The Edison Effect and its Modern Applications

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WE are so accustomed to thinking of Thomas A. Edison as the father of the incandescent lamp and of the electric lighting industry that we sometimes forget that his first achievements were in the field of the electrical communication of intelligence, and that in this field he is no less distinguished. To say nothing of his inventions in multiplex and automatic telegraphy, it is well to recall that the field of telephony owes no less to the fundamental inventions of Mr. Edison than to those of Alexander Graham Bell. Bell, it is true, invented the telephone receiver of today, but Edison invented the transmitter, and afterwards invented a highly efficient receiver on a principle entirely different from that of Dr. Bell's.

The art of the mechanical reproduction of sounds is based on a fundamental discovery which, to the writer's mind at least, exemplifies the scientific insight and intellectual audacity of Mr. Edison far more brilliantly than anything that he has done in the lighting field. It may be said that a trained physicist would scarcely have been tempted to waste his time in making an experiment so foredoomed to failure as that which Mr. Edison tried and from which the phonograph and the whole phonograph industry as it exists today resulted. Mr. Edison had through his long experimentation a better conception than the physicists of the character and magnitude of the forces brought into play when sound waves set a diaphragm in vibration, and hence his phonograph experimentation was not a piece of foolishness or a piece of luck but the result of reasoned analysis of facts which Mr. Edison himself had gathered through his previous work.

Quite comparable in importance with the above is the moving picture which has given rise to an industry of enormous financial and sociological importance and of which also Mr. Edison was the progenitor.

Thus, without considering his manifold other activities, such as his pioneer work on electric railways, his ore milling processes, his alkaline storage battery, his improvements in cement manufacture, etc., we have a picture of his paternal relationship to three great industries other than electric lighting; namely, those having to do with the transmission of speech, the reproduction of speech and the pictorial reproduction of objects in motion.

By some professional physicists and by certain others, Mr. Edison has been reproached as being a pure empiricist. He has been considered to have tried everything, possible and impossible, and as a result of countless experiments made by the hands of many able assistants, to have stumbled upon a number of important discoveries, which with a keen commercial instinct he has exploited to the limit. To those who are familiar with Mr. Edison's powers of insight and deduction this charge needs no refutation, but it is interesting in this connection to recall a discovery of his which has been acknowledged by the physicists as a discovery appertaining to the field of pure physics. This is the phenomenon which has long gone by the name of the "Edison Effect." The discovery of this effect came as a by-product of Mr. Edison's work in investigating the peculiarities and behavior of the incandescent lamp, which had led him into the study of the physical and chemical actions which take place in highly evacuated glass bulbs containing a glowing filament. That it was a by-product of this other work no more detracts from the value or merit of the scientific discovery than does the fact that Roentgen's discovery of X-rays was incidental to other experimental work which he was doing.

By an "effect" physicists have long designated phenomena or groups of phenomena which are new in themselves and which fail to arrange themselves into any given theoretical classification or to admit of an explanation under existing theories. Thus we have in physics a large number of effects (to which have been given the names of their discoverers, all of whom have been distinguished in the field of pure science), such as for instance, the Peltier effect, having to do with the absorption and evolution of heat at the junction of two metals carrying a current; the Thomson effect, having to do with thermoelectric currents in a given metal; the Hall effect, having to do with the deviation of currents in a thin film under the influence of a powerful magnetic field; the Purkinje effect, having to do with the variation of sensibility of the eye for the red and the blue ends of the spectrum with high and low illumination; the Zeeman effect, having to do with the displacement of spectral lines when a radiating gas is submitted to a powerful magnetic field, etc. Of all these effects none has been so prolific in practical consequences as the Edison effect.

The earliest carbon incandescent lamps as well as all of their successors have been subject to discoloration or blackening of the bulb by an opaque deposit thereon. This bulb blackening was very naturally a challenge to Mr. Edison. In the course of his investigations of it, he noticed that frequently there was on the bulb in the plane of the filament, a line which was not blackened, something which looked like a shadow of one leg of the filament. Furthermore he found that the leg which cast the shadow was always the one connected with the positive side of the circuit. It appeared as if the negative leg of the filament were throwing off minute carbon particles which traveled past the positive leg and deposited themselves on the glass everywhere excepting directly in the line of or behind the positive leg. In further investigation

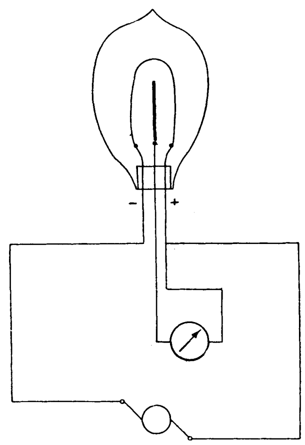
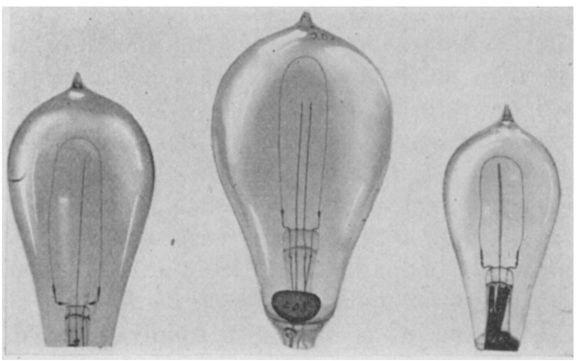


Fig. 1—Circuit for Demonstrating Edison Effect

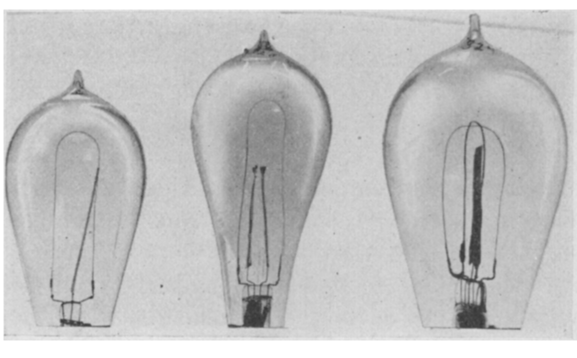
of this phenomenon he made lamps with wires and with plates set up between the two legs of the filament with wires brought out from them to permit



16-c. p. 110-volt, bamboo filament with single wire. 1884.

Replica of double-wire lamp. 1904.

10-c. p. filament with single plate of platinum foil. 1884.



16-c. p. filament with single plate of platinum foil. 1884.

16-c. p. filament with two plates of platinum foil. 1884.

Two bamboo filaments crossed with single plate platinum foil at center. 1884.

Fig. 2—Edison Effect Lamps

the determination of their electrical condition. With arrangements of this kind he found that when he connected such a plate or wire through a galvanometer to the positive leg of the filament, as shown in Fig. 1, a current passed through vacuum or rarified atmosphere of the lamp and affected the galvanometer. If the terminal were connected to the negative leg of the filament, no such current passed. This is the Edison effect discovered by him in 1883. Some of the original lamps which were the subjects of Mr. Edison's investigation are shown in Fig. 2.

The effect was described as follows in a patent specification filed by Mr. Edison on November 15th, 1883.

> I have discovered that if a conducting substance is interposed anywhere in the vacuous space within the globe of an incandescent electric lamp, and said conducting substance is connected outside of the lamp with one terminal, preferably the positive one, of the incandescent conductor, a portion of the current will, when the lamp is in operation, pass through the shunt circuit thus formed, which shunt includes a portion of the vacuous space within the lamp. This current I have found to be proportional to the degree of incandescence of the conductor or candle power of the lamp.

In response to an inquiry as to the line of experimentation on which he was engaged in 1883 when he discovered the Edison effect, and the line of reasoning which led to the experiments in which he inserted dead electrodes of wires and plates in the lamps, Mr. Edison prepared a written statement under date of September 2nd, 1921 for use in connection with this paper. He states:

> As to the "Edison Effect" let me say that I was investigating to find the reason why such black shadows were cast by the filament. This led to the experiment.
>
> My theory was that the residual gas coming in contact with the filament, and part of the filament itself, became charged and were attracted by the glass and discharged themselves. As the polarity was unchanged I thought this should give a constant current. The extra pole was put inside afterward to increase the current, as my first experiment was with only a piece of tin-foil pasted on the outside of the bulb. This gave a good deflection on the galvanometer. In fact the needle went off the scale.
>
> On putting wires and plates on the inside of the bulb the effect was greatly increased, so much so that at the Philadelphia Exposition I put a telegraph sounder in the circuit and it worked well.
>
> As I was overworked at the time in connection with the introduction of my electric light system I did not have time to continue the experiment.

The name "Edison effect" seems first to have been given to it by William (afterwards Sir William) Preece. After having been shown the effect by Mr. Edison, he investigated it further in some lamps which Mr. Edison had given him and reported the matter in 1884 to the Royal Society of London. He spoke of it at that time as a matter on which Mr. Edison was still working.

The effect was investigated later at some length by Prof. J. A. Fleming who introduced metallic shields around the filament at various places and showed conclusively that the effect was due to projected particles negatively charged quite in accordance with Mr. Edison's earlier belief. The nature of these particles, now known as electrons, was, however, not understood until modern theories of the conduction of electricity by gases had been developed.

Afterwards Richardson investigated the law of the emission of these electrons from a hot filament and formulated the law according to which it occurs. The final development of the theory has been due to Langmuir, who showed the influence of the "space charge effect."

It is supposed that in the interior of a metallic conductor free electrons exist and that it is the motion of these electrons which constitutes the conduction of current. The electrons are held within the surface of the conductor by some kind of a force which is stronger in some substances than in others. The activity of the electrons is increased by an increase in the temperature of the conductor, so that in a hot conductor there is an occasional very fast moving electron which breaks through the surface and escapes from the conductor as a minute free charge of negative electricity.[1]

If now, no means are employed to carry away the free electrons from the vicinity of the surface of the heated conductor, the repulsive effect of the charge in the vicinity of the conductor retards the emergence of further electrons. Furthermore some of the electrons remaining close to the heated filament are caught within its sphere of influence and return to it. When the rate of return of electrons to the filament is equal to the rate of emission of electrons from the filament, a condition of saturation is reached. If the electrons are drawn away from the surface, other electrons will escape continuously and a current of electricity is set up—a true convection current. In the Edison effect the electrons are so removed by the electrostatic attraction of the positive leg of the filament. Thus there is a current, called a thermionic current, passing from leg to leg of the filament through the vacuous space. The plate inserted between the legs of the filament enables this current to be detected, for the electrons which strike the plate give up their charge to it, so that if the plate is connected by a wire to the positive leg of the filament, a current will flow from the positive leg to the negatively charged plate. Evidently no such current would result from a connection to the negative leg.

The emission of electrons from a conductor under the influence of heat is called thermo-ionization, and the currents so produced are referred to as thermionic currents.

In the foregoing it has been assumed that there are no gas molecules in the evacuated space which can interfere with the electrons emitted by the heated filament. If such gas molecules are present, as they are in what is ordinarily called a high vacuum, the electrons will from time to time collide with such gas molecules and will, if the electrostatic attraction on them has been great enough to impart to them a sufficient speed, strike them hard enough to knock off an electron or two from the molecules collided with. These electrons so set free from the gas molecules, behave like the electrons liberated from the filament, and under favorable circumstances may be much more numerous than the original electrons emitted by the filament itself. The residual gas molecules which, having been deprived of part of their negative electricity, are now positively charged, become gas ions and tend sluggishly to carry a current in the reverse direction.

For a long time it was a debatable question whether the thermionic currents were possible in the absence of all gas from the surroundings of the heated conductor, or whether the currents must not be ascribed to the residual gas present in the bulb. This question was finally answered by Langmuir who evacuated bulbs to a degree unknown before, by absorbing the residual gases in charcoal at the temperature of liquid air. Langmuir showed that the Edison effect occurred in such an ultra-vacuum, but that the amount of current which could be taken from an Edison effect bulb depended very greatly on the speed with which the electrons emitted were continuously swept away under the influence of electrostatic force.

The whole thing is a good deal like ordinary evaporation. We know that from the surface of water, vapor is continually passing off and that the rate of emission of vapor depends upon the temperature of the water. We know that if the water is totally enclosed, the space within becomes saturated with water vapor, so that no more is given off from the surface unless the temperature is raised. If, however, the surface is opened to the air, and the air is caused to pass over it rapidly, as by the use of a fan, the evaporation goes on at a certain definite maximum speed dependent upon the temperature. Furthermore, we know that different liquids evaporate at different rates. So with thermionic currents, the rate of emission of electrons depends upon the temperature, and depends upon the rapidity with which the free electrons are moved out of the way so that they will not impede those which follow them. The movement is caused by an electrostatic field due to a voltage influence between the filament and the plate to which the electrons are attracted. With a given filament temperature the current increases with increases in the electrostatic field until the point is reached at which the filament can produce no more electrons at that temperature, no matter how strong the electrostatic field is, and the current remains constant even though the electrostatic field is increased. Conversely, with a given electrostatic field, the current increases with the filament temperature until so many

1. It had been known before Edison's discovery that certain substances when heated would impart an electric charge to a nearby insulated conductor, and this matter had been studied at great length by Elster and Geitel, who however, did not extend their researches to the phenomena in evacuated bulbs until something like five years after Mr. Edison's discovery.

electrons are given off that the field is incapable of handling them, and a condition of saturation ensues in the space surrounding the filament, so that the current remains constant with increase in filament temperature. If the voltage applied to the plate, however, is increased, the thermionic current takes on a higher value.

In analogy with the evaporation of liquids we find also that different materials differ in their thermionic emission at given temperatures.

The pure metals at a given temperature are far less efficient in emitting electrons than are the oxides of the alkaline metals such as oxides of barium and strontium which Wehnelt showed to have far greater electron emissive power than any of the pure metals, or than carbon.

Few laboratory experiments have had greater and altogether unexpected practical consequences than those of Mr. Edison in 1883. In what follows an attempt is made, through the citation of certain specific examples, to give a picture of some of the developments and present-day applications of the Edison effect. In so doing an explicit disclaimer is made of any intention to attempt to write a treatise on the subject or to make the picture complete. It is hoped, however, that the account given is accurate as far as it goes.

Mr. Edison applied in 1883 for a patent on an electric indicator employing an Edison effect lamp. This indicator was not a practical success because of its inconstancy, which again no doubt was due to the instability of the vacuum conditions in carbon filament lamp bulbs. No practical application was made of the Edison effect until Fleming took advantage of the property of Edison effect lamps of conducting current in one direction while suppressing it in the other; that is, what is known as the rectifying effect, and applied such lamps to the reception of signals in wireless telegraphy. Fleming's work in wireless telegraphy brought him in contact with the fact that the coherer, which was the wireless detector of those days, owed its effectiveness to a similar rectifying or valve action, and so he applied the lamp instead of the coherer to a wireless receiving circuit. As a wireless receiver the lamp was, however, not particularly effective.

It remained for DeForest to make the great step in advance by introducing into the lamp between the plate and the filament a little grid or sieve through which the electrons must pass to the plate, and which could be given an electrostatic charge whereby the rate of passage of the electrons could be controlled. To this device he gave the name of "audion," and to the audion and its related devices under other names, such as the "pliotron," all of which however depend upon the Edison effect, are due the greatest advances in the art of the electrical communication of intelligence at the present time. Capable as it is of operating as a detector or receiver of signals, as an amplifier and as a producer of alternating currents of any frequency, it is a most versatile apparatus.

To understand the action of the three-electrode thermionic tube or audion, consider an evacuated bulb containing a filament heated to incandescence and emitting electrons, and facing the filament a plate which is maintained by a battery at a potential higher than that of the filament. Then the positively charged plate attracts to itself the elementary negative charges of electricity which we call electrons, and a thermionic current is set up which may be detected by a galvanometer in series with the battery. Any acceleration of the velocity of the electron stream increases the current, and vice versa, any slowing down of the rate of flow of electrons decreases the current. Now let us put in the midst of this stream between the filament and the plate a fine wire metallic grid through which under ordinary conditions practically all the electrons pass without interference, and let us by means of a battery or otherwise bring this grid to a negative potential with respect to the filament. The negatively charged

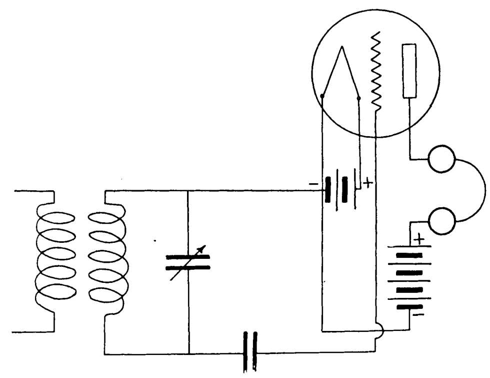


FIG. 3—DETECTOR CIRCUIT FOR WIRELESS

grid will repell the oncoming electrons, preventing their free passage, slowing down the stream and diminishing the current. A positive charge on the grid will have the opposite effect; that is, it will cause the current to increase. The charge on the grid required in either case may represent an exceedingly small amount of energy. The thermionic current, however, represents considerable energy, so that we have here a device in which a very small amount of energy controls the rate of expenditure of a very much larger amount.

The method of use of the device in the reception of wireless messages is illustrated in Fig. 3. Here we see that the antenna connections are brought through a primary of an air-core transformer. The secondary of this transformer has in parallel with it an adjustable condenser which is brought to such a capacity that the natural period of oscillation of the circuit is the same as the frequency of the incoming waves. Hereby through the principle of resonance, the maximum voltages are produced. One side of this resonating circuit is connected to the filament of the receiving tube, which filament is brought to incandescence by a few cells of battery. The other side of the circuit is connected through a small condenser to the grid. The plate is connected to the positive terminal of a battery, which through the receiving telephones is joined to the filament. Without going into details as to the mechanism of reception, it is sufficient to say that the incoming

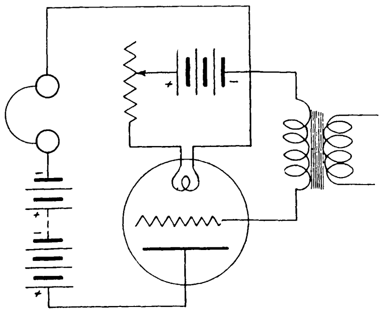


FIG. 4—AMPLIFYING CIRCUIT FOR WIRELESS

wave trains acting through the condenser on the grid cause the grid to acquire a negative potential and hence cause a diminution of the battery current passing from the filament through the telephone to the plate, so that for each set of incoming wave impulses, which themselves would be inaudible in a telephone, a signal is heard. The energy represented by the incoming wave train is extremely minute, but as noted above, it alters the flow of energy represented by the plate current and so produces a relatively large effect. This is the three-electrode tube used as a receiver or detector of wireless signals sent out by damped or non sustained oscillations such as are produced by a spark transmitter.

Now if instead of the telephone, the primary of a small step-up transformer is connected directly in the plate circuit, with the secondary of this transformer connected between the grid and the filament of another three-electrode tube, Fig. 4, the signals cause variations in the potential of the grid of the second tube, and these produce larger changes in the plate current of the second tube, so that with the telephone connected in the plate circuit of the second tube, the strength of the signals is greatly increased. This typifies the three-electrode tube used as an amplifier.

The three-electrode tube may be used also as an alternating-current generator for the production of sustained or nondamped waves of all frequencies from one cycle in several seconds to millions of cycles per second. To do this, advantage is taken of the amplifying property of the tube. As has been said, a small amount of energy applied to the grid is able to control a much larger flow of energy in the plate circuit. If some kind of coupling, as by inductance coils or condensers, is made between the grid and the plate circuit, so that some of the energy originating in the plate battery is transferred to the grid in such a way that any oscillation in the grid circuit is helped on and maintained by the more powerful oscillations produced thereby in the plate circuit, the tube can be made to operate as a generator.

A simple form of generator circuit is illustrated in the so-called "feed-back" circuit shown in Fig. 5. It will be seen that this differs from the circuit shown in Fig. 3, in which the tube is used as a detector, only in that a coil in the plate circuit is coupled inductively with the coil of the oscillating circuit to which the grid is connected. If an oscillation is started in the grid circuit, similar and stronger oscillations are produced in the plate circuit. Through the inductive coupling these plate current oscillations reinforce the grid voltage oscillations which govern and control them and through this interaction the process goes on continuously, the source of energy being the plate battery. The frequency of the oscillations depends upon the inductance, capacity and resistance in the circuits, but chiefly on the inductance and capacity in the resonant circuit to which the grid is connected. Many other forms of generator circuits involving different connections of inductances, capacitances and resistances are possible.

One interesting application of the feed-back circuit is in the reception of signals sent out by means of sustained waves. Such waves are generated either by a high-frequency alternator or by a Poulsen arc generator or by three-electrode tubes used as generators. The frequency of such waves is so high that they are inaudible in the telephone and recourse is had to so-called heterodyne reception. The principle of heterodyne reception is as follows: Suppose the sending station is using alternating current of a frequency of 100,000 cycles per second; this gives a wave length of 3000

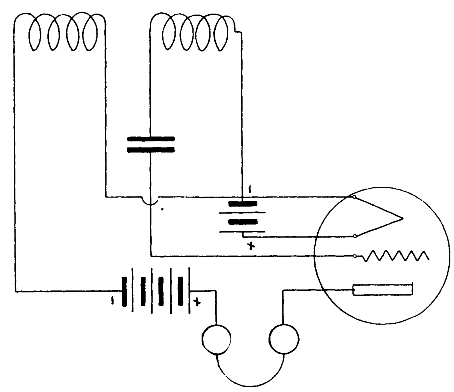


FIG. 5—FEEDBACK CIRCUIT FOR WIRELESS

meters. The receiving circuit is tuned to this frequency, but the ear hears nothing. Now, suppose we introduce into the telephone circuit a locally generated alternating current of a frequency of 99,000 cycles per second. The telephone diaphragm will be acted upon by both frequencies and will vibrate strongly when the two currents are in phase with each other and feebly when they are in opposition to each other. These alternations in phase will occur at a rate equal to the difference in frequency of the two currents, giving rise to the phenomenon of beats. In the case considered, the beat frequency will be 1000 cycles per second, a frequency which gives good audibility. When the sending current is interrupted, the beats no longer occur and the sound disappears. Now, the tube with the feed-back circuit may be used in heterodyne reception, because the tube itself will generate the required local alternating current.

Wireless telephony may be considered to be built up on the basis of the three-electrode tube used in its various capacities. A high-frequency alternating current is produced by a tube used as a generator. The grid is acted upon by the output current of a tube called the modulator tube, the input of which is controlled by a telephone transmitter. Thus the high-frequency currents are varied in amplitude in accordance with the variations in the telephonic transmitter current. The high-frequency currents thus sent out are received by the detector tube at the distant station, and after suitable amplification by tubes used as amplifiers, reproduce the original sound in the telephone receiver. In "wired wireless" the stations are connected by a wire which guides the waves in the ether directly from one station to another with a great gain in efficiency of transmission.

In the foregoing we have considered tubes in which the electron flow from cathode to anode is controlled by electrostatic action. Very recently Hull of the General Electric Research Laboratory has described a tube in which magnetic instead of electrostatic force is used, and to which the name "magnetron" has been applied. In these tubes the anode and the cathode are concentric one with another, and the tube is surrounded by a longitudinal helix of wire through which a current may be passed.

To understand the operation of this device, suppose that the hot filament is in the axis of the tube, and the anode, in the form of a wire cylinder is near the walls of the tube. A battery connects the two, raising the anode to a high positive potential. When the filament is heated, electrons will flow radially from the filament to the anode. Now, if a current is passed through the external helix, magnetic lines of force will pass through the tube parallel with the axis. Under the influence of these magnetic lines, the electrons will be deflected from their radial motion, and if the magnetic field is sufficiently powerful, the electron paths will be curved to such an extent that the electrons never reach the anode, but return to the vicinity of the cathode. When this happens, the flow of current through the device ceases. The effect is very abrupt, for until this critical value of the magnetic field has been reached, all the electrons while pursuing a curvilinear path, reach the anode eventually and the thermionic current has its full strength. When the critical field value has been passed, none of them get through.

Hull points out the possible use of the magnetrons not only as amplifiers and generators in wireless, but also in heavier engineering. He sees an application of them in the protection of machines from surges and from lightning.

Three-electrode tubes, being capable of use in such

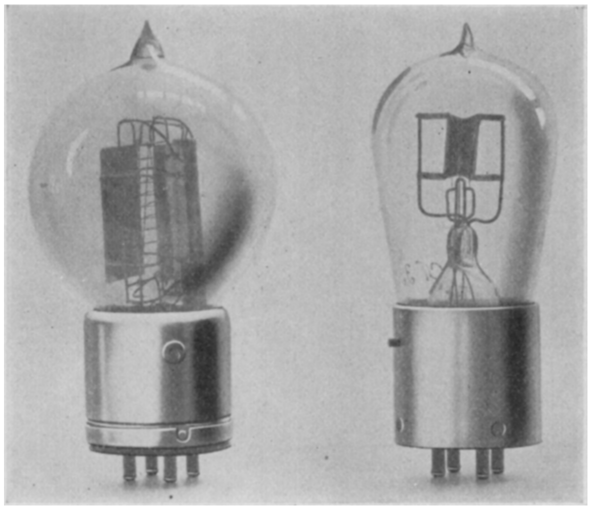


FIG. 6—WESTERN ELECTRIC AND GENERAL ELECTRIC TUBES

different capacities, naturally differ in form and size in accordance with the use for which they are intended. They differ also in the degree of vacuum maintained within, the original ultra-high vacuum tube being the "pliotron". Moreover they are divided into two classifications in accordance with the character of the filament which produces the thermionic currents, which are

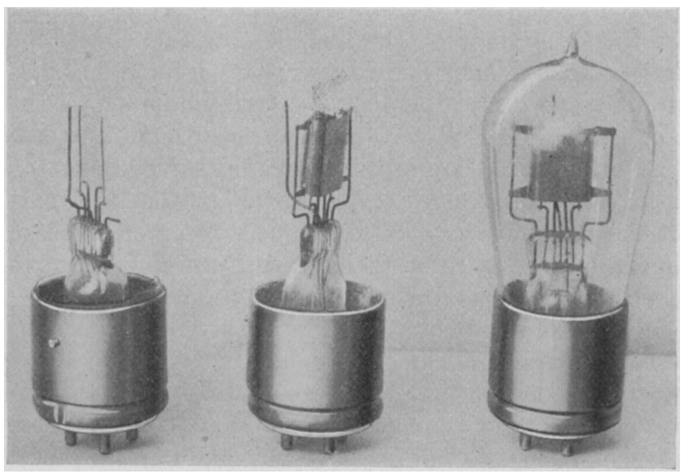


FIG. 7—PLIOTRON DETECTOR

either of tungsten or of platinum coated with metallic oxides. As has been noted above, the latter type gives off electrons very freely at relatively low temperatures.

Fig. 6 shows side by side an example of each of these types of tubes. The tube in the round bulb is a high-vacuum tube, having a platinum filament coated with rare earth oxides. This general type of tube is widely used in telephone work as an amplifier. The tube with the straight sided bulb is a high-vacuum, tungsten-filament pliotron. Each of these types contains the

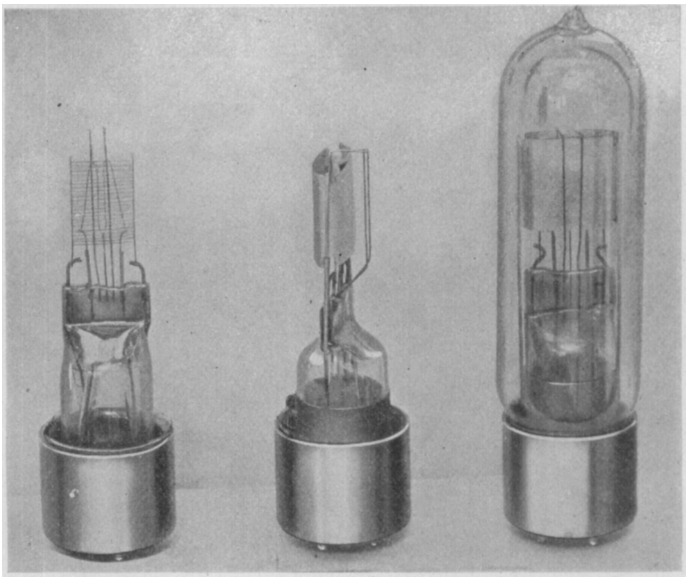


Fig. 8—Pliotron Generator—Medium Size

filament, the grid in the form of a fine wire, and the plate. The scheme according to which these different elements have been united is so different in the one tube from what it is in the other that the comparison is very interesting.

Fig. 7 shows a modern detector pliotron having a tungsten filament and a very minute quantity of argon gas within the bulb. The figure illustrates how the parts of the tube are assembled. At the left is shown the stem with the filament and the grid, the latter being a fine wire wound with suitable spacings around two vertical supports. The middle shows the application of the plate which is in the form of a hollow box of elliptical cross-section, closely surrounding the grid. The final assembly is shown in the next part of the figure. The minute quantity of argon is introduced for the purpose of increasing the flow through the tube by the ionization of the gas.

Fig. 8 shows a pliotron generator tube or "dynotron" used for transmitting where outputs of 50 to 150 watts are desired. It will be seen that the construction follows in principle that of the small tube. Where it is necessary to obtain very much power, the form of construction is varied, as will be seen in Fig. 9. In this tube two plates take the place of the hollow elliptical box and the support for the plate is introduced from the opposite end of the tube in order to secure the necessary insulation for the very high voltages applied to the plate in order to obtain large power outputs. The tube illustrated is rated at ¼ kilowatt.

Having now examined very briefly the modern developments of the Edison effect in the art of wireless communication, it may be of interest to know that lamps like Edison's original ones have been experimented with by the writer at the Electrical Testing Laboratories, to see what relationship they bear to the modern three-electrode tube. It was desired to know how these lamps would function when used in circuits such as are employed in modern wireless telegraphy and to find out just how near Mr. Edison was to a fundamental discovery in the wireless art of today. Mr. Edison, as has been said, experimented with lamps with one wire and with two wires; also with one plate and with two plates. For the purpose of this experiment lamps were used containing one wire and one plate located between the legs of the carbon filament as shown in Fig. 10. These lamps were made at the Edison Lamp Works through the courtesy of Mr. John W. Howell, to whom the author's thanks are due. Evidently if we connect the leg of the

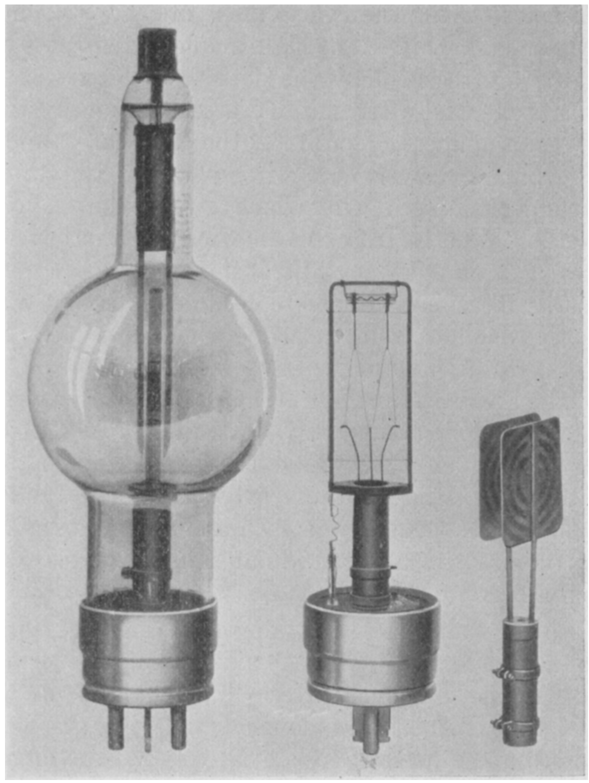


Fig. 9—Pliotron Generator—250 Watt Size

filament which is nearer the wire to the negative side of the circuit, we have an arrangement in which the wire may be considered as a crude kind of grid and the plate as a fairly good plate. The characteristic curve between the grid voltage and the current flowing between the plate and the positive leg of the filament of several of these lamps was obtained by measurement, and one such curve is shown in Fig. 11. Fig. 12 shows corresponding curves of modern three-electrode tubes. The similarity of the curve is quite striking, but as was to be expected, the single wire makes a very inefficient grid. If the wire were crinkled or if a number of wires in parallel were used, it would be much better. However, a lamp of this kind was connected as a wireless detector, the grid wire being connected through a condenser to one side of the oscillating receiving circuit, the other side of which was connected to the negative leg of the filament. The plate was connected directly through a telephone to

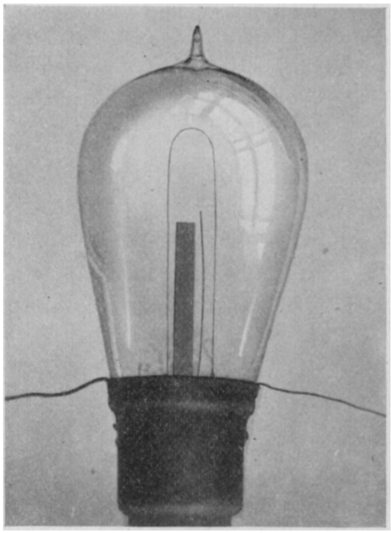


FIG. 10—EXPERIMENTAL EDISON EFFECT LAMP

the positive leg of the filament, all as shown in Fig. 13. No plate battery was used. The experiment showed that this made a very efficient form of detector, comparing quite favorably with a modern three-electrode tube

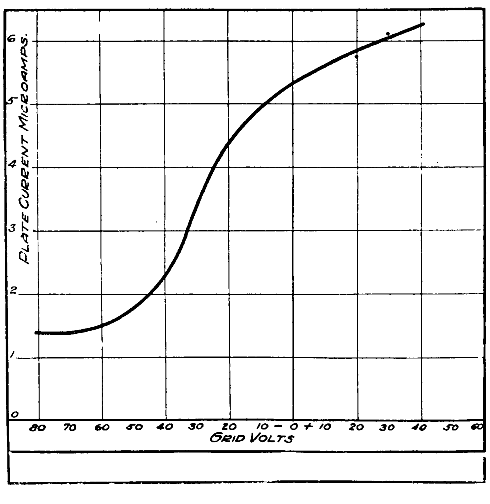


FIG. 11—CHARACTERISTIC CURVE OF EXPERIMENTAL EDISON EFFECT LAMP

Thus we find that Mr. Edison not only discovered the Edison effect, upon which more than upon any one thing the modern wireless art is based, but that he actually constructed apparatus which would perform the same as the modern tubes. He made in effect a detector of wireless signals. With slight modifications no doubt his apparatus would act as an amplifier and as an oscillator.

We know now that Langley's original airplane was capable of flying, for when handled in accordance with the aeronautical art as it has been developed since the days of Langley's experiments, it actually did fly over the waters of Keuka Lake. Similarly the Edison

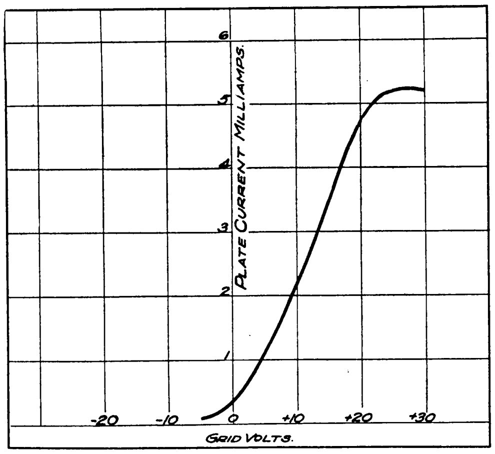


FIG. 12—CHARACTERISTIC CURVE OF AUDION

effect lamps were capable of use as wireless detectors and when fitted into a modern circuit will operate as such.

While on the subject of the relationship of Mr. Edison's early work to the modern wireless art, it may not be amiss to point out certain other things which he did having a direct bearing on the development of a wireless system. As far back as 1875 he made an experiment in which an electromagnet with an interrupter was connected by a wire to the gas

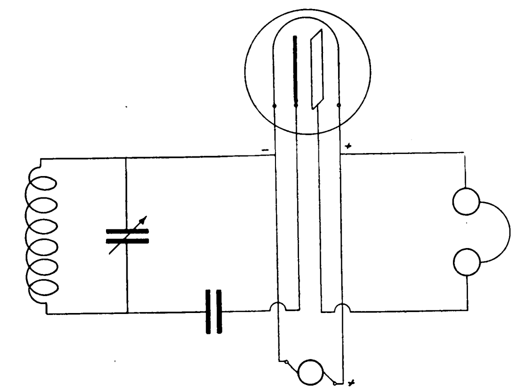


FIG. 13—EXPERIMENTAL EDISON EFFECT LAMP IN DETECTING CIRCUIT

pipes in the building. By setting up in another part of the building a little dark box containing two conducting points very close together, one of which was connected to the gas pipes, the other being free, minute sparks were observed between the points. Here was apparently a transmission of electric energy in an open circuit. The only way in which the circuit could be closed was through intervening ether, and Mr. Edison with remarkable clearness of vision designated this phenomenon as a phenomenon of "etheric force." At the time, his etheric force idea was ridiculed by many, but his experiments were confirmed by certain other investigators. They were exhibited amongst others to Sir William Thomson, later known as Lord Kelvin, who recalled them in a discussion before the Institution of Electrical Engineers as late as 1889. They were exhibited at the Paris Exposition of 1881 and were seen by physicists from all over the world.

In 1887, Hertz came out with his discovery of the so-called Hertzian waves, in which he used a high-voltage spark between electrodes to set up sparks between two adjacent metallic points in a dark box, which points were connected to conductors not metallically connected to the high-tension circuit. Hertz's discovery evidently related to the same phenomenon as Edison had discovered many years before and had designated as a manifestation of etheric force, and the apparatus which Hertz used showed a marked similarity to that which Edison had employed and had exhibited in Paris in 1881. Hertz had the advantage that he had an explanation at hand for his phenomenon on the basis of Maxwell's electromagnetic theory. Edison's experiments lacking their theoretical basis at the time they were first made, were never taken very seriously by the scientific world, and fell into oblivion. Concededly Hertz's experiments lie at the basis of wireless transmission. Edison had the same basis many years before.

Furthermore, we know that Edison experimented in telegraphy to and from moving trains and that he expanded his ideas to the extent of applying in the year 1885 for a patent which was granted in 1891, for means of transmitting signals electrically. This patent shows the use of elevated masts carrying condenser surfaces on them for spreading abroad the electrical impulses, and even shows two vessels equipped with the equivalent of modern antennas high on their masts (See Fig. 14) The specification for this patent[2] is wonderfully prophetic. It reads in part as follows:

* * * * * * * *

The present invention consists in the signaling system having elevated induction plates or devices, as hereinafter described and claimed.

I have discovered that if sufficient elevation be obtained to overcome the curvature of the earth's surface and to reduce to the minimum the earth's absorption, electric telegraphing of signaling between distant points can be carried on by induction without the use of wires connecting such distant points. This discovery is especially applicable to telegraphing across bodies of water, thus avoiding the use of submarine cables, or for communicating between vessels at sea, or between vessels at sea and points on land; but it is also applicable to electric communication between distant points on land, it being necessary, however, on land (with the exception of communication over open prairie) to increase the elevation in order to reduce to the minimum the induction-absorbing effect of houses, trees and elevations in the land itself. At sea from an elevation of one hundred feet I can communicate electrically a great distance, and since this elevation or one sufficiently high can be had by utilizing the masts of ships—signals can be sent and received between ships separated a considerable distance, and by repeating the signals from ship to ship communication can be established between points of any distance apart or across the largest seas and even oceans. The collision of ships in fogs can be prevented by this character of signaling, by the use of which, also, the safety of a ship in approaching a dangerous coast in foggy weather can be assured. In communicating between points on land poles of great height can be used or captive balloons. At these elevated points, whether upon the masts of ships, upon poles or balloons, condensing-surfaces of metal or other conductor of electricity are located. Each condensing-surface is connected with earth by an electrical conducting-wire.

Thus we see that Mr. Edison had almost within his hands all the elements of wireless transmission. He had the high-frequency currents, he had the elevated masts and he had the detecting apparatus. It needed only the coordination of these several elements to make the modern wireless system. We cannot but feel sorry that his necessary preoccupation with the electric light prevented him from concentrating his attention upon this other great field, for we cannot doubt that had he done so the wireless art more or less as it is known today would have emerged from Menlo Park.

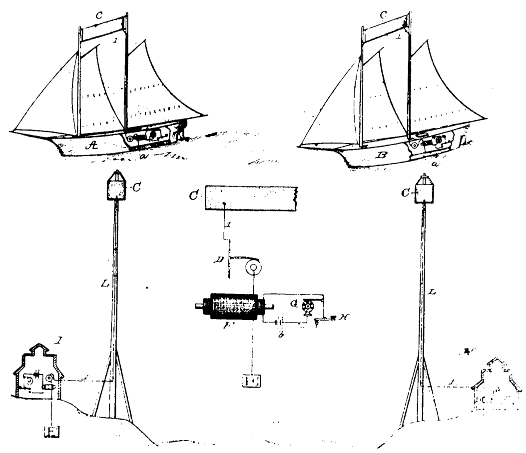


Fig. 14—Edison's Wireless System

It is not in the wireless art alone that the Edison effect has found its application. As has been noted, the Edison effect is essentially a rectifying effect, the electrons which carry the current being produced by a hot filament. Two classes of commercial rectifiers have been made on this principle. The first is known as the "kenotron." The kenotron rectifier as described by Dr. Dushman consists of a bulb containing a tungsten filament as cathode, and facing the filament an anode plate. The bulb is evacuated to an ultra-high vacuum condition. Under this condition no gas molecules being present, no positive ions exist, and the current being carried only by negative electrons, can go in only one direction. Furthermore, because of the absence of gas molecules, very high voltage can be applied between the filament and plate without a

2. This patent was sold in 1903 to the Marconi Wireless Telegraph Co.

breakdown. Hence a kenotron may be used as a rectifier in a high-voltage alternating circuit and will give as its output high-voltage direct current. Direct voltages of 100,000 volts may thus be obtained, a result more or less impracticable by any other form of apparatus. Such high voltages are employed in

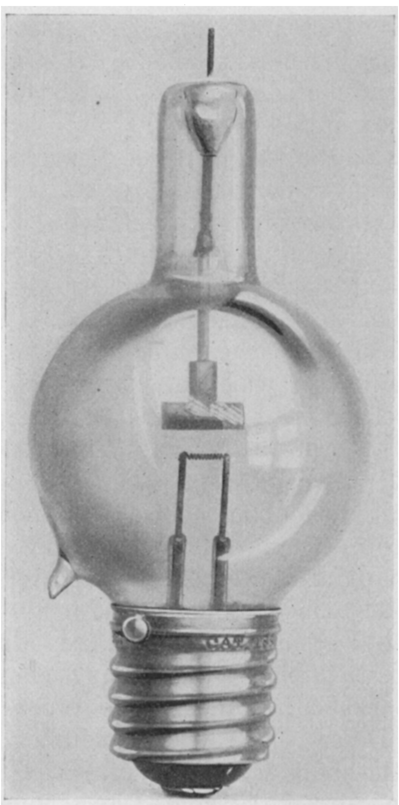


FIG. 15—TUNGAR RECTIFYING BULB

testing work and in fume or smoke collection by the Cottrell process, and for direct-current X-ray tube operations. Kenotron rectifiers are also sometimes used for furnishing the plate current of pliotron tubes. What fascinating possibilities may lie concealed in the suggested application of the Edison effect to high-tension transmission of electrical energy by rectified alternating current may be judged from the following quotation from Dr. Hull's paper on "The Magnetron."

> One may predict that one year will see these tubes in use as kenotron rectifiers for series arc lighting. Five years will see them in substations replacing synchronous converters. In ten years they will be on electric locomotives, either as rectifiers, allowing the use of d-c. motors or as variable frequency alternators, taking their power from a high-tension d-c. trolley line. Twenty years will see d-c. transmission lines, fed through transformers and kenotrons, at any convenient points, by alternators of any frequency, and tapped by the same tubes acting as magnetron alternators, or some equivalent pliotron or combination vacuum-tube alternator.

The second class of rectifier using the Edison effect is the so-called "Tungar" rectifier, see Fig. 15. This rectifier is used chiefly for low-voltage work such as the charging of storage cells. It is necessary that it should conduct freely with very small potential drop, hence the bulb contains pure argon gas at a pressure of about five centimeters of mercury. This gas is readily ionized by the electrons given off from the heated tungsten filament and the profusion of electrons thus set free gives a path of high conductivity. The filament acts as a cathode and the anode is brought close to it so as to diminish as much as possible the voltage drop.

Another important application of the Edison effect is in the Coolidge X-ray tube, an apparatus which has changed X-ray work from a happy-go-lucky, hit-or-miss sort of operation to a basis of scientific precision. The ordinary X-ray tube is a low vacuum or "gas" tube. It depends for its operation upon the ionization of the residual gas by the high-voltage discharge. The electrons so liberated are then hurled with great velocity under the influence of the electrostatic force against the cathode and so produce the X-rays. Its operation is dependent upon the condition of the vacuum in the tube. With use, the vacuum becomes higher and the tube becomes inoperative, so that it is necessary to provide an auxiliary device whereby a small quantity of gas can be passed into the tube. The character of the X-rays produced varies with the degree of vacuum and with the voltage applied, and the operation of such tubes is more of an art than a science.

In the Coolidge tube, Fig. 16, the electron-producing and electron-hurling functions are separated. The electrons are liberated by the Edison effect, that is, by heating a filament of tungsten. The tube is evacuated to the point where no residual gas is present. Hence the only electrons present are those given off by thermionic action. A high voltage is applied between the filament and the cathode and this voltage serves

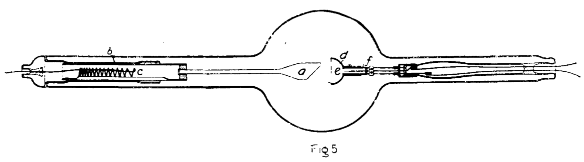


FIG. 16—COOLIDGE X-RAY TUBE

to drive the electrons to the cathode and so to produce the X-rays. Evidently here is an apparatus in which all the elements are under control, for the quantity of electrons liberated, and hence the strength of the X-rays produced, can be gaged exactly by the temperature of the filament, which is determined by the current through it, while the speed with which the electrons strike the target, and hence the hardness or softness of the rays, that is, their penetrating power, depends upon the high voltage which is applied and which also is under exact control.

A hemispherical shield surrounds the filament and concentrates the flow of electrons onto the target. The latter is made of massive copper to conduct away the large amount of heat resulting from the electric bombardment, and into the copper is set a piece of tungsten at the point where the electrons strike, so that there is no danger of melting this portion of the target. The tube acts as a rectifier; hence it can be operated either with high-voltage direct current or with alternating current, for with alternating current the inverse discharges are suppressed.

The original X-ray tube was a Crookes tube, the X-ray effect having been discovered by Roentgen. Improvements which have been made in it are detail improvements only. The Coolidge tube represents a radical departure from the Crookes tube and marks the greatest advance in X-ray science since its inception.

We must not forget, however, in this connection that the fluoroscope, or screen coated with tungstate of calcium fixed in a box which fits about the eyes, and which is used for visual observation of X-ray effects, is also an invention of Mr. Edison's. So that he has contributed not only the Edison effect, on which the modern tubes producing X-rays depend, but also that invaluable apparatus for their visual observation.

Before closing this very inadequate and fragmentary resumè of the modern application of the Edison effect, justice requires that a tribute be paid to two of the great agencies through which these have been carried on. For a large part of the development of the audion, especially of the type with the oxide coated filament, and for its widespread application to telegraphy and telephony, as well as for theoretical and experimental development along other lines, we are indebted to the fruitful labors of the corps of talented scientific men connected with the Research Laboratory of the Western Electric Company under Dr. Jewett, and to the engineers of the American Telegraph and Telephone Company, under Col. Carty. They have performed a magnificent work. For the development of the ultra-high voltage apparatus, as exemplified in the pliotron and the kenotron and the Coolidge tube, credit is due to the Research Laboratory of the General Electric Company, where under the inspiring leadership of Dr. Whitney, physicists and chemists and engineers, men of genius themselves, have produced scientific discoveries and practical applications almost revolutionary in their character. It is particularly gratifying that these developments from the scientific "effect" which he discovered and which bears his name have come now when Mr. Edison is able to see the field which he opened up yield such rich fruits under the hands of able successors.

The *Electrician*, of London, recently published a "diamond jubilee" issue in celebration of its 60 years of publication. It first appeared on November 9, 1861 and in its 60 years of life has recorded most of the epoch-making inventions in the various fields of applied electricity. Its anniversary issue contains messages of congratulation from Thomas A. Edison, Sir Oliver Lodge and other eminent scientists, and also contains interesting historical accounts of the application of electrical energy to various industries.

COPPER IN 1921

The smelter production of copper in 1921 from ore mined in the United States, as shown by the actual production for the first eleven months and by estimates made by smelting companies for December, was about 461,000,000 pounds, according to a report by H. A. C. Jenison of the United States Geological Survey, Department of the Interior. The refinery production as similarly shown was about 601,000,000 pounds from domestic material and about 320,000,000 pounds from foreign material.

According to the records of the Department of Commerce the total imports of copper for the first eleven months of the year in ore, concentrates, matte, blister, and refined copper were about 318,000,000 pounds, of which about 68,000,000 pounds was refined copper and 157,000,000 pounds was blister copper. The exports for the first eleven months totaled about 567,000,000 pounds, of which about 538,000,000 pounds was new refined copper and 29,000,000 pounds was manufactured—wire, rods, pipes, tubes, sheets, etc.

The total new supply of primary refined copper for the year was about 989,000,000 pounds, which includes refined copped produced from foreign and domestic material as well as imported refined copper. The stocks of refined copper in the hands of domestic refineries on December 31, 1921, excluding those in transit, as estimated by the refining companies, were about 496,000,000 pounds. The stocks of blister copper on December 31, 1921, including material in process, in the hands of smelters, in transit to refineries, and at refineries were estimated by refining and smelting companies at about 297,000,000 pounds.

The quantity of primary refined copper withdrawn on domestic account during the year was about 572,000,000 pounds, calculated as follows:

	1920	1921
Refinery production from domestic sources	1,182,000,000	601,000,000
Refinery production from foreign sources	344,000,000	320,000,000
Imports of refined copper	109,000,000	75,000,000
Stocks of new refined copper Jan. 1	631,000,000c	659,000,000
Total available supply	2,266,000,000	1,655,000,000
Exports (exclusive of manufactured copper)	553,000,000	587,000,000
Stocks on hand December 31,	659,000,000	496,000,000
	1,212,000,000	1,083,000,000
Total withdrawn on domestic account	1,054,000,000	572,000,000

The domestic imports and exports of primary refined copper in December, 1921, are assumed to be equivalent to the average monthly imports for the first eleven months. Disregarding the imports and exports for December the quantity of primary copper withdrawn on domestic account would amount to about 614,000,000 pounds.