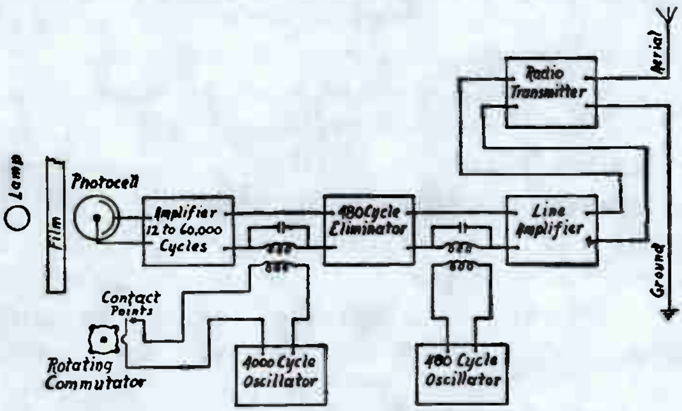


FIG. 184—A Television Transmitter Circuit for a Moving Picture Film.

are required, namely: (1) the picture signals, (2) the horizontal scanning frequency signals and (3) the signals for framing. It was found possible to combine all of the three sets of signals in one channel. In this case the photo-electric cell voltage of the transmitter is first amplified to a level sufficiently high for transmission. This is then superimposed upon the series of high audio-frequency impulses

[1] U. S. patent Mar. 17, 1924; U. S. patent, July 13, 1928.

which last for a few cycles only, when the light beam passes the interval between the pictures.[1]

The picture frequencies, together with the framing frequencies, are then passed through a band-eliminating filter which removes the picture component of the same frequency as that for horizontal scanning. Following this, a portion of the voltage which drives the transmitter vibrator is impressed upon the signals which pass through the filter, and

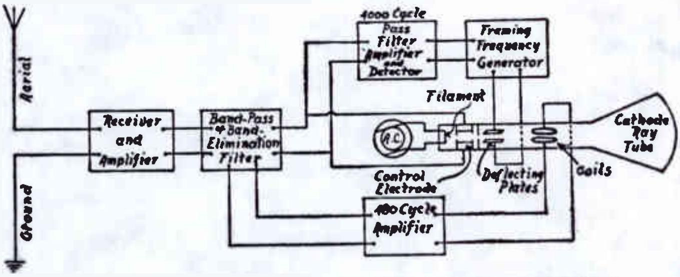


FIG. 185—A Cathode-Ray Tube Circuit Television Receiver.

the entire spectrum is used to modulate the radio-frequency carrier. A diagramatic representation of the transmitter is shown in Fig. 184.

The Cathode-Ray Tube Receiver.—At the receiving station the output of the receiver is amplified and then divided by a band-pass band-eliminator filter with two parts, one of which is the synchronizing frequency and the other the picture frequency plus the framing frequency. The synchronizing frequency is amplified by a tuned amplifier which supplies current to the deflecting plates of the tube. The receiving circuits are shown diagramatically in Fig. 185.

1 With this apparatus moving pictures on a film were transmitted.

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