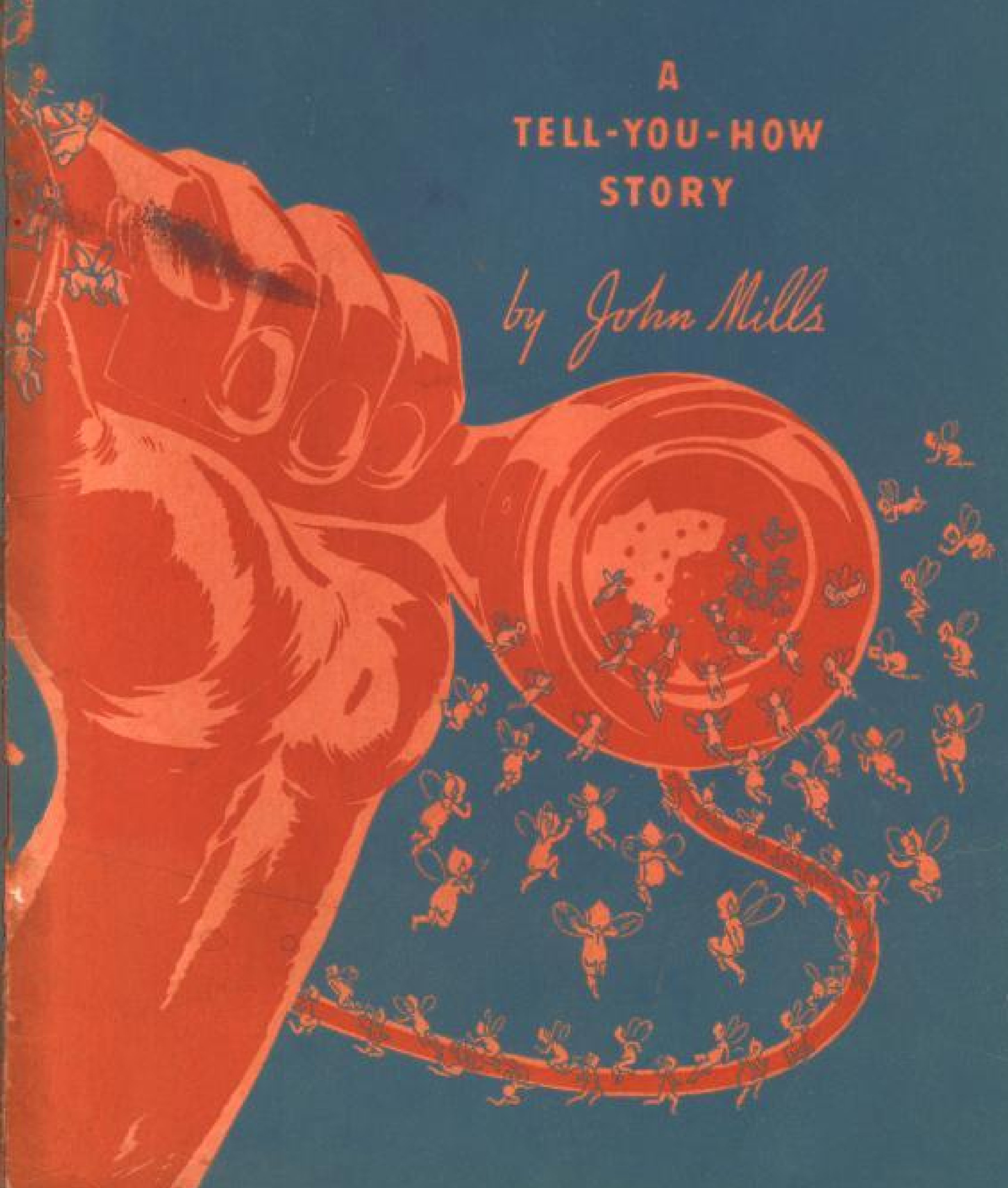
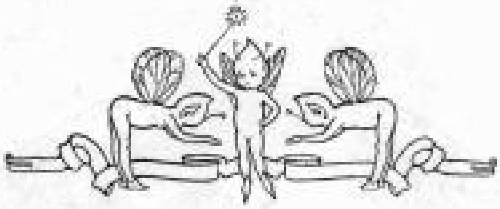
THE *Magic* OF COMMUNICATION

A
TELL-YOU-HOW
STORY

by John Mills





The MAGIC of COMMUNICATION

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A tell·you·how story

By JOHN MILLS

Author of "Letters of a Radio Engineer to His Son"
"Signals and Speech in Electrical Communication"
"A Fugue in Cycles and Bels"

Information Department

AMERICAN TELEPHONE and TELEGRAPH COMPANY

Alexander Graham Bell

Portrait of the Inventor at the age of 29, in the Year in which the Telephone was Patented

The MAGIC *of* COMMUNICATION

A TELL · YOU · HOW STORY

The History of Human Speech Before our earliest ancestors could communicate their thoughts and ideas they had to learn to talk. Spoken sounds came to be words and language began. In time men learned to write; and much later to print. When man could write, his words could be preserved. No longer was it necessary to be within sound of a man's voice to get his words. Written messages could be sent from one man to another. But written messages take time to write, and to send, and to be read.

What man has always needed is some method of communication that would enable his actual speech to be heard miles away and only by the particular person addressed. For thousands of years this was so impracticable that it was not even a dream.

After the discovery of electricity, men learned how to make batteries send currents of electricity through long wires. They learned about electromagnets which a current of electricity would operate. When the current flowed, the electromagnet would attract a little piece of iron, pulling it up sharply until it struck with a click.

The electromagnet and the battery could be far apart, with only wires to connect them. And with this idea the telegraph was born; and for years it has permitted communication between persons who are widely separated. Of course, there has to be some agreement as to how the clicks shall stand for letters; and each word of a message has to be spelled out in dots and dashes according to a code.

The Discovery of the Telephone And then in 1875 came a more marvelous discovery. Alexander Graham Bell, a teacher of elocution and a student of electricity, had the vision of a new machine which would carry not dots and dashes but the human voice. In the ear the tiny disc of the eardrum responds to a spoken word. Could he make a disc of iron to catch the sound and to send it electrically to another disc which would give it out again? In 1875, working with strips of clock spring, he built a transmitter which could send the feeble twang of a vibrating reed and a receiver which could reproduce sound.

This he called the "harmonic telegraph," and by its use he hoped to send several telegraph messages simultaneously over the same wire. It was while experimenting with this apparatus that he discovered the way to make the speaking telephone of which he had dreamed for years. But it required nearly ten months of further experimenting to make his instrument transmit an intelligible sentence.

"Mr. Watson, come here, I want you," he called into the instrument, and his assistant, listening intently at the other end of the line, dropped the receiver and rushed to Bell in the adjoining room shouting, "I hear you. I can hear the words."

Bell's historic words were repeated thirty-nine years later under circumstances which gave them double significance. At the official opening of the Transcontinental Line, in January, 1915, Dr. Bell took part in the exercises at New York, while Watson was

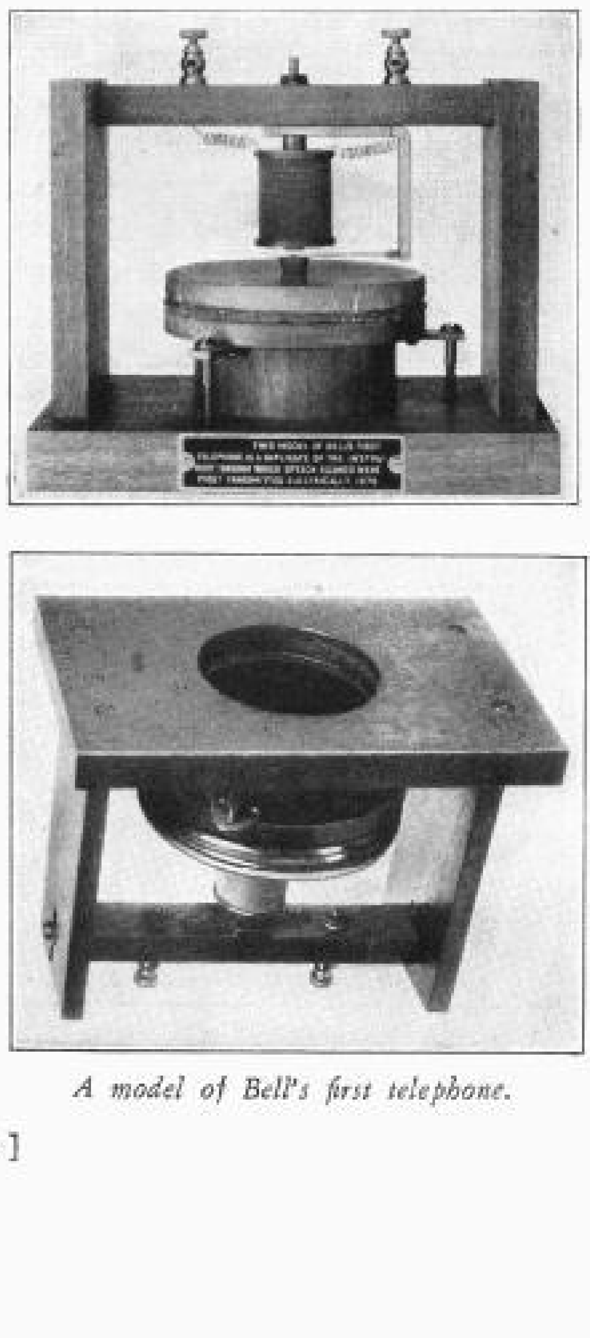
This garret, at 109 Court Street, Boston, where Bell discovered the principle of electrical speech transmission, was the forerunner of great laboratories devoted to the development of this magic of communication.

at San Francisco. Over a circuit 3,400 miles long, Dr. Bell repeated to the man who had been his assistant the first sentence ever spoken over a wire, and Watson laughingly replied that this time it would take him a week to come.

At first the invention seemed too wonderful for belief. Judges at the Centennial Exposition in Philadelphia almost passed it by. Perhaps they would have, had it not been for Dom Pedro, the Emperor of Brazil, who had met Bell as a teacher of speech to deaf-mutes. He recognized him and spoke. Then Bell went to the other end of the wire and spoke into his transmitter while Dom Pedro listened at the receiver and the judges watched. "My God—it talks," cried the Emperor.

The Telephone What is the telephone? A marvelous device—it catches a spoken word and turns it like magic into something we cannot see or hear which speeds along the wires to another telephone; and there the magic is undone and the hidden word comes forth. In the old fairy stories there always was an enchantment and then later a charm which broke the spell and freed a living person. Our modern fairy story is the story of electricity. The transmitter in your telephone set casts a spell upon each word it catches, sending it noiselessly away along the telephone wires. The receiver breaks the spell and a living word issues, bearing its message from a far distant speaker.

The Spoken Word What is the spoken word? It is a motion of the tiny particles or molecules



A model of Bell's first telephone.

which compose the air about us. But it is a particular kind of a motion which our ears can receive and our brains appreciate. It is started by the voice of the person who is speaking. His breath and tongue and lip positions control it. As he changes these he changes the kind of motion which he gives to the air molecules. And so they produce a different motion of the delicate drum of the ear, of the bones and fibres within, and hence a different sound for the listener *(see Figure 1)*.

The motion which one gives to the molecules of air when he speaks is not like that of the wind where a multitude of air molecules sweeps along. In a spoken word, or in any musical sound, the molecules dance back and forth *(see Figures 1 and 1-A)*. First they advance, pushing against the eardrum, and then they retire and the membrane of the ear flies back. Over and over again this happens, hundreds and even thousands of times every second. The higher pitched the voice of the speaker, the more rapid is the dance. And yet it is a dainty dance, for the weight of a snip of human hair only about one-thousandth of an inch in length would press as heavily upon the sensitive eardrum.

The Telephone Transmitter What is the transmitter? It is an electrical ear which receives the shock of the dancing molecules, just as does the membrane of the human ear. Within the human ear these motions are taken up by the tiny bones and sent on to the brain by the nerves. We do not know how, for we know less about transmission along nerves than we

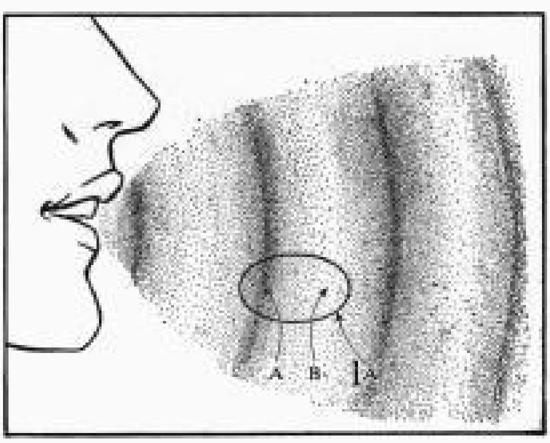


FIG. 1. *If you could see the molecules of air, this is the way they would appear at one instant. See point 1 in the chart on page 7.*

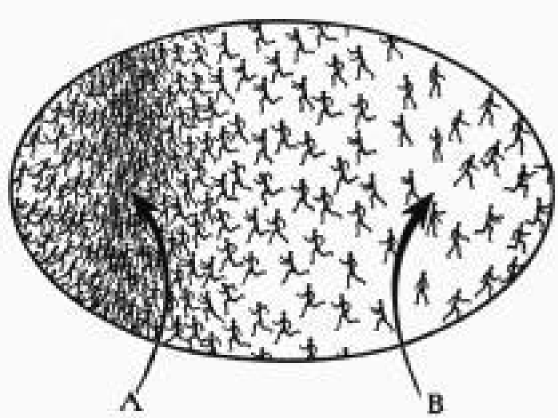
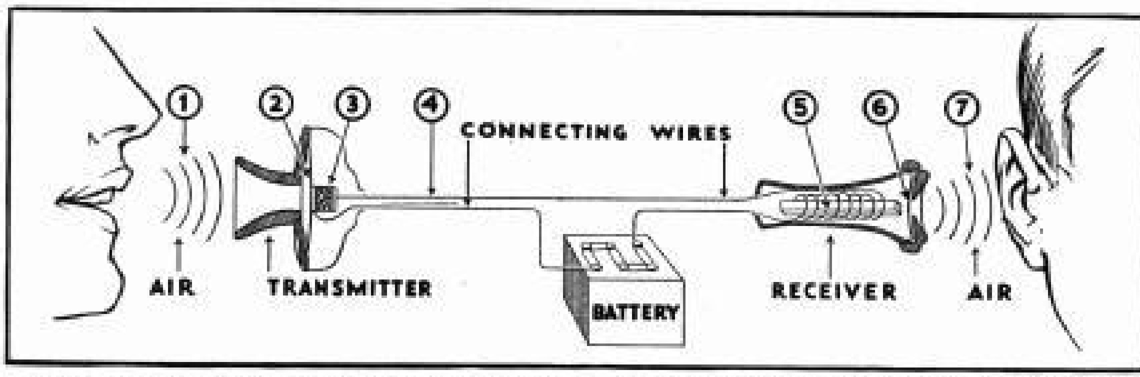


FIG. 1-A. *This is an enlargement. Think of the molecules of air if they were tiny beings rushing toward A and away from B.*

know about transmission over wires.

The transmitter has its ear-



This chart shows the simplest telephone circuit. Pictures on these two pages and following will show just what happens at the points 1, 2, 3, and so on.

drum, the diaphragm, indicated by numeral 2 in the chart above, which is set vibrating by the dance of the air molecules *(see Figure 2)*. Back of the diaphragm is a small chamber partly filled with grains of carbon — grains of roasted coal, in fact. Through this carbon chamber and the connecting wires a battery sends an electric current. It is indicated by the numeral 3 in the above chart.

From grain to grain of carbon and through the wires and battery there is a steady procession of billions of tiny specks of electricity—electrons they are called. Too small ever to be seen, the existence of these electrons has been proved by careful scientific experiment. They are a multitude of little gnomes which reside in the wires and carbon grains; and all the marvels of electricity are due to their activities. The battery causes the procession and under its steady urge billions of electrons march each second around the circuit formed by the wires and the close-packed carbon grains *(see Figure 4 on the next page)*.

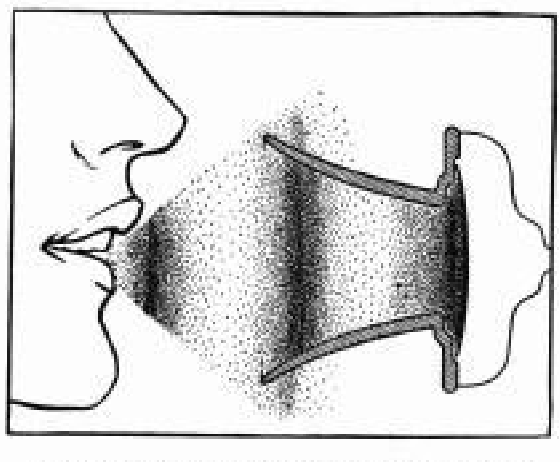


FIG. 2. *When the molecules of air which are set in motion by the voice of the speaker rush against the diaphragm of the transmitter shown in the chart above, they bend it in. When they rush away, it springs back.*

The telephone transmitter is an electric ear and when its eardrum is moved back and forth ever so slightly by the dancing molecules of air, the carbon grains behind it are first packed more closely and then less closely *(see Figure 3)*.

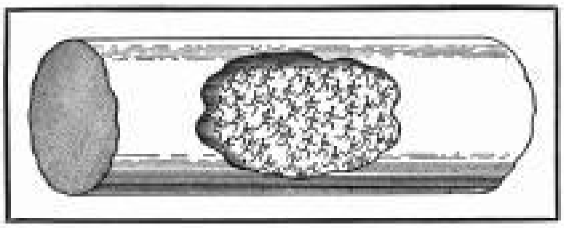


FIG. 4. *If you could go inside the copper wire in a telephone circuit you would find tiny electrons rushing along between the atoms of copper.*

Over and over this happens, as often as the transmitter diaphragm vibrates back and forth. Imagine a vast army of men crossing a lake on floating blocks of ice while the wind freshens and dies alternately. When the blocks are blown close together crossing is easier, and more men get over than when the irregularly spaced blocks are loosely packed and only occasionally are close

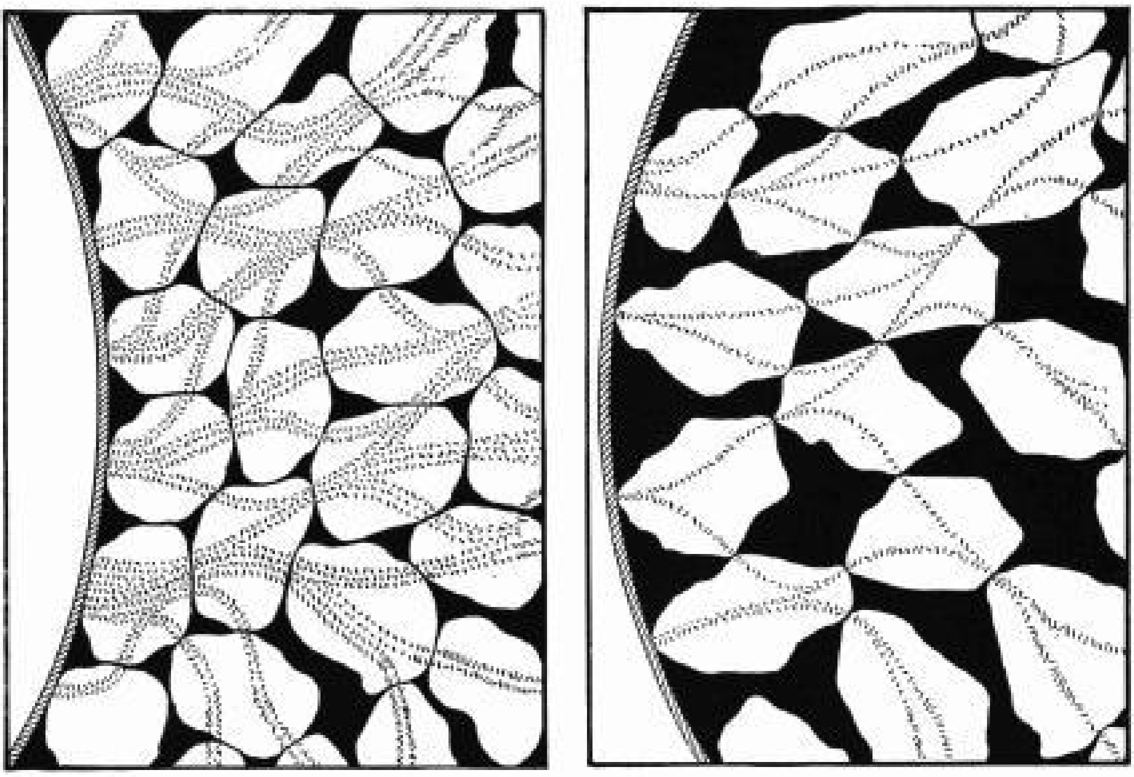
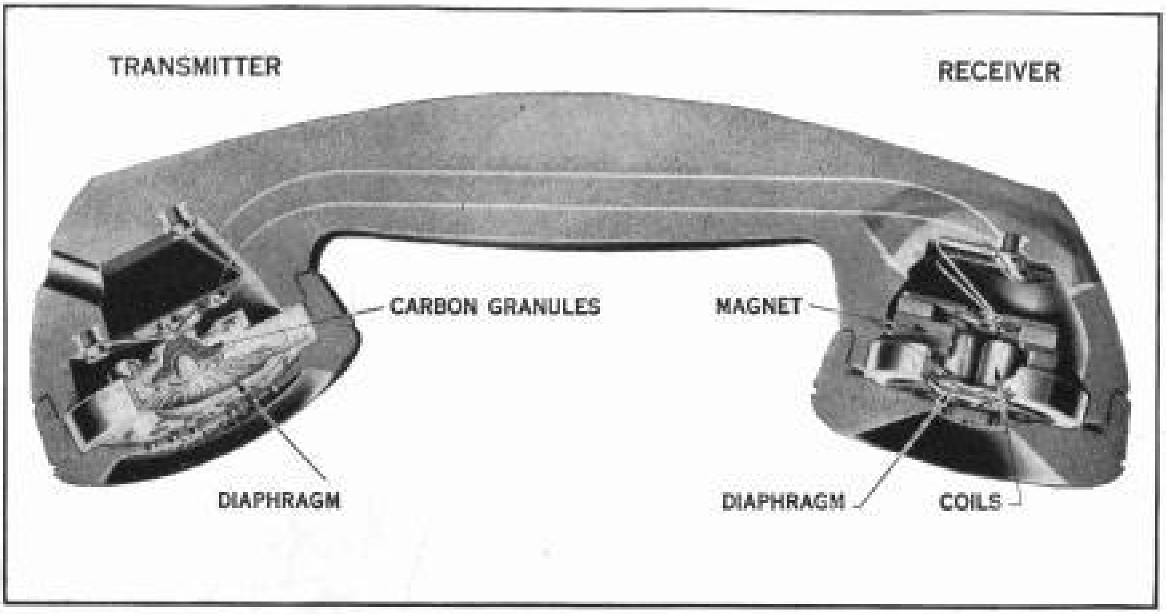


FIG. 3. *Carbon grains in a transmitter magnified about fifty times each way. When the diaphragm is bent in (at left), the grains are closely packed together and many electrons can pass through. But when the diaphragm springs back (at right), the grains are loosely packed and fewer electrons can pass from grain to grain through the chamber.*

enough together. This, on an enormous scale, is a picture of what happens when electrons cross from grain to grain in the carbon of the transmitter. Men can move only slowly, but the tiny electrons there are many, we say the electric current is larger than when there are few. So the current changes, increasing and decreasing alternately, as the diaphragm compresses the carbon more or less.



You will see from this picture that the transmitter and receiver in a hand telephone are really separate units just as in a desk telephone.

move with an enormous speed of thousands of miles a second.

If you could stand beside the road leading from the shore of this lake and count the men as they marched past, you would find that there would come a group and then some stragglers; and then another group, and so on. It is the same with the procession of electrons which moves along the wire from one of the plates between which lie the carbon grains. When

The Telephone Receiver What is the receiver? It is an electric mouth which can utter human sounds. There is a thin diaphragm of iron, indicated in the main chart by the numeral 6, and a coil of wire wound on the magnet indicated by the numeral 5. The magnet attracts the iron diaphragm, bowing it slightly toward itself. The stronger the magnet pulls, the more the iron bows toward it, but if the pull de-

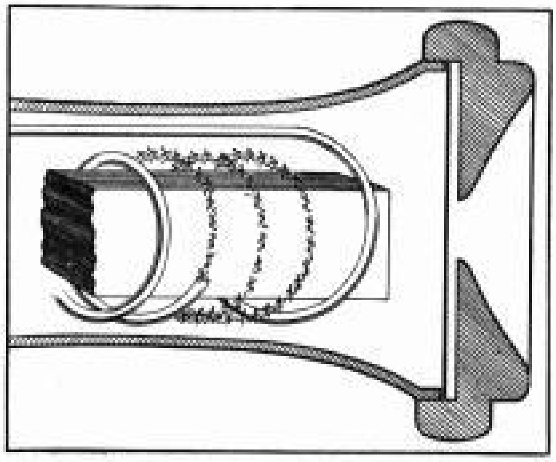


FIG. 5. *In the receiver the marching electrons follow the wire coils around a magnet. When there are many electrons marching through this coil the magnet pulls harder on the diaphragm.*

creases the iron flies back, like the bottom of a pan which you are bending with your fingers.

When the electrons follow through the turns of wire which form the coils about the magnet they increase its pull upon the iron diaphragm *(see Figure 5)*. When a great crowd of electrons is marching the magnet pulls harder; but when only stragglers come the bent diaphragm springs back.

The motion of the diaphragm of the receiver is just the same as that of the diaphragm of the dis-

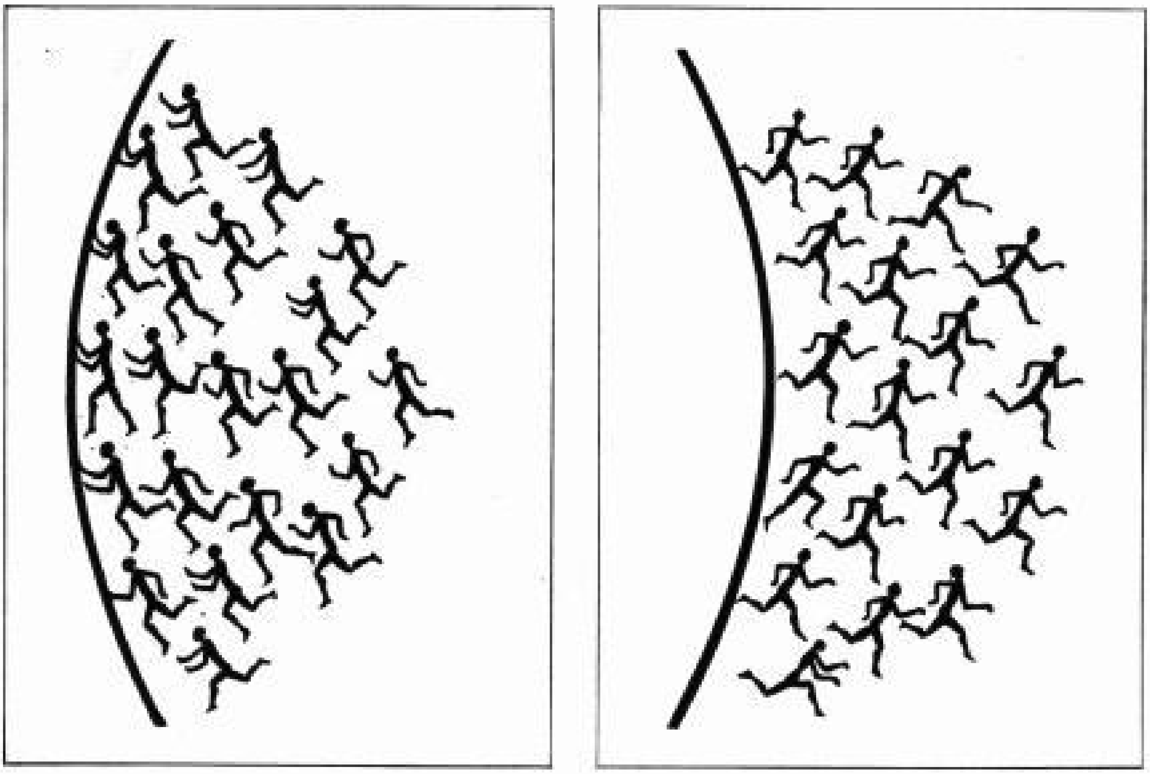
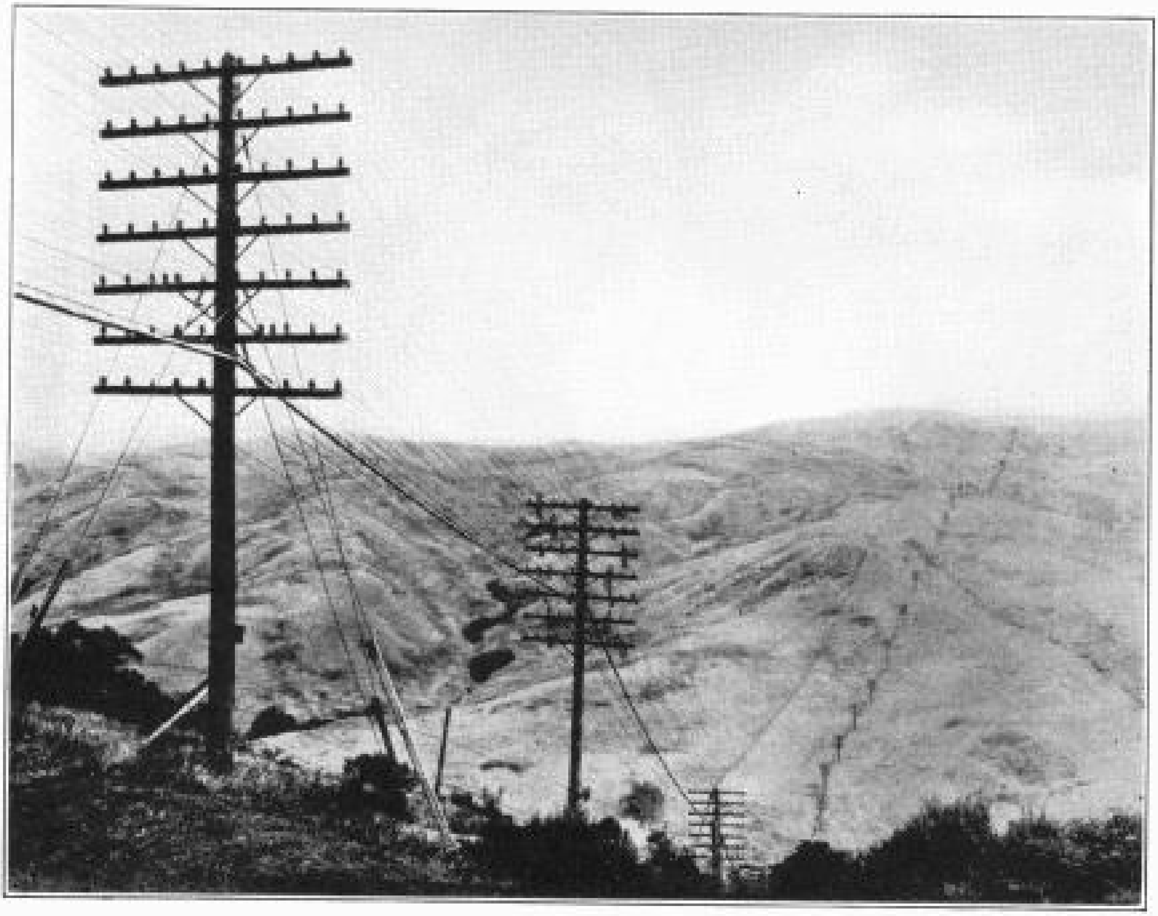


FIG. 6. *When the receiver diaphragm of Figure 5 bows in, like the left picture here, the molecules of air rush after it. When the diaphragm bows out, as at right above, the molecules are pushed away. So the molecules rush back and forth just as do those shown in Figure 2.*



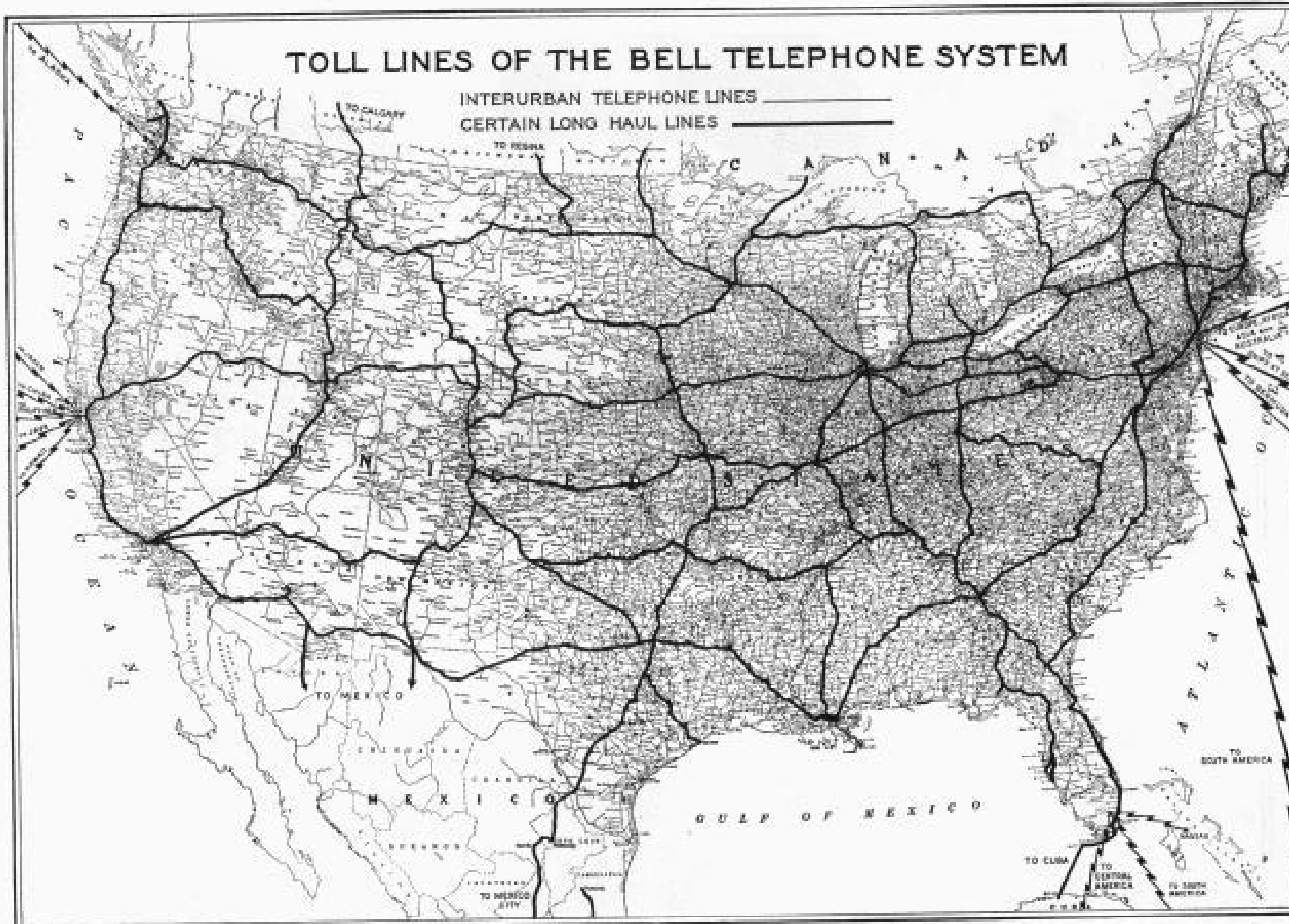
The cable in this California picture carries many times as many circuits as the open wire line which pioneered this highway of speech across the continent.

tant transmitter. And the air molecules near the receiver are set into the same kind of motion as those which danced against the transmitter diaphragm. That is why the receiver speaks, undoing the magic which turned a spoken word into an irregular procession of electrons *(see Figure 6)*.

The Highways of Speech You have seen maps showing the main railroad lines stretching across the United States. Have you ever seen one like that on the next page? Its lines show the wire routes of the Bell Telephone System which developed the telephone and made it useful to the people of our country.

These are the highways of a nation's speech.

You have seen them in your walks about country or town. Sometimes they are high poles with crossarms, carrying glisten-


TOLL LINES OF THE BELL TELEPHONE SYSTEM
INTERURBAN TELEPHONE LINES
CERTAIN LONG HAUL LINES
CANADA
UNITED STATES
MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
TO CALGARY
TO REGINA
TO MEXICO
TO MEXICO CITY
TO CUBA
TO CENTRAL AMERICA
TO SOUTH AMERICA

ing copper wires which stretch straight across country, up and down hill, across fields and streams. Each pair of wires is a private speedway for the spoken words of the two persons whose telephones are connected to it.

Aerial Cable Lines Between any two cities there must always be enough lines to carry the conversations of all the people who might need to talk at the same time. That is why between the most populous cities like New York and Chicago, the highways are taking a different form. The wires are not separated by inches of air but by thin ribbons of paper, wrapped about each wire; and the wires of each pair are twisted together. Many such pairs together form a cable which is protected by a sheath of lead.

Sometimes these cable highways run underground through conduits. This is always true of the speech highways in the larger cities.

Here is a section of an aerial telephone cable fanned out to show the paper-insulated wires.

Crossing Pennsylvania along one of the New York-Chicago cable routes.

Telephone Cities Many of our cities have so many telephone users that the telephone company divides a city into sections, each with several thousand telephone subscribers. Each section is a telephone city, with a convenient name like "Market" or "Canal," and its own central office from which there are wires to each telephone in that section.

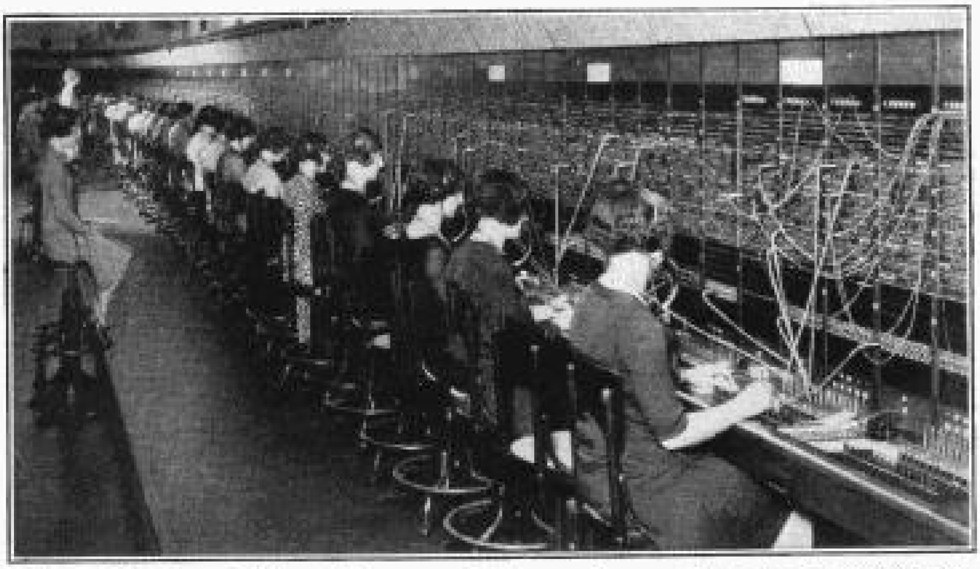
When you telephone to some one in the same telephone city as yourself your telephone wires are connected at the central office to those leading to the other person's telephone.

The metropolitan area of New York City is divided into more than a hundred and fifty telephone cities, each with its central office. In the lower part of Manhattan Island, the financial center of the world, with its tall buildings, each holding thousands of persons, there are a half dozen of these telephone offices. Each serves about ten thousand subscribers; and yet in this part of the city the number of telephones is so great that central offices may be only a few blocks apart.

When you telephone to someone in another telephone city your line must be connected at your central office to a highway, or trunk line, which leads to the central office in the other telephone city. There the highway is connected to the wires which go directly to the other person's telephone.

Tens of thousands of miles of such trunk lines interconnect the various central offices of a large city, for there always must be enough wires so that, without waiting for a telephone highway to be free, a telephone call can go right up to a subscriber's private telephone door and find out if he is busy.

The Doors of a Telephone City The line of a telephone subscriber is like a hallway leading from the house, or office, where he has his



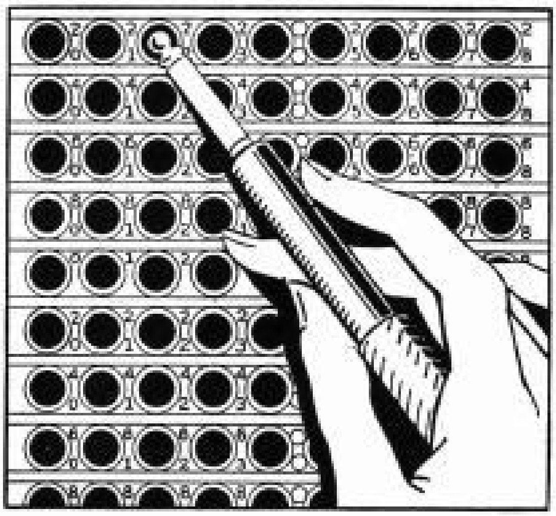
The multiple switchboard in your telephone city may have up to 10,000 connected telephones, and your operator can connect you with any one of them.

telephone instrument, to the central office of his telephone city. And there he has a door opening onto all the national highways of speech. Through this telephone door and along the hallway, formed by the wires which connect his instrument to the central office, conversation can take place with anyone else who also has a door on the national highway.

Opening the Telephone Doors For every conversation two telephone doors must be opened, yours and that of the person whom you are calling. If the call starts from a dial telephone the doors are opened, that is, the connections are made, by ingeniously-designed electrical equipment. Otherwise they are opened by girl operators.

At the central office your hallway is closed by a number of doors, all alike except for the one through which your operator answers. This is the door through which conversations pass when you are calling someone else. When you are being called one of the other doors is used. Of these there are enough so that any operator may reach you without delay or inconvenience.

For the telephone calls which you make there is a door directly in front of the operator who gives you telephone service. Beside it is a small electric lamp; this lights and attracts her attention when you take your receiver off its hook. In front of her are several short lengths of paired wire—cords, as they are called. Each is a flexible hallway with which she can connect you to a speech highway or



Each of these "jacks" on the switchboard is a door to a subscriber's telephone.

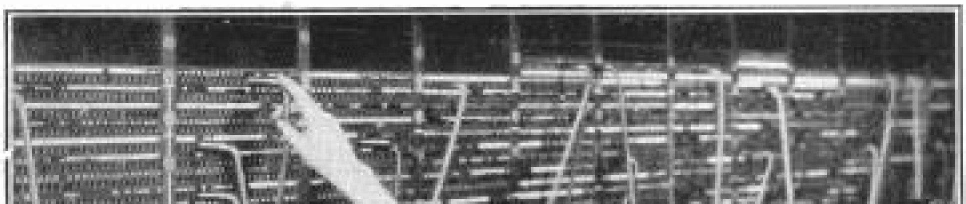
directly to the hallway of anyone who is in your telephone city.

A telephone cord is shaped at each end like a plug to fit into the doors, or jacks as they are called.

Switchboard Operating The operator wears her telephone set. This leaves her hands free to handle the cords and some special telephone "doorknobs" before her. Her own telephone connects with all of the cords; but it is shut off from each cord by a separate door which she controls by a "knob" on the desk in front of her. All these doors remain tightly closed unless she holds one open by its knob, or "listening key," as she calls it.

When she sees the light beside your telephone door she picks up a cord and plugs one end of it into the door. Automatically the light goes out. With her other hand she then opens the door which connects her telephone with the cord she is using and so is able to answer you.

Suppose you wish to talk to someone in your own telephone city. Every subscriber in that city has a door within reach of your operator. These doors are arranged in numerical order on a panel in front of her. It takes her only an instant to plug the other end of the cord into the proper door and send a ring down that hallway to call the other person to his telephone.



These operators are the ones who complete the connection for you to the number that you are calling.

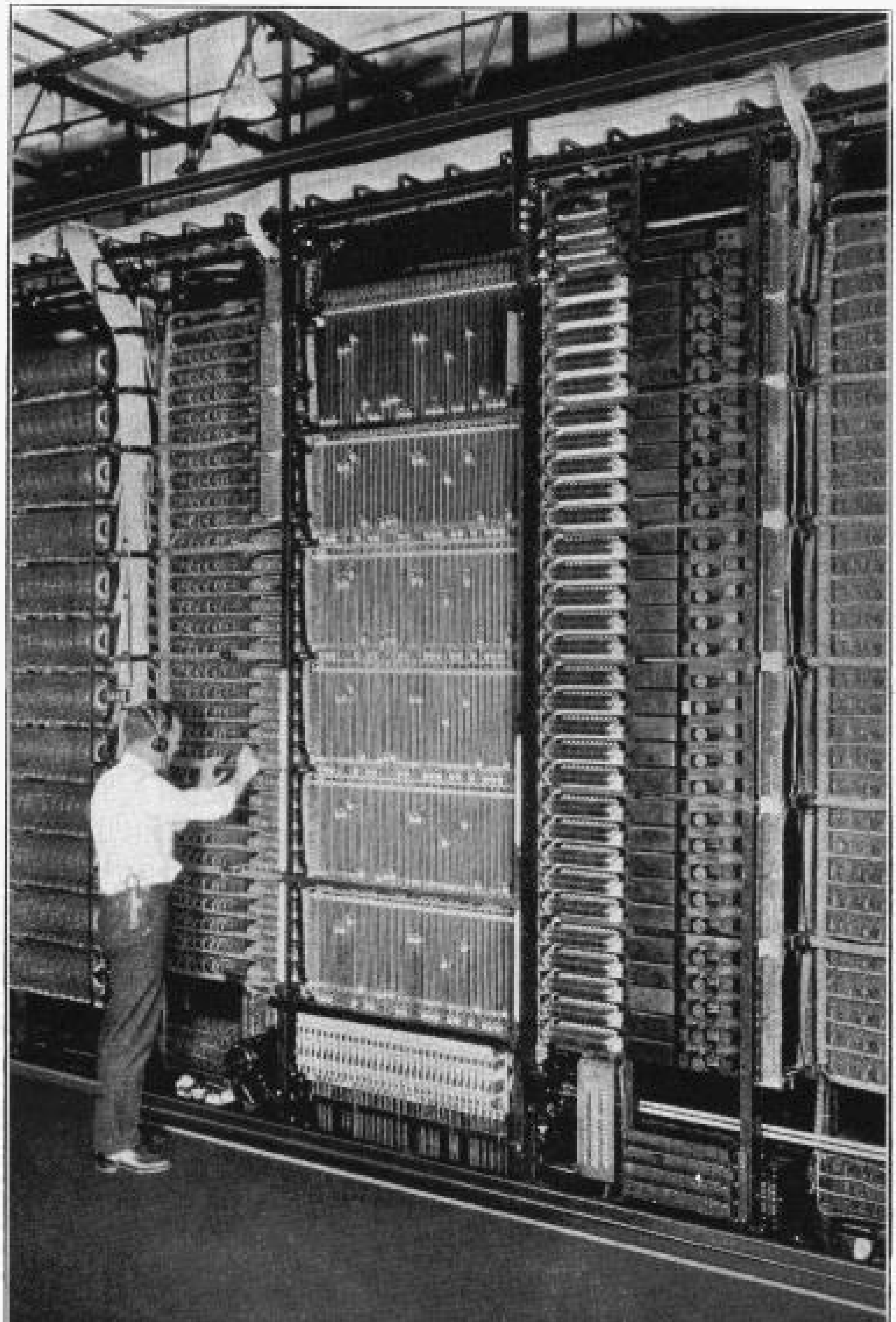
A signal lamp, close to the cord the operator is using, lights when she plugs into the telephone door of the person you are calling. It stays lighted until he takes his receiver off its hook; so she knows at a glance whether or not he has answered your call.

If the telephone you are calling is busy, the operator must know it to avoid interrupting. Special devices help her. She tries his telephone door before opening it. With the tip of the plug she touches the jack. If his receiver is off the hook, because his private telephone hallway is busy, she knows it instantly, for she hears a little clicking sound in her telephone. If she doesn't hear this warning, she pushes the plug all the way into the door and rings to call him.

Between Two Telephone Cities If the person whom you are calling is in another telephone city your talk must follow a trunk line to the other telephone city. So your operator tests the trunks to the particular telephone city until she finds one that is not in use. Then she inserts the plug into this door. In a moment a sound tells her that the operator at the other end of the trunk in the distant telephone city is ready to make the connection. Then your operator gives the number and the distant operator connects the trunk with the line of the person you are calling.

Dial Switchboards Similar operations must be performed by electrical equipment if your call starts from a dial telephone. This equipment is very complex; that is, it has a great many parts. The parts themselves really are simple mechanisms; and the complexity is due to the way in which they are arranged to work together. That is true of many things. A long steel bridge, for example, is a complex structure, although it has few kinds of parts. Usually, in fact, it has only two: first, steel beams which will hold up weights, that is, withstand compression; and second, steel rods which will resist pulling, that is, withstand tension.

In the machine-switching equipment of a telephone central office there are several kinds of parts, but the most important is the electromagnet. This gives a pull on its armature when a current passes through its winding. The pull can be used for almost any purpose. It can close a switch so as to send current into other electromagnets and so make them work. Or, the

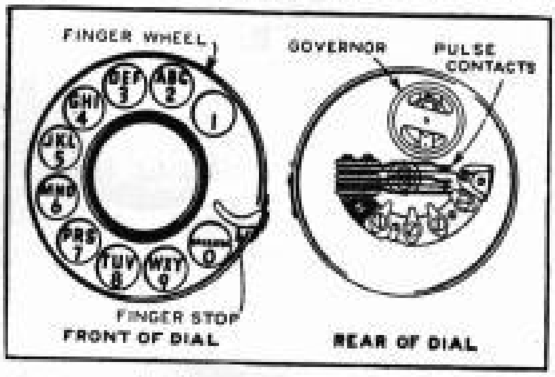


In the center of this picture of a section of a dial central office, you will see a typical bank of the little elevators which run up and down under the control of electromagnets to establish your connection.

pull can move some other piece of equipment, sliding it along a little way, or giving it a part of a turn if it is something which rotates. An electromagnet, for example, can be set to push some piece of apparatus along, moving it a certain distance each time a current is sent through the magnet winding. For each pulse of current which reaches the electromagnet, the apparatus can be made to move another step along whatever path its designers wish it to take.

In dial switching equipment the complexity comes from the large number of telephone lines which the equipment must be able to handle and from the wide variety of operations which it must perform. In the first place, for example, the equipment must find your telephone line when you lift your receiver off its hook, picking out your line from the thousands of others which end in the same office.

You remember how the operator does this when the switchboard is manual instead of mechanical in its operation. She is guided to your line by a lamp which lights as your receiver is raised. The electrical mechanism, having no eyes, would not be aided by a lamp; it must hunt in the dark; and it does so by feeling electrically. When your receiver is raised the switch in your telephone set is closed, and current flows along your line from a large battery at the central office. At that office a switching mechanism is set into motion by this sudden flow of current. The mechanism starts sliding over the terminals of a small



group of lines among which is yours. It runs along until it feels a line with current in it; then it stops and is ready to do what you want; in that regard it acts like an operator on a manual board.

The girl operator would ask you "Number please?" The mechanism cannot talk, so it sends you a musical tone to say it is ready for your instructions. And since it cannot hear, you dial the number. As the dial swings back there is a click for each unit of the digit you dialed. With each click a pulse of current passes through some electromagnet in the mechanism at the central office. That mechanism then proceeds to put the call through for you. Each of its actions is simple, but taken all together they are very complicated, and a very large amount of equipment is needed.

The Telephone in Our Daily Life We have a national habit of using the telephone. Is someone sick? Telephone to the doctor. Is there a fire? Report it at once over the telephone. We grow up in homes with telephones. They are in the houses of our friends, in stores and public garages, in police and fire departments, in our hospitals, our schools, and our churches. Almost as soon as we can talk we learn to answer the telephone, if only to say that "Mother is out," and to ask "Who is calling, please?"

The telephone is a convenience, a necessity. It saves time and money and is of assistance in all the business of our country. But the great reason why we turn to the telephone in arranging our pleasures, in our worries and griefs, in emergency, and in our business dealings, is because it permits personal communication.

Miles of separation vanish as this boy says, "Daddy, it seems just as if you're in the next room."

The Value of Personal Contact Do you remember when you were younger how in your pleasures or your fears you ran to your parents and felt their arms around you? That was a personal contact. When in pain from an accident or sickness, you remember how cooling and quieting your mother's hand would feel. Sometimes you needed only the sound of her voice to comfort you. Perhaps you had awakened at night with a nightmare and had called out. Through the dark you heard your mother's voice telling you it was only a bad dream and to go to sleep again.

All through our lives we are moved and influenced by the human voice, but most of all by the voices of those we know and love or trust. Very early, as we grow up, we learn to distinguish voices, and the finer meanings which their tones add to the spoken words.

The marvel of the telephone is that it carries all the delicate shades of meaning, all the familiar tones, and all the emotion with which words may be spoken. That is why, whether young or old, we turn to the telephone.

"Credit" Basis of Business As you enter into business you will find that business is founded on "credit." Perhaps you know that this is a word with a long history, and comes from the Latin which means "to believe" or "to trust." The man who was believed or trusted was called "creditus" and something which was trusted was called "creditum." What was most frequently trusted was the payment of a sum of money so that "creditum" came to mean a loan. And our word "credit," which is derived from that, means "an expectation of the fulfillment of a promise which has been given."

Businessmen save themselves many a long trip by sending the voice instead on a quick round trip.

Business goes best when there is credit; and then it takes only a word to complete a transaction involving large sums of money. Do you wish to sell something and

Splicing telephone wires where the cable highway crosses a river.

will the other man buy? Your business is based on the mutual confidence of credit. If he says he will buy, you know that when you are ready to deliver he will accept and you will be paid. He knows that he may count on delivery on the day you promise and that the price will not change. A word from each of you will complete the deal. The telephone permits such agreements wherever you may be; and underlying all business dealings carried on over the telephone is the sense of security in having heard the other person's spoken agreement.

Business Uses of the Telephone You will find that the telephone is used in a thousand and one ways for business purposes, for the collection of news, for distributing information on market conditions, on weather conditions, and on all the other factors upon which our farming, mining, and manufacturing depend. Along the speech highways which connect our cities and towns stream the words which control the business of our nation. Each day finds new conveniences in the telephone and new methods of increasing and speeding business by its use. By telephone the spoken word travels so fast that only by comparison can we realize its enormous speed.

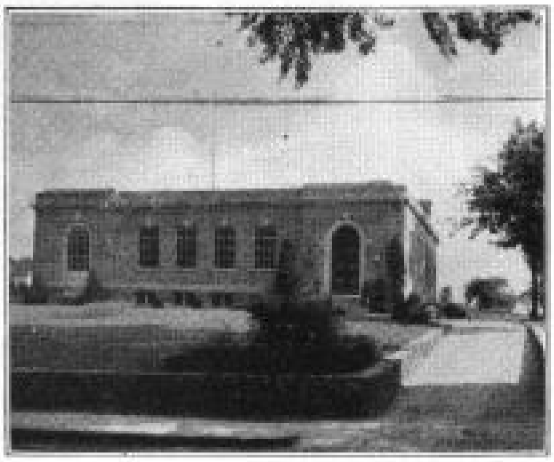
Long Distance Telephony From New York to San Francisco, for example, a word can fly by telephone in a twelfth of a second. That is almost as fast as light travels. Compare that speed with the speed of sound traveling in air. If you ever happened to watch a baseball game from quite a distance away, or perhaps even from the centerfield bleachers of a large baseball field, you know the relative speeds of light (which is an electromagnetic phenomenon) and of sound in air (which is mechanical). You have seen the batter hit, drop his bat, and start for first before the crack of the bat reached your ears. A telephone line can carry a spoken sound from Minneapolis to New Orleans in one-fifth the time it would take for a word to pass from catcher to second baseman across a diamond.

Between cities telephone "repeaters" are installed, the devices which make practicable telephoning over long distances.

At each repeater station along the route new energy is given to the electrons which are carrying the speech. Just why we shall now proceed to see.

You remember how the telephone operates. In the receiver a magnet pulls an iron diaphragm. When there is a procession of electrons through the coils around the magnet the pull is increased. The procession starts from the distant transmitter; and when its carbon grains are packed more and then less closely together the procession changes. That is why the diaphragm of the receiver bends more and then less, alternately.

To make a receiver diaphragm vibrate it isn't necessary, however,

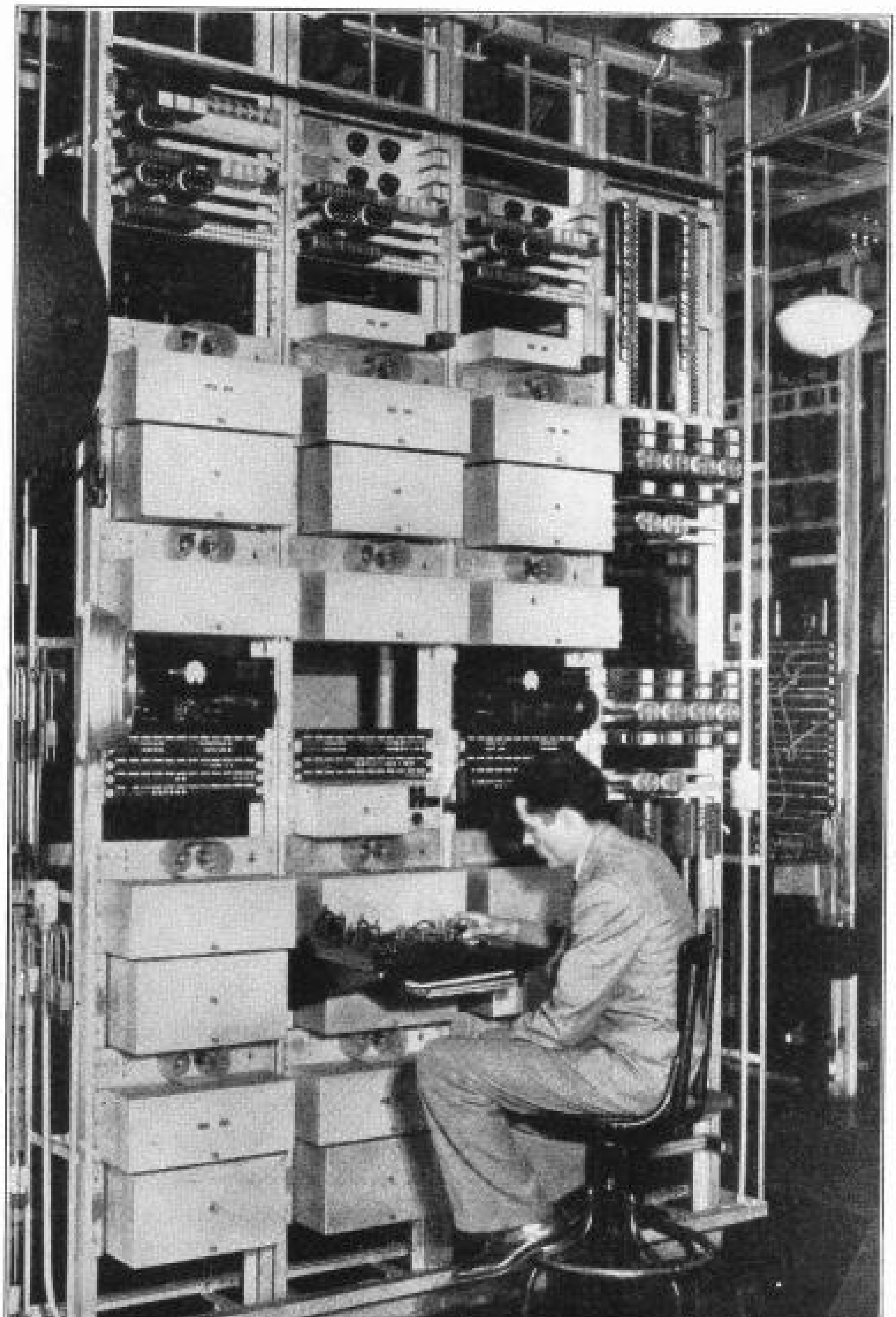


A repeater station where vacuum tube amplifiers are installed on long distance circuits to maintain volume and quality.

to have a varying procession of electrons. Electrons dancing back and forth in the coils will produce the same effect.

The Dance of the Electrons It is very easy to change into a to-and-fro dance from a procession of electrons which is alternately larger and smaller. All that is needed are two separate coils side by side or wound on the same iron core. If through one coil marches an irregular procession then in the other the electrons will dance, moving in one direction when the procession increases and in the opposite direction when it decreases. A double-wound coil like this is called a transformer.

In your telephone the procession of electrons through your transmit-



Interior of a telephone company repeater station where weakened currents are built up again and sent along to the next such station.

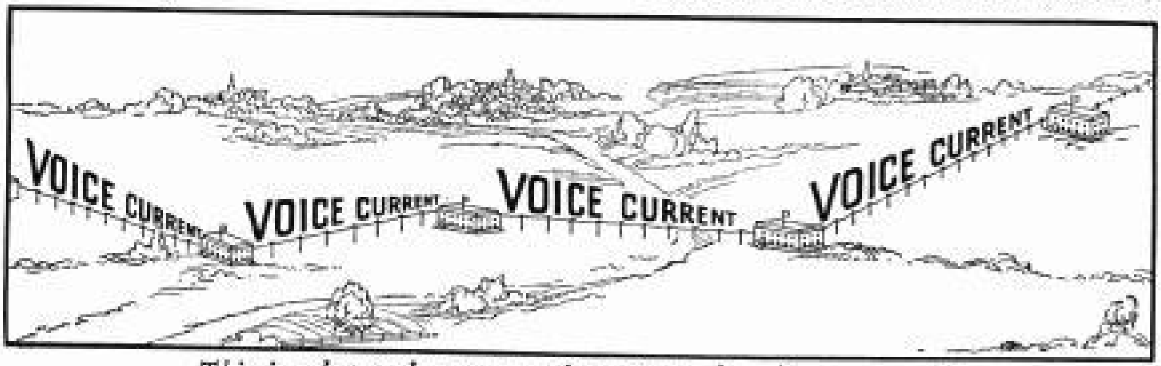
ter is changed into a dance by a transformer at the central office. Along the highways, speech is always carried by dancing instead of marching electrons. Dancing molecules of air and dancing electrons in wires transmit our speech. The telephone transmitter and the transformer are the magic which changes a dance of air molecules into one of electrons. And the receiver undoes this magic.

Along the wires which form a speech highway, the electrons pick up the step one from another, first those in the coil of the transformer and then those farther and farther away. Just an instant and all along the line the dance is on. Back and forth they go, once for every vibration of the transmitter diaphragm.

It is work to get electrons dancing even though they are so very tiny. And those nearer the beginning of the line must do the work of starting others farther away. The ability to do this work is used up along the line and there are fewer and fewer electrons engaged in the dance. If the line is very long there may be so few dancing at the distant end that the receiver diaphragm either will not respond or will reproduce the speech too feebly to be understood.

More Energy for Dancing Electrons Somewhere along the line, therefore, the electrons must be given more ability to do their work, more energy, as it is said. And that must be done without changing the step of the dance, because the speech is hidden in it and would lose naturalness or even sense. The device which can supply this energy is a repeater, for it starts electrons dancing anew but repeating old figures. It is connected at a repeater station to the end of one section of the speech highway and to the beginning of the next.

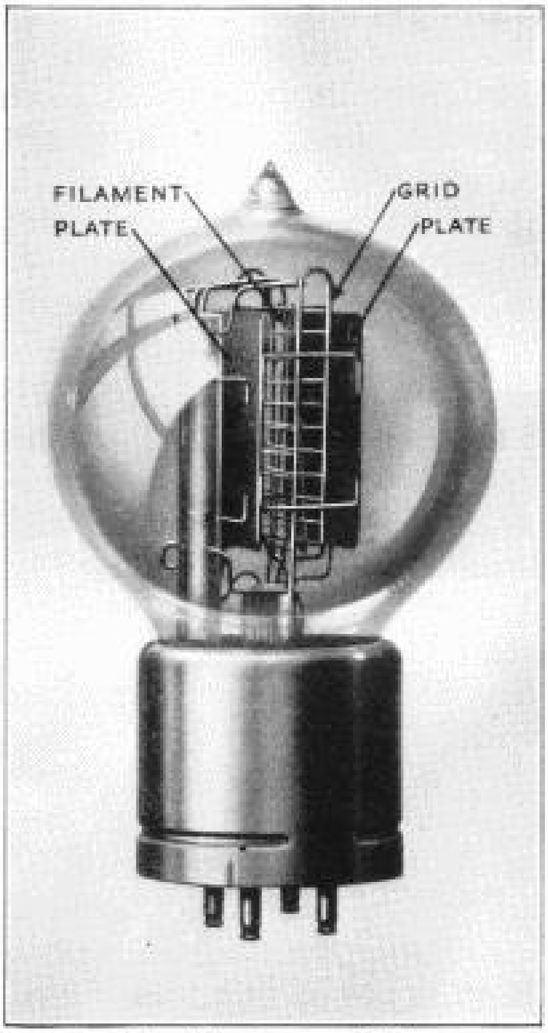
Between the transmitter and the



This is what each vacuum tube repeater does for your words.

receiver in a long distance telephone circuit there is a repeater which makes more electrons join the dance. These three instruments—transmitter, repeater, and receiver—are the most interesting devices in the story of electrical communication. But they are only a part of the very complicated arrangement of apparatus and lines which the telephone engineers have learned how to design and to operate. Of telephone repeaters several different kinds have been developed in the laboratories of the telephone company. The one now used is called a vacuum tube amplifier.

The Vacuum Tube It is a wonderful device in which a few dancing electrons can control a great procession of other electrons. There is a glass tube, like a lamp bulb, from which the air has been pumped as thoroughly as possible. Within it is a filament which is heated dull red by current from a battery. The heat drives some electrons out of the filament into the vacuum. Then there is a metal plate which is connected to another battery; and this battery forms the electrons into a procession which shoots through the vacuum between the filament and plate and then marches around one coil of a transformer. The other coil is connected to the beginning of the outward bound line. If the procession varies, a dance will



Amplifier Vacuum Tube.

be started along that highway. The energy for the procession, and hence for the dance, also, comes from the two batteries.

Between the plate and the filament is a wire grid which is connected to the incoming section of

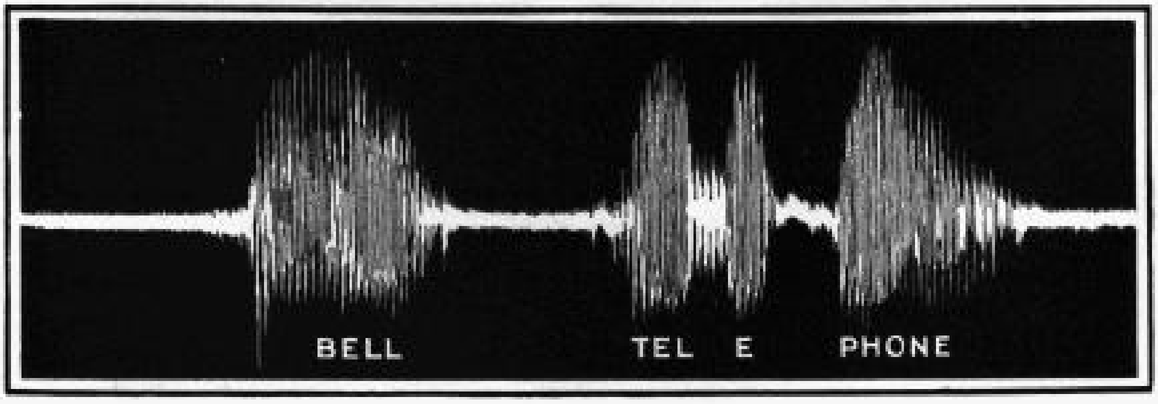
These Long Distance operators have scores of cities at their finger-tips and timing devices at each right hand which stamp the length of your conversation on the record of your call.

line. The electrons of this line dance in and out of the grid. They have an enormous effect on the procession, making it much smaller when they dance in and larger when they dance out. So the procession increases and decreases in number just as does the original procession through the transmitter, where the talking is being done. On the other side of the transformer, therefore, a new dance starts, just like the old but amplified, that is, increased in numbers.

Long Distance Repeater Stations A repeater of this kind, embodying two amplifiers, one of which repeats in one direction and the other in the opposite direction, is used at each repeater station. But just how they are connected to the line would require too long to explain.

Other Marvels of the Amplifiers These vacuum tube amplifiers which can repeat every step in a complicated dance of electrons, and are so necessary to long distance telephony, can perform other marvels. Suppose one is used at the end of a telephone line just before the receiver. It can set so many electrons dancing in the coils around the magnet that the receiver will talk very loudly. Wherever telephone loudspeakers are used, whether behind the curtains of a sound-picture theatre or in one's radio set at home, there are vacuum tube amplifiers.

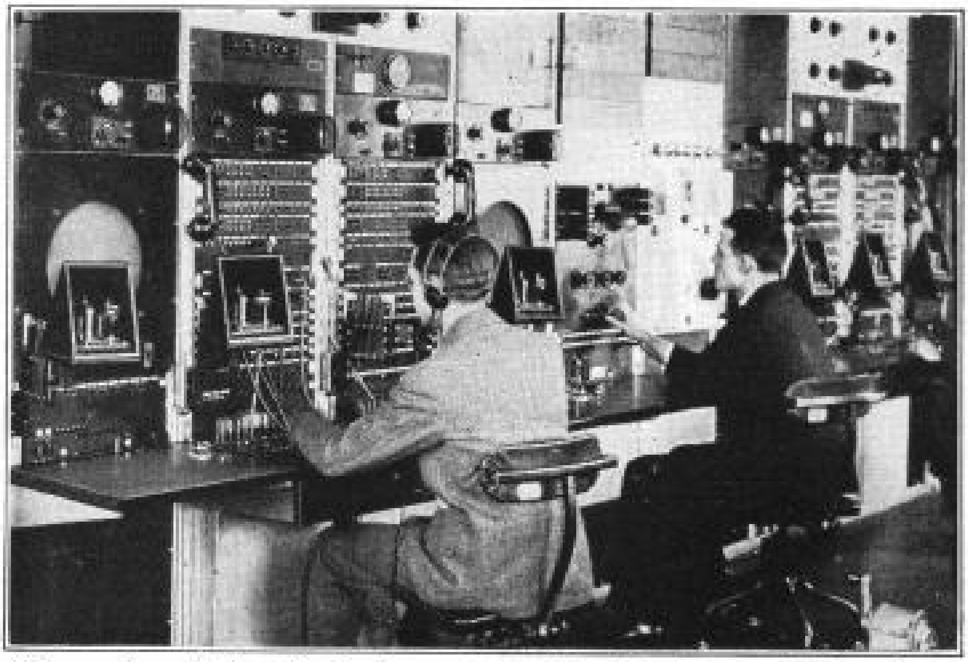
In the production of sound pictures, what the actors say is recorded while the motion picture camera photographs their action. A telephone transmitter, or microphone as it usually is called, picks up their speech and by its magic



This picture shows the variations in the current through a telephone transmitter when the words "Bell Telephone" are spoken into the transmitter.

turns the words into a dance of electrons. From the microphone wires lead through vacuum tube amplifiers to the apparatus where the record is made either on film or a phonograph disc. When later the record is played in a motion picture theatre a current is obtained which is just the same in its variation as the original current from the pick-up microphone. That current, after amplification by vacuum tubes, goes to the loud speakers; and through them the audience hears what the actors said when the picture was taken.

In radio telephony speech starts either from the transmitter of a telephone set or from the microphone in the studio of a broadcasting station. The current goes by telephone line to the radio station. If it is a broadcasting station the program which is radiated is received by radio sets in thousands of homes. Even though a radio set is all contained in a single cabinet it really consists of two parts. One part handles the radiation which is received and obtains from it a telephone current just like that which flowed from the microphone to the broadcasting station. This current has to travel only a few inches to reach the second part of the set, which consists of the loudspeaker and the necessary vacuum tube amplifiers.



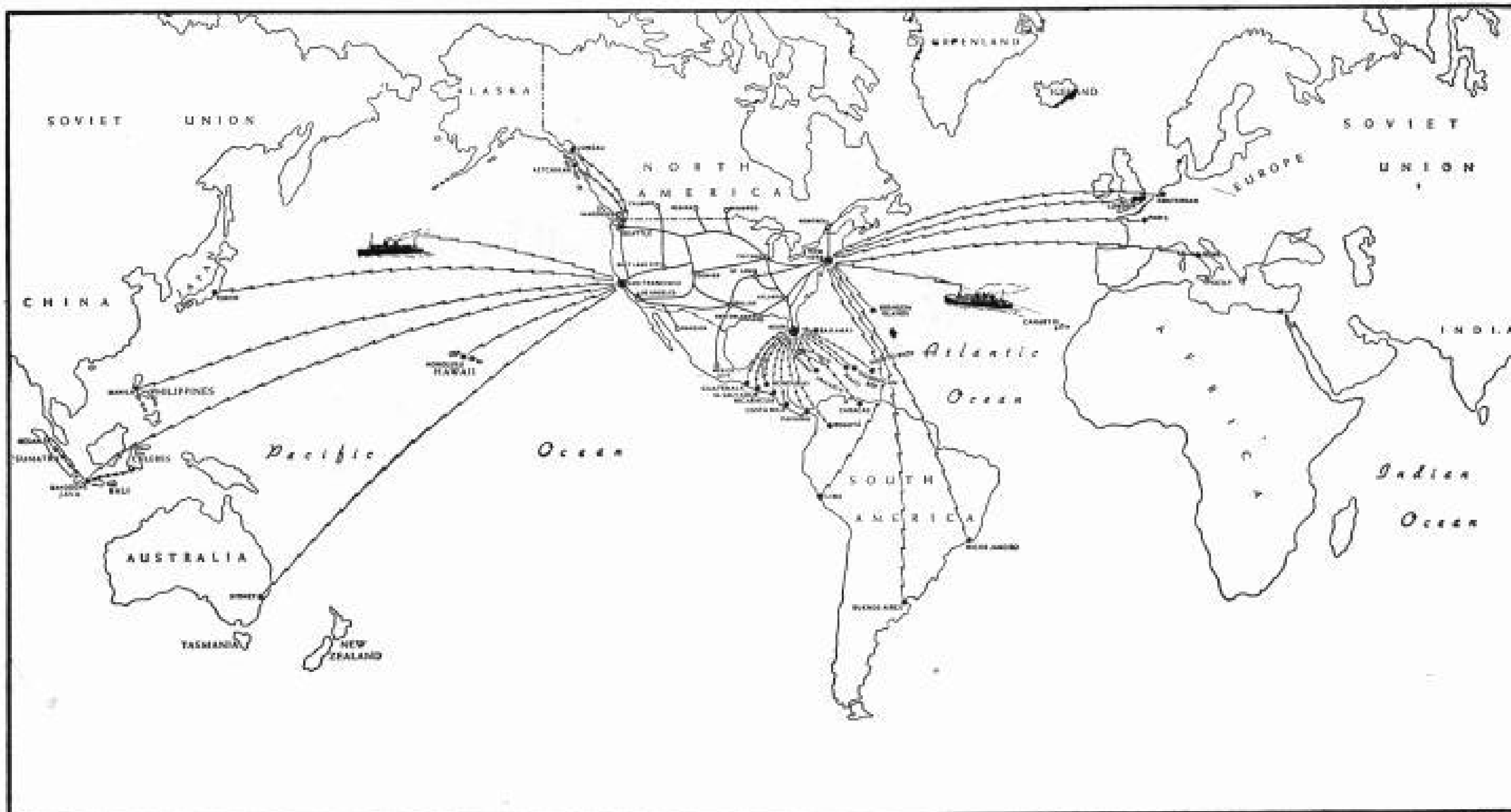
One section of the distributing center in New York for radio broadcast programs. Controlled and safeguarded by telephone engineers, the wire network transports programs to radio stations from coast to coast.

This radio telephone in the pilot house of a U. S. Coast Guard patrol boat permits voice communication with other similar boats or the shore.

Almost the same thing is true when the radio transmission is from some telephone set on land to a ship at sea. The current goes from the transmitter to the radio station. This station transmits by radio and on the ship is a receiving station. There the radio apparatus detects, in what it receives, the telephone current.

That current, with the speech it carries, is then sent along a short telephone line to the particular cabin or room where the other party to the conversation has his telephone.

Of course, whenever there is to be conversation by radio telephone there must be on each side of the gap, across which radio transmission takes place, both a radio transmitting station and a radio receiving station. Radio stations go in pairs, transmitting and receiving, just as do the transmitter and receiver of a telephone set. The map on the next page shows the routes over which radio telephone calls are sent by the American Telephone and Telegraph Company. When one telephones from America to Europe his speech goes by wire, via New York City, to a transmitting station on the Atlantic coast; then by radio to the coast station in England and on by



Overseas radio telephone connections extend the service of the Bell System (as of January 1, 1940) to more than 19,000,000 telephones in foreign countries, so that altogether 93% of the world's telephones can be reached from the telephone in your home.

wire via London. The return speech follows the reverse of this route.

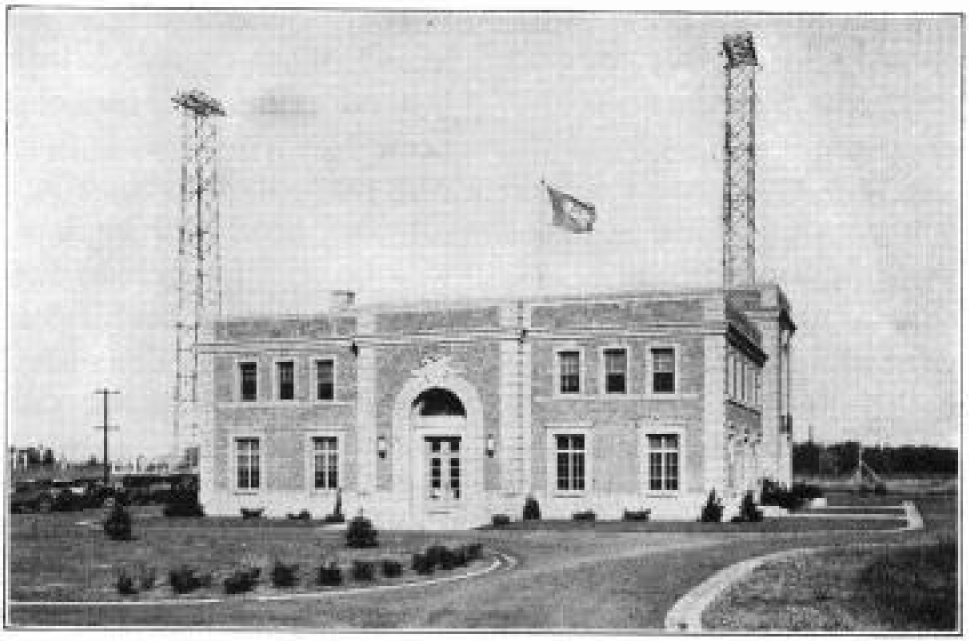
That is the route of the link which radio makes in transatlantic telephone circuits. But that doesn't explain what happens at a radio station.

Radio Telephone Transmission Radio transmission is easily understood if one remembers how the telephone operates. In an ordinary telephone transmitter there is a steady procession of electrons and the vibrating diaphragm alters this procession. In a radio transmitter the electrons are already dancing. Hundreds of thousands of times a second they rush up and down the antenna wires. Usually a vacuum tube is used to make them do so, but just how is another story. When the electrons from a speech highway come into the tube which is responsible for the dance in the antenna, they change the number of dancers.

You see there isn't so much difference in principle, after all. A procession is merely a group of dancers all of whom are marching along in the same direction. The diaphragm of a telephone transmitter varies the number of marching electrons. In a radio transmitter electrons are marching back and forth and through the antenna to which it is connected. The number of electrons engaged in this countermarching is much altered as electrons dance in and out from a speech highway.

Wherever there is a receiving

Foreign telephone directories are available for quick reference by the overseas operators at long-distance headquarters in New York.



Transoceanic radio telephone transmitting centre at Lawrenceville, N. J., with two of the line of tall antenna towers that stretch for more than a mile.

station electrons are set rushing back and forth in its antenna, keeping step with those in the large broadcasting antenna. In radio communication there are no highways with guiding wires to carry the message directly from sender to receiver. If the march in the large antenna varies, then in all the receiving antennas the tiny electrons will also change their march. A radio-receiving set detects these changes. When the most electrons are busy rushing up and down your antenna there will be the most electrons moving through the coils of the telephone receiver which is connected to your radio set. When there are fewer marching and countermarching in the antenna there will be fewer in the receiver. That is why the receiver diaphragm will be moved back and forth just as is the diaphragm of the distant transmitter. And that, of course, is why the receiver reproduces the speech or music which is being transmitted from some distant source.

Kilocycles and Kilowatts Summer, winter; summer, winter; over and over again, the seasons follow each other as if they swung around a circle passing through a "cycle" once a year. This word describes also the current in an antenna, for that current passes through a cycle of changes once for every time the electrons rush up and down.

In "cycles per second" we describe any alternating current. Household lighting current is sixty cycles per second. In the antenna current of a broadcasting station the alternations occur much more frequently, for example, five hundred thousand cycles per second for station WLW. Transoceanic stations use currents of still higher frequency. Instead of saying "thousands of cycles," engineers use the Greek word "kilo," meaning "thousand of," and say "kilocycles."

If the messages from different radio stations are not to interfere with each other at a receiving station, each transmitter must use a different frequency for its antenna current. That is why broadcasting stations operate on legally assigned frequencies ten kilocycles apart. A radio receiver tuned to the frequency of one station picks up very little, comparatively, from all the other stations which happen to be operating at the same time. Also picked up are the miscellaneous electrical disturbances, atmospheric or man-made, which are conveniently called "static." It is like listening to someone in a noisy place; unless he talks loudly, what he says is lost in the general noise and cannot be understood. And that is one reason why radio stations must be powerful and send out signals which will be so strong at a distant receiving set that they'll stand out clearly above all the interference.

Another reason, of course, is because radio stations waste their signals on places where there are no receiving sets, sending them out in every direction. That is necessarily so for broadcasting stations but not quite so true for transoceanic stations where there is a single fixed receiving station and the transmitter sends its energy principally in that general direction.

The power required to operate most important radio stations is measured in kilowatts; that is, in thousands of watts. In household lighting, lamps are used of 25, 40 or 60 watts; and twenty or so lights at a time take only a kilowatt of electrical power. In household radio sets the vacuum tubes use only a few watts apiece; but in large radio transmitters some of the more powerful tubes may use ten kilowatts or more; and the station may require several hundred kilowatts for its operation.

Radio and Wires Radio transmission is very convenient when a large number of widely scattered receivers are to be reached simultaneously as in broadcasting. Radio transmission is more than convenient, for it is necessary when the route over which communication is to take place is not such that wires or cables can be used to connect the transmitting and receiving stations. That is the case in communication to ships or to airplanes; and practically it is the case for most transoceanic communication.

Where wires can be strung between a radio transmitter and its receiver, antennas are not needed. The wires from the transmitter, instead of going one to the ground and the other to an antenna, can stretch out across the country and connect to the receiving set. If every so often along this line there are amplifiers, then the total of power needed at the transmitter and at the intervening amplifier stations can be less than would be required for good radio transmission over the same distance. Also, there will be less interference from "static."

Multi-Channel Telephony A pair of wires can be used to carry high-frequency current from a radio transmitter. But more important is the fact that a single pair can carry the different currents of a large number of different radio transmitters, all at the same time. In that regard wires serve just like the clear space through which radio makes its way; but they direct transmission very definitely from the transmitter to a particular receiver. If in one city there were a number of radio transmitters and in another city an equal number of receiving sets, all the transmissions could be over a single pair of wires between the two cities. Along the route, of course, there would be amplifiers just as on any other long line. Because of these amplifiers the transmitters themselves could be much less powerful. The transmitters, therefore, could also be smaller; and a large number of them could be grouped together in a space of a few cubic feet.

Because all this is so, "multi-channel" telephone systems are practicable; that is, systems in which a single pair of wires carries a number of different messages, each transmitted by a distinctive high-frequency current. In detail the equipment is quite different from that of a radio station—and its development was

Telephone engineers at the 240 circuit terminal of the experimental coaxial cable system.

practically independent of radio—but in principle and for the purposes of easy explanation the operations are as just described.

The accompanying illustration shows equipment for sending 240 different telephone messages simultaneously over a single pair of conductors. The picture shows one terminal of the experimental multi-channel system, using coaxial cable between New York and Philadelphia. Telephone lines from 240 persons can be connected, one each to the 240 different transmitters. The current output of all these transmitters can travel along the coaxial pair of conductors — one conductor, a tube; and the other, a wire at the center of the tube — to the other terminal. There 240 telephone lines can be connected, one each to the receivers, to carry the various messages to the proper subscribers. Similar equipment and another coaxial conductor carry conversation in the opposite direction.

A coaxial cable system somewhat similar to that pictured is being installed between Stevens Point, Wisconsin and Minneapolis. This multi-channel system, however, is capable of carrying 480 simultaneous telephone conversations. Each conversation requires about 10 watts of power at the terminals. Along the route about every five miles is an amplifier which can amplify, all at once, the 480 different currents in the coaxial cable. These amplifiers use only about 16 watts per mile of cable.

Four hundred and eighty conversations at a time is an extreme case; but in the wire plant of the Bell System there are many stretches where a single pair of conductors is carrying simultaneously two to twelve different conversations. The advantage is obvious. If twelve ordinary circuits are needed between two distant cities, and if they would cost more to build and to operate than would a single pair of wires with all the terminal and intermediate equipment to make it a twelve-channel system, then the multi-channel system is the economical one to use.

This same method of using alternating currents of distinctive frequencies to carry telephone messages is also applied to telegraph messages, whether sent by key and received on a sounder or printed by teletypewriters. Twelve teletype messages can be sent simultaneously over a single pair of wires, or, in fact, over any transmitting system which will carry a telephone message. Sometimes, therefore, a single line in the telephone plant will be carrying not only a number of telephone messages, but as many or more teletype messages. Sometimes the line may also be carrying current from a picture-transmitting apparatus. And some of the lines with their terminal apparatus, when need arises, will be capable of carrying television currents from a television transmitter to distant radio stations for broadcasting to nearby observers.

Scientific Achievement and the Telephone

When Alexander Graham Bell invented the telephone it was no accidental discovery, although the invention was so novel that there were no suitable words to describe it and it was listed for patent as "an improvement in telegraphy." How did this invention come about? And what peculiar qualities of Bell himself made it possible?

In the first place, Bell was a student of phonetics, the science of the sounds of speech. His father had been one before him; and Alexander as a boy had excellent training which developed his ability to study and to analyze physical problems for himself. His interest in speech carried him into the study of acoustics, the science of vibrating bodies, sound, and its transmission by dancing molecules.

The science of electricity was then in its infancy and Bell pursued its study also with a freshness of mind and a zeal which were well rewarded.

So much for his training. It was broad and fundamental to the work in which he was interested. And what was that work? Scientific research in the communication of speech, and inventions which would be of service to his fellow men. He was applying his knowledge to the relief of deaf-mutes, teaching them how to use their mouths to utter speech sounds, when the idea of a musical telegraph and then of the telephone came to him. The idea was the thought of a genius and to it he brought the highest type of inventive instinct and a dogged persistence.

Looking back over his life, which illustrated these qualities consistently, it no longer is a wonder that he invented the telephone. The wonder would be if he had not done so, because fundamental training, the desire to be of service, a creative instinct, and untiring persistence are the qualities which will always make the wonderful advances in science and engineering.

Development and Research The study of human speech led Bell's genius to the invention of the telephone. This study has been kept up by the Bell System in its research and development laborato-

Bell Telephone Laboratories.

ries. And with speech there has been investigated the related subject of human hearing, because the fullest knowledge of both is fundamental to the electrical art of speech communication.

The qualities of human speech which make it what it is, the complex sound of the most flexible musical instrument, are being determined by ingenious experiments with precise apparatus. The sensitiveness of the human ear to sounds has been determined by careful study. In these laboratories hundreds of scientists are engaged in researches and special investigations. Some are busy with speech and hearing and others with methods of electrical transmission. Many invent and design new forms of equipment or entirely new systems of communication. Some are engaged in studying electrons and their interesting behavior, for a knowledge of electrons is fundamental to telephony. They are adding to the world's fund of knowledge in the new science of electronic physics. During such researches important discoveries and inventions arise.

Today every science that can contribute to the electrical art of communication is constantly being studied by these experts; and their investigations are enriching the sciences. And in all these researches and developments and inventions there is the spirit of Alexander Graham Bell, working for the advancement of science and the creation of new instruments for the service of mankind.

A TELEPHONE CHRONOLOGY

1876 First telephone patent issued to Alexander Graham Bell.
First complete sentence transmitted by telephone.
First two-way telephone transmission over an outdoor line, two miles, Boston to Cambridgeport.

1880 47,900 telephones in the United States, all Bell owned.

1881 Conversation by overhead line, 45 miles—Boston to Providence.
Conversation by underground cable, ¼ mile.

1884 Conversation by overhead line (hard-drawn copper), 235 miles—Boston to New York.

1890 227,900 telephones, all Bell owned.

1892 Conversation by overhead line, 900 miles—New York to Chicago.

1900 855,900 telephones owned by or connecting with Bell System.

1902 First conversation by long-distance underground cable—New York to Newark.

1906 Conversation by underground cable, 90 miles—New York to Philadelphia.

1910 5,883,000 telephones owned by or connecting with the Bell System.

1911 Conversation by overhead line, 2,100 miles—New York to Denver.

1913 Conversation by overhead line, 2,600 miles—New York to Salt Lake City.
Conversation by underground cable, 455 miles—Boston to Washington.

1915 First conversation by transcontinental line, 3,650 miles—Boston to San Francisco.
Speech transmitted for the first time by radio telephone from Arlington, Va., across the continent to San Francisco, to Hawaii, and across the Atlantic to Paris.

1920 12,602,000 telephones owned by or connecting with Bell System.

1921 Conversation by deep sea cable, 115 miles—Key West, Fla., to Havana, Cuba.
First conversation between Havana and Catalina Island by submarine cable, overhead and underground lines and radio telephone—distance 5,500 miles.
Extension of Boston-Philadelphia cable to Pittsburgh—total distance 621 miles.

1922 Ship-to-shore conversation by wire and wireless between Bell telephones in homes and offices and the *S. S. America* 400 miles at sea in the Atlantic.

1923 Successful demonstration of transoceanic radio telephony from a Bell telephone in New York City to a group of scientists and journalists in New Southgate, England.
First broadcasting of a presidential message to Congress.
Completion of Southern transcontinental line.

1924 First public demonstration of picture transmission over telephone circuits—New York and Cleveland.

1925 New York-Chicago Telephone Cable completed—overhead—underground.
16,720,000 telephones interconnected in the United States.

1926 Successful test of two-way transatlantic radio telephony.
New York-Chicago, all-cable telephone line extended to St. Louis.

1927 Transoceanic telephone service inaugurated between New York and London.
Northern transcontinental telephone line formally opened.
First public demonstration of television by wire and radio.
Telephone service opened between the United States and Mexico.

1928 Transoceanic telephone service extended to principal countries of Western Europe.

1929 Ship-to-shore telephone service established.

1930 Transoceanic telephone service opened to South America and Australia.
Two-way television demonstrated by Bell System engineers.
20,098,000 telephones interconnected in the United States.

1931 Teletypewriter exchange service inaugurated.
Fourth telephone cable to Cuba opened.
Transoceanic service extended to Java, Sumatra, Bermuda, Hawaii, Canary Islands.

1932 Transoceanic service extended to South Africa, Egypt, Siam and the Bahamas.

1933 A telephonic system for high quality transmission and reproduction of orchestral music demonstrated by Bell System engineers.
Transoceanic service extended to the Philippines, Canal Zone, and Central American countries and to Palestine, and India in Asia.

1934 Transoceanic service extended to Japan.

1935 First telephone conversation around the world.

1937 Transoceanic service extended to China, Bulgaria, Alaska, Haiti and Iraq.
93% of world's telephones within reach of any Bell System telephone.

1938 Direct radio telephone circuit established between San Francisco and Australia.

Printed in U. S. A.
1-1-40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