THE first important contribution of physics to the art of communication was the electric telegraph early in the last century. This was followed by the telephone some years later, and then, at the end of the nineteenth century and the beginning of the twentieth century, the wireless telegraph was developed by Marconi, and this was followed a few years later by the wireless telephone, or radio broadcasting. It will not be possible for me to discuss all these different modes of communication, so I am going to confine myself to radio broadcasting, and I think that is the most interesting as well as the most recent of these methods of communication.

In radio broadcasting the speaker talks into a microphone, or mike. This generates an electric current which is conveyed to the transmitting station. In the transmitting station there is an electric oscillator, in which electricity oscillates to and fro and emits electric waves. These electric waves travel out into the surrounding space and can be picked up by receivers thousands of miles away. The receivers contain an electric oscillator which is tuned to the oscillations of the transmitting oscillator. The current from the microphone is made to modify or modulate the oscillations of the transmitting oscillator, and so the electric waves emitted are modulated to correspond to the sound of the speaker's voice. When the waves are picked up by the receiving oscillator, the modulations are impressed on the oscillations of the receiving oscillator, and are then transmitted to a loudspeaker, which
reproduces the sound of the speaker's voice. So the whole thing is rather complicated, and I am going to talk about the principles involved in this process, omitting technical details.

The electric waves which carry the message travel through the air around the earth. The air, however, takes no part in this transmission. The electric waves will travel equally well through empty space. Although they do actually travel through the air, the air does not help them or hinder them in any way. They could travel equally well through a perfect vacuum.

Now there are three different kinds of effects which can be transmitted by what we call a perfect vacuum. They are electric effects, magnetic effects, and gravitational effects. We all know of course that the earth attracts bodies near it and that this action takes place through a vacuum just as well as through the air. So a gravitational attraction is one of the actions which is transmitted through a perfect vacuum.

I can very easily show magnetic effects or actions with two magnets. We stand one up, and if we bring another magnet near it, it attracts it, but if we take the other end of the magnet, it repels it. Or if we put the two magnets side by side and they repel each other, they will fly apart. If we turn one the other way, then they attract each other. There you have an action which is transmitted through so-called empty space. That is the magnetic action.

Now electric actions are also transmitted equally well through empty space. I have here a rod of lucite, which I will rub with a piece of flannel and it will then become electrified and will attract this ball, and that action will take place across empty space. It can be shown in another way. I have here an electric detector, which I am going to explain later on. Just now I am going to show the action of the electricity on this lucite rod. Here is a small neon lamp, and
the apparatus is arranged so that the electrical attraction of
the electricity on the lucite rod will turn off the lamp. Notice
that the lamp goes out when I pull the rod away.

There are two kinds of electricity. This electricity we have
on the lucite rod is called positive electricity. Now if I take
a piece of hard rubber and rub it with cat's skin—cats are
supposed to be rather electrical, so cat's skin is considered
good for this purpose—you will see that the lamp goes out
when I move it towards the apparatus. It comes on when I
pull it away. So the effect is just the opposite of the effect
obtained from the lucite. The lucite gets positively electrified
when we rub it and the hard rubber gets negatively electrified. So the electricity exerts an effect, you see, across empty
space.

So we have electrical and magnetic and gravitational ef-
fects which are transmitted across empty space.

At one time it was thought that space was merely volume,
or that space just had length and breadth and thickness, and
so occupied volume, but there was nothing there. It was just
empty. But now we know that space has physical properties.
It has the properties of transmitting gravitational effects and
electric effects and magnetic effects. These properties of space
are just as much the properties of space as the geometrical
properties. At one time during the nineteenth century it was
argued that, since empty space would transmit these mag-
netic and gravitational and electric actions, there must be,
besides space, a medium present which transmitted these
actions. This medium was called the ether, and it was said
that the electric and magnetic effects were transmitted
through the ether which occupied the otherwise empty space.
That idea has now been given up. We do not think now of the
empty space as filled with ether. Of course if it is filled with
ether it is not empty. But we do not separate the two things.
We say that there is space, and space has these geometrical and physical properties which cannot be separated, and therefore the idea of an ether filling the space has been given up. The observed properties are the properties of space.

The most interesting thing about radio broadcasting is the way the message is transmitted from the transmitter to the receivers, and this transmission is said to be due to electric waves. The electric telegraph, where you have a wire, was once described as something like this: "Suppose you had a very long dog and his tail was in New York and his head was in Boston. Then you could pull his tail in New York and he would bark in Boston," and that was like the electric telegraph. But with wireless there is no dog. There is nothing but space in between. So I want to talk about these electric waves.

There are two important properties of electricity and magnetism. It is found that a moving magnet produces an electric field, or will generate an electric current. Of course if the magnet moves, then the magnetic field moves with it. So we have a moving magnetic field. Now it is found that a moving magnetic field produces an electric field. I can show that by an experiment here. I have a coil of wire—a lot of wire wrapped in a coil—connected with a galvanometer, which will indicate an electric current. If I push a magnet into the coil it will produce a current which will be indicated by the galvanometer. If I move it in, I get a current. If I hold it still, there is no current. If I move it out, we get a current in the opposite direction. So you see the magnet produces or excites in the surrounding space a magnetic field, and when this magnetic field moves across the wires in this coil, an electric current is generated in the coil. The electric current in the wire is produced by an electric field acting along the wire. So we see that the moving magnetic field generates an electric field.
Now there is a sort of reciprocal relation. An electric current, that is, moving electricity, or a moving electric field, will produce a magnetic field. I have another experiment here to show that. Here I have a coil of wire with an iron bar through it. If we pass an electric current through this coil, it will produce a strong magnetic field. One way of showing that is to put some nails close to the bar and then pass a current through the wire. The nails are attracted to and stick on to the iron bar; if we stop the current, they drop off. Another way of showing it is to have two magnets. Suppose I put up a magnet near one end of the iron bar and another magnet near the other end. When I turn on the current they are attracted by the bar. Now I will turn them upside down and then turn on the current, and you see now they are repelled by the bar. You see the iron bar becomes strongly magnetized. It repels one end but attracts the other end of a magnet. Of course these magnets will attract the nails.

So then it appears that a moving magnetic field produces an electric field and a moving electric field, which you get with the current, because in a current the electricity is moving along, and so the electric field of the electricity of course moves along with it, and produces a magnetic field.

Now in radio broadcasting electric oscillations are used. Oscillation means movement from side to side or backwards and forwards. For example, if you take this lucite rod and rub it so that you have some electricity on the end, then one way of getting an electric oscillation would be simply to move it backwards and forwards; then you would have the electricity moving backwards and forwards, or oscillating, which will produce electric waves. So in order to produce electric waves all we have to do is to get the electricity to oscillate backwards and forwards. To produce the waves used in broadcasting the rate of oscillation has to be very high—millions of times per second.
Physics and Communication

An electric oscillation is similar to a mechanical oscillation. I have here a weight on a spring. If we pull it down, it will oscillate up and down. That is what we call a mechanical oscillation. To get an electrical oscillation, suppose we take, as I have here, a metal ball connected by a wire to another metal ball. Now suppose you have positive electricity on one ball and negative on the other. Then the positive electricity attracts the negative electricity so that they tend to move together. In fact, you get a current along the wire. The electricity flows along the wire so that the positive electricity flows towards the negative and the negative electricity flows towards the positive, and they neutralize each other; that is, equal amounts of positive and negative electricity, when put together, destroy each other. Thus you get a current and the electricity disappears. The positive flows towards the negative and the negative flows towards the positive and they neutralize each other, so that the charge disappears.

At first, then, you would think there would be no oscillation. The charges would simply disappear. But when the electricity flows along the wire you get a magnetic field, because the moving electric field produces a magnetic field. So you get a magnetic field which is around the wire. The current at first increases and then gets smaller as the charges neutralize each other. When the current begins to diminish, the magnetic field, which is produced by the current, also diminishes or moves away; but we have seen that a moving magnetic field generates an electric field, so that as the current diminishes the diminishing magnetic field keeps the current flowing. So the magnetic field around the rod, when the current begins to get smaller, helps to keep the current going. So, instead of the current just stopping, it goes on until the ball which was negative becomes positive and the other ball becomes negative; that is, you start with positive at one end
Science and Human Welfare

and negative at the other end, and then the positive goes to the other end and the negative also goes to the other end, and then it begins all over again; the positive goes back and the negative also, and again you get the magnetic field which keeps the current going, so instead of the positive and negative just neutralizing each other and the current stopping, you get an electric oscillation from one end to the other and back again. You get the current first going one way and then the other way. The current oscillates and we get what is called an alternating current. That is the way in which electric oscillations are produced. It is similar to the oscillation of a weight on a spring. If you pull the weight down, then the spring pulls it up, but when it gets to its equilibrium position it does not stop; it overshoots the mark and goes too far up, and then it comes down again. It is analogous to the way in which the electric oscillations occur.

When a body is moving, it tends to keep on moving. It has inertia. So when the spring has pulled the weight up and has it moving, it goes on moving; it goes too far, so to speak, and then comes back, and so keeps on oscillating up and down. Electricity does very much the same thing. When the positive charge moves across the wire it produces a magnetic field, and the magnetic field is analogous to the motion of the weight and keeps the current going, because when the magnetic field diminishes it generates an electric field and so keeps the current going, and the current, so to speak, overshoots the mark and the positive charge that was on one ball goes to the other ball, and the negative charge which was on one ball goes to the other ball, and that process is repeated. So you get the electric oscillations.

I have an experiment here on electric oscillations. We have what is called a Leyden jar. It is a glass jar and the inside and outside have metallic coatings. The outside coating is con-
Physics and Communication

connected with a wire, and the inside coating is connected with another wire. The two wires are connected to two knobs with a small gap in between. Now if we put positive electricity on the inside of the jar and negative on the outside, then when the charges are big enough the electricity will spark through the gap, and when the spark passes, the inside and the outside are connected through the spark. The spark is a conductor of electricity. Then you get a current in the wire and the positive charge on the inside flows through the wire, around to the outside. You have the positive on the inside and the negative on the outside. The positive flows towards the negative and neutralizes the negative, but it produces a magnetic field, which keeps the current going, and so the current goes on until the outside is positive and the inside negative, and you get oscillations from the inside of the jar to the outside, just as with the two balls connected by wire.

Now in order to detect these oscillations we have another similar jar, also with the outside connected to the inside by a wire, but in this case there is no gap. I have a wire here attached to the outer coating and another wire attached to the inner, and they are almost touching. The one wire is connected with the inside metallic coating and the other to the outside metallic coating, and there is a little gap between them of about a sixteenth of an inch. If we have the electric oscillations going in the first jar the current will be oscillating backwards and forwards along the wire through the spark, and the magnetic field which the moving electricity produces will act on the wire of the second Leyden jar, and will set up oscillations in it, and, if the oscillations are sufficiently powerful, it will produce sparks across the little gap. In order for that to happen, the two oscillators must oscillate with the same frequency, or, we say, we have to tune the second circuit so that the frequency of oscillation in it is the same as
the frequency of oscillation in the first circuit. That is what
they call tuning in radio. You tune your receiver to the waves
that you want to receive. To tune the second circuit I have a
movable wire across it which can be moved about so as to
alter the size of the second circuit. Now you see we are get-
ing a little spark in the small gap. I will move the wire now
to a different position. Then the circuits should not be tuned
any longer. Now we do not get any spark. In order to get the
oscillation in the first circuit to set up the oscillation in the
second, you have to tune the second.

You get a similar effect with sound vibrations. I have two
tuning forks. If we strike this one, you hear it give out a
musical note and the other one gives out the same note. So
the two tuning forks are tuned so they both make the same
number of vibrations per second. Now if we start one of
them, the sound vibrations from it, falling on the other one,
will make the other one vibrate. I will stop the one that was
started, and then you can hear the other one going. So you
see, when the number of oscillations that one fork makes per
second is the same as the number that the other one makes,
then they are tuned and the one fork will set the other one
going. It is just the same in the case of two electric circuits:
if they make equal numbers of oscillations per second, the
one will set the other one going. But if they are not tuned,
that does not happen. For example, if I put a weight on one
of the forks, that will alter its number of vibrations per
second. Then they will not be tuned and will not set each
other going.

I have another illustration of the same sort. This weight
on the spring can vibrate in two ways. It can vibrate up and
down, but it can also vibrate by rotating. So you see it has
two ways of vibrating, and the number of vibrations per
second it makes when it rotates is equal to the number it
Physics and Communication 311

makes when it goes up and down, so the two sorts of vibrations are tuned, and if we set one going it will set the other one going. As it goes up and down it begins to rotate, and as it rotates more, the up-and-down motion gets less. After a little while the up-and-down motion will stop and it will just be rotating. Then the rotational motion will set the up-and-down motion going. You see now it has practically stopped going up and down, but it is rotating strongly, and now the up-and-down motion will begin again. So when the two motions are tuned, one sets the other going.

When you have an electric oscillation, each oscillation emits an electric wave. Suppose we have these two balls connected by a wire one above the other, and one is positively charged and the other negatively. The positive electricity will come down and the negative go up. Then we will have the negative at the top and the positive will go up. So you will have the electricity oscillating up and down along the wire. The electric charges produce or excite in the space around them what we call an electric field. The electric field goes from the positive charge to the negative charge. We represent the electric field by lines going from the positive charge to the negative charge. Suppose the positive charge very quickly moves to the bottom and the negative charge goes to the top. Then the line that starts from the positive charge will very quickly move down to the bottom and the negative end will move to the top, and so the line will cross over itself near the balls.

If the positive charge moves to the bottom very quickly there will not be time for the part of the electric field some distance away to get reversed. It will get reversed near to the wire first, before it has time to get reversed farther out. The part of the electric field which has not become reversed then breaks off from the reversed part and moves away. The part
of the field that moves away is an electric wave. For each oscillation of the oscillator an electric wave is emitted in that way. The electric field, so to speak, breaks off from the oscillator and travels out into the surrounding space.

The electric waves travel out into the surrounding space with a very great velocity; in fact, their velocity is nearly 200,000 miles per second. So the electric waves which are produced by the electrical oscillations travel out in all directions into the surrounding space with this velocity of nearly 200,000 miles a second. It is exactly 186,000 miles per second.

Now suppose the oscillator makes a thousand oscillations per second. Then each oscillation emits a wave. So we get a thousand waves emitted per second and the waves travel 186,000 miles per second. Thus in one second the waves will be spread out over 186,000 miles. If a thousand waves are emitted per second, that is, if the oscillator makes a thousand oscillations per second, then each wave will be 186,000 divided by a thousand, that is 186 miles long. So to get the length of the waves which are produced you divide the velocity, that is the 186,000 miles per second, by the number of oscillations per second made by the oscillator.

Of the radio stations in Houston, for example, KPRC gives 950 kilocycles, that is, 950,000 oscillations per second. A kilocycle is a thousand oscillations per second. Therefore the wave length is 186,000 miles divided by 950,000, and that is just about one-fifth of a mile. So the electric waves from KPRC are a fifth of a mile long.

Now KTRR has 740 kilocycles, so the wave length for KTRR is 186,000 divided by 740,000, which is about a quarter of a mile.

KXYZ gives 1320 kilocycles, so the wave length for that station is 186,000 divided by 1,320,000, which is about a seventh of a mile.
So these waves that are used in broadcasting are ordinarily from around a quarter to a tenth of a mile long; that is, the number of waves emitted per second is usually about a million extended over the distance the first wave goes in one second, which is 186,000 miles. So you divide the 186,000 miles by the number of waves per second and you get the length of one wave.

I have here an oscillator which gives waves about two yards long, so you see it makes about 150,000 kilocycles, which is 150,000,000 oscillations per second. It is what is called a short wave oscillator. It is oscillating now. Here is another circuit which is tuned to it. When we get the oscillations in the oscillator it lights up a small lamp in the tuned circuit. When you have electricity oscillating in a circuit of course energy is used up in maintaining the oscillations. So to maintain the oscillations, power has to be supplied to the oscillator, otherwise the oscillations will stop very soon. In this oscillator we have two vacuum tubes which furnish the power to maintain the oscillations, so the oscillations go on steadily, instead of just quickly stopping after being started. Thus vacuum tubes are very important in radio broadcasting. I wish, therefore, to consider these vacuum tubes for a few minutes.

The vacuum tubes which are used so much for radio work depend on the fact that negative electricity escapes from a hot body. Suppose you have a metal wire which you make red hot or white hot. Then negative electricity escapes from it, but not positive. I have here an apparatus to show that. Here is a glass bulb which has a metal cylinder in the middle, and inside the metal cylinder is a filament, similar to the filament of an incandescent lamp. That is, it is just a hollow metal cylinder with the ends open, and inside there is a wire, which does not touch the cylinder, and there is a vacuum in
the bulb. We can heat the wire by passing a current through it. If we heat the wire sufficiently hot, then negative electricity will escape from the wire to the cylinder, so you get a current from the cylinder to the filament. Now I am going to heat the wire, and I have a galvanometer here to indicate the current. Here is a battery which is connected to the cylinder and the other end of the battery is connected to a galvanometer; the other end of the galvanometer is connected to the filament inside the cylinder. If negative electricity escapes from the filament to the cylinder, we should get a current through the galvanometer. At first there is no current because it is not sufficiently hot. As it becomes hotter we get a current. The cylinder is connected to the positive end of the battery. Positive electricity attracts negative. So if you put positive electricity on the cylinder it will attract the negative out of the filament, or, if electricity comes out of the filament, it will be attracted by the cylinder and will go across, so you will get a current across to the filament from the cylinder.

Now suppose we connect the negative end of the battery to the cylinder instead of the positive end. Then, if we have negative electricity on the cylinder, it will not attract the negative that comes out of the filament; in fact, it will repel it and drive it back into the filament. So when you make the cylinder negative, you get no current. I will reverse the battery, that is, turn it around so that the negative end will be connected to the cylinder. Of course if you did not connect the battery at all you would not get any current, but I have it properly connected. Now I will make the wire hot again. We get no current at all, though it is as hot now as it was before. Even when it is hotter than it was before we get no current. There is a great difference between positive electricity and negative. The negative escapes from a hot body, but the positive does not.
That fact is made use of in the vacuum tubes that are used so much in radio. They are made very much like the cylinder and filament we have just used. The filament is in the middle of the cylinder. But in addition to the cylinder and filament we have a wire grating which is between the filament and the cylinder. The cylinder is usually called the plate in these vacuum tubes. So we have the plate and the filament. The filament is in the middle of the plate, and between the filament and the plate there is a wire grating, which is called the grid. So there are the plate, the grid, and the filament, with the grid in between the other two.

Now suppose you have the filament hot enough so it emits negative electricity, and the plate is positive. Then you will get a negative current from the filament to the plate. The positively charged plate attracts the negative electricity that comes out of the filament, and the electricity that comes out of the filament goes through the grid, because the grid is just a wire grating with wide spaces between the wires. A little of the negative electricity may hit the grid, but nearly all of it goes through from the filament to the plate. But now suppose you put negative electricity on the grid. Then the negative electricity on the grid will tend to stop the electricity coming out of the filament, and so if you put a negative charge of electricity on the grid it will tend to stop the current. You can have such an amount of negative electricity on the grid that it nearly stops the current, but you still get a small current. If you put too much negative electricity on the grid you will stop the current entirely, because the negative electricity on the grid repels the negative electricity that comes out of the filament. Suppose, however, you have a small amount of negative electricity on the grid; then it will very much diminish the current; you will get a small current. If you change the amount of negative on the grid, diminish it slightly, the
current will increase; or if you increase it, the current will diminish; so the grid enables the current that passes through the tube to be controlled. You can control the current by putting more or less negative charge on the grid.

The apparatus used to show the difference between positive and negative electricity works with a vacuum tube. The grid is connected to a wire. Then the current passing through the vacuum tube lights up a small neon lamp. If we have a negative charge on a rod and hold it up near the wire connected to the grid, we get negative on the grid, which stops the current so it makes the lamp go out. So by the use of one of these vacuum tubes we can show the electric field of the charge on a rod of lucite or hard rubber.

These vacuum tubes are used to maintain electrical oscillations. For example, there are two of these tubes on this oscillator. Each tube has a plate, a grid, and a filament. There is a thick wire twisted around into one turn, and the two ends of this wire are connected, one end to one plate and the other end to the other plate. The two grids are connected to the opposite ends of the thick turn of wire. The connections of the two grids to the ends of the wire are, so the speak, crossed. Now suppose you have electricity oscillating through the turn of wire, going backwards and forwards along it. Then, if one end of the wire is positive, that will make the grid connected to it positive, and the grid will increase the current because it attracts the electrons from the filament, so you will get more negative electricity coming out of the filament and going to the plate connected to the other end of the wire. The plate currents therefore help the oscillation and maintain it so that it just keeps on going steadily.

Oscillators like this are used in radio broadcasting, although of course this is a very small one, that gives small
waves. The much more powerful oscillators used in broad-
casting act in a similar way.

I have here an arrangement for detecting the electric
waves that come out of the oscillator. It is just a long metal
rod with a gap in the middle, and in the gap there is a small
electric light bulb. This is not a sensitive detector, but it will
detect the waves at a short distance. I am going to attach two
rods to this oscillator, one to one end of the wire and the
other to the other end. These wires correspond to the an-
tennas that are used in radio broadcasting stations. Of course
you know the antennas are usually vertical wires; that is, you
have a vertical wire going up from the oscillator; but here
I have two horizontal wires.

Now when the oscillator is working you have the electricity
oscillating across from one side to the other. With this oscil-
lator you get about 150,000,000 oscillations a second. The
electric waves which are emitted will fall on the detector, and
if it is tuned so that the frequency or the number of oscilla-
tions per second of the detector is the same as for the
oscillator, then the waves from the oscillator will set up
oscillations or currents along the detector rod and will light
up the lamp. Of course if we alter the length of the rod, the
light will grow dimmer and eventually go out. If we make
the rod still shorter, then it will not be tuned and the lamp
will not light up. Though we put them nearer, the lamp will
not light up, since the rod is not tuned. You have to have the
rod the right length for tuning. This rod must be approxi-
mately parallel to the other rod. If you turn it at right angles,
the bulb will not light up. That is because the electric field
in the waves goes across from one end of the oscillator to the
other end. So when the detector is parallel to the oscillator,
the field in the waves produces a current along the detector.
The magnetic field is perpendicular to the electric field. If you put a metal plate between oscillator and detector it will stop the waves. Of course with a very sensitive detector, the waves would be detected perhaps a hundred miles away, but this electric oscillator is of course not a sensitive detector.

There are different sorts of microphones that are used in broadcasting. One kind is called the crystal microphone. It is rather interesting. In a crystal microphone there are crystals, of Rochelle salt. Now Rochelle salt is rather a remarkable crystal. If you bend it slightly, it becomes electrified. So in the crystal microphones they have some plates of Rochelle salt with metal coatings and the plates are arranged so that when the sound falls on the microphone, the pressure in the sound waves slightly bends the crystals, and that causes electricity to appear on the metal coatings; then the coatings are connected to wires and you get a current through the wires that goes to the oscillator.

I have an apparatus here to illustrate this. We have two crystals of this Rochelle salt, which have metal coatings, and the metal coatings are connected to a small neon lamp. Now if we suddenly bend the crystals, the crystals will give enough current to light up the lamp, though not very brightly. By tapping the top of the container holding the crystals, which slightly bends the crystals, the lamp lights up, though the light is faint.

The microphone is connected to the grid of one of the vacuum tubes of the transmitting oscillator so that the current from the microphone changes the intensity of the oscillations. This is called modulation. The waves emitted are modulated so that the variations of intensity correspond to the sound vibrations falling on the microphone.

In the receiver the process is reversed. The vacuum tubes of the receiving oscillator are connected to the loud-speaker
so that the current to the loud-speaker corresponds to the modulations. The loud-speaker therefore reproduces the sound picked up by the microphone connected to the transmitting oscillator.

There are many technical details which have been omitted, but the principles on which broadcasting depends have been very briefly outlined.

H. A. Wilson.