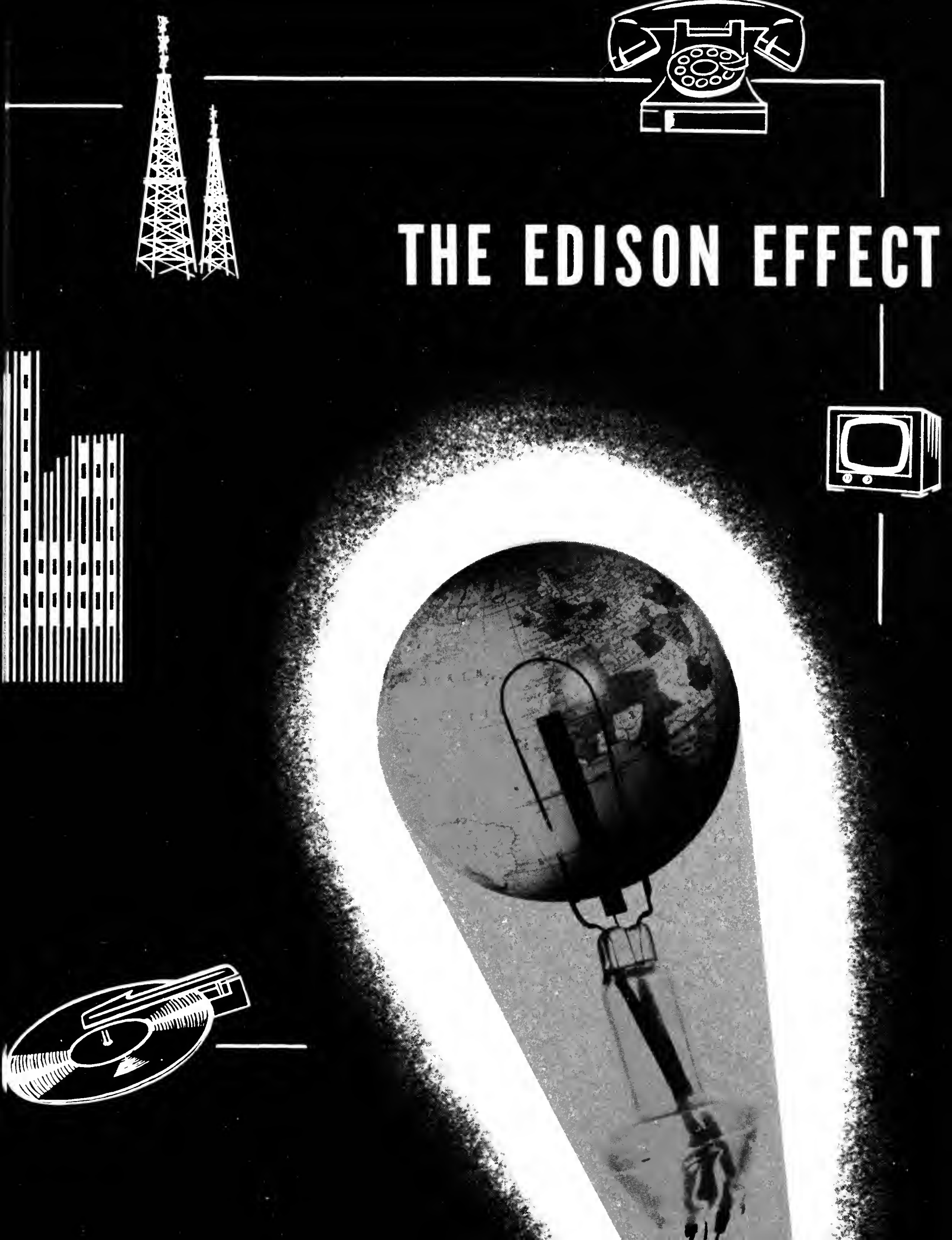
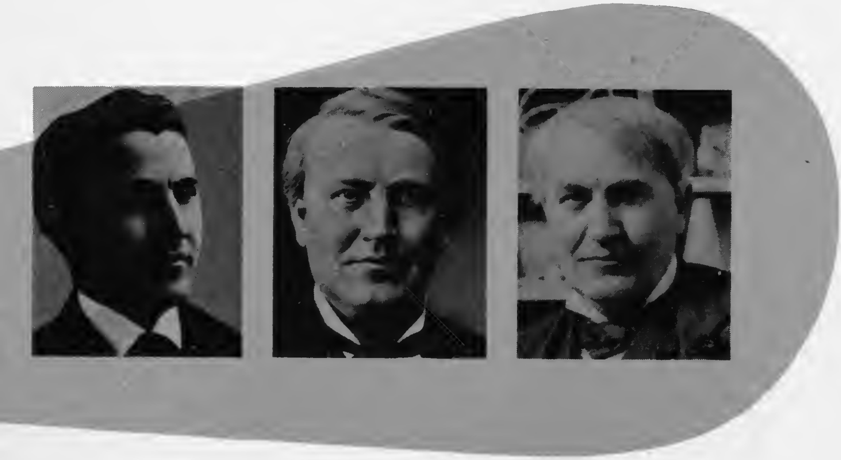
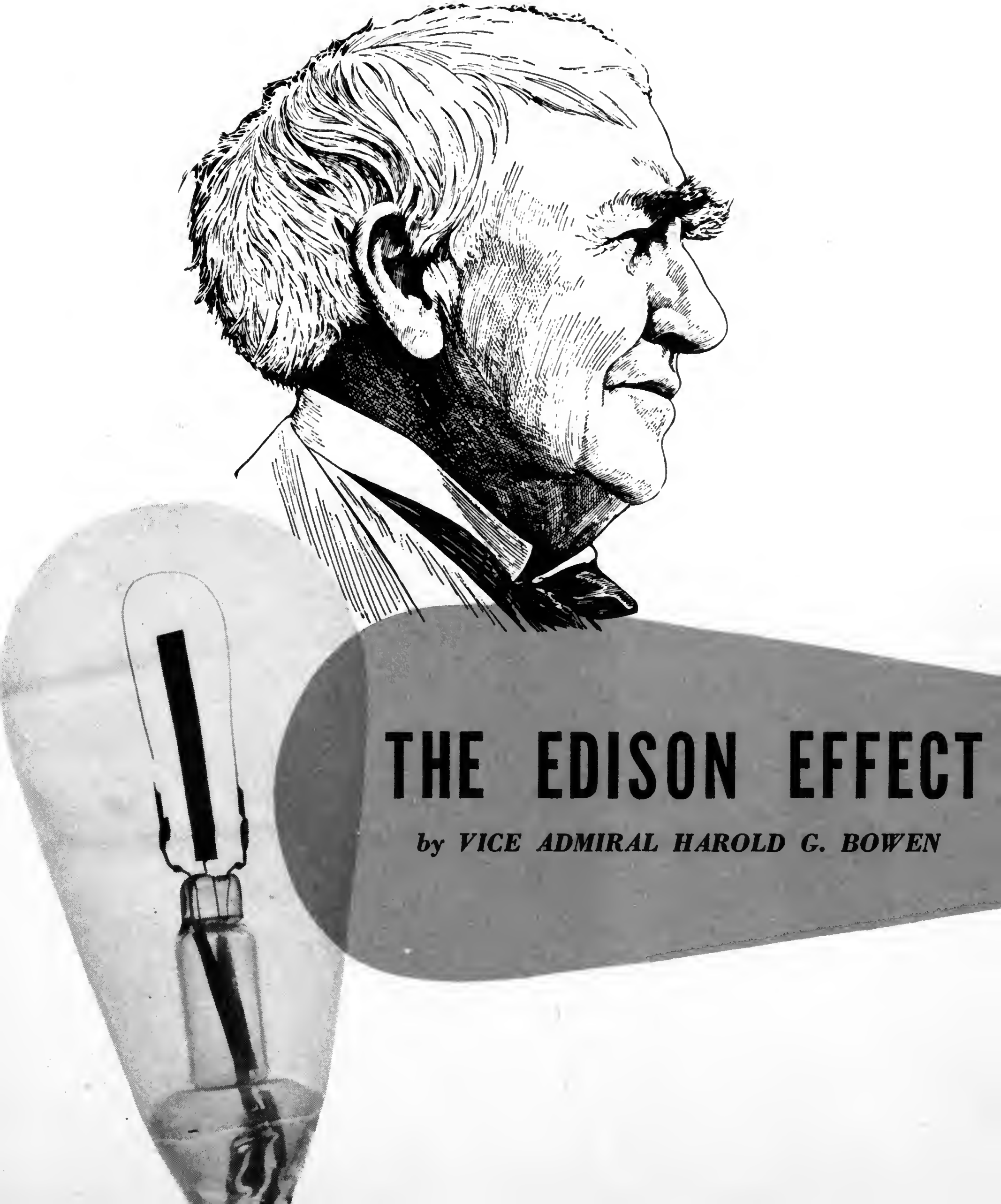
THE EDISON EFFECT







THE EDISON EFFECT

by VICE ADMIRAL HAROLD G. BOWEN

Printed in the U. S. A.

THE EDISON EFFECT

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THE THOMAS ALVA EDISON FOUNDATION, INC.
WEST ORANGE, NEW JERSEY

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Foreword

by Charles F. Kettering

When Thomas A. Edison discovered that, by inserting a straight wire into an incandescent light bulb, he could pull a current of electricity out of a vacuum, he did more than discover the Edison Effect; he discovered an inexhaustible source of free electrons. It is this inexhaustible source of free electrons which is most responsible for the enormous strides made in telephony, radio, phonography, radar, and television, to name just a few of the many branches of electronics based on free electrons.

This discovery was so far ahead of any related development in electrical engineering that it was years before it was utilized and much later before its full significance was appreciated.

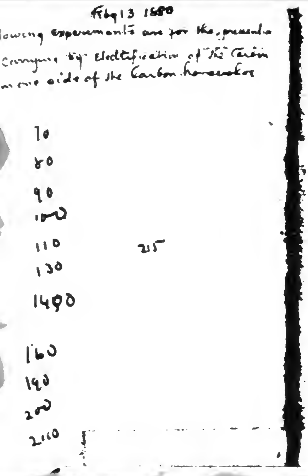
True, Edison discovered this natural phenomenon by accident when he was looking for something else, but accidental discoveries have rescued or added to the lustre of many a famous name.

The point is, Edison discovered something because he was looking.

Most of us don't look.

Edison investigated everything he didn't understand; and, since he was always looking, he became the greatest inventor who ever lived.

The lesson is, I think, if you don't look, you won't see anything and you may get run over.



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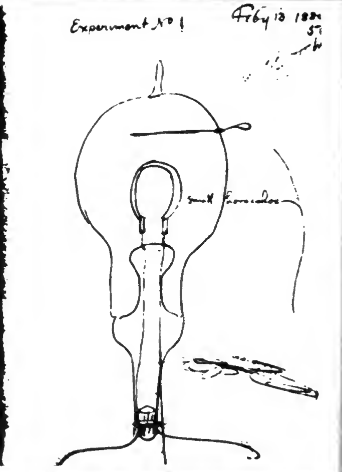
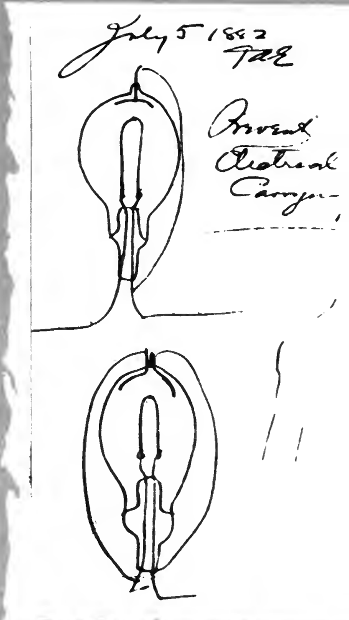




Chapter I

DISCOVERY OF THE EDISON EFFECT

In 1880 or before, Thomas A. Edison began experiments to determine what caused black material to accumulate on the inside of the incandescent light bulb which, at that time, used a carbon filament. Of course, the black material was carbon. He had noticed that each lamp, after it had become sufficiently blackened, had a white streak on the inside as if the positive leg of the filament shielded the glass of the bulb from carbon particles cast off by the negative leg. In fact, the positive leg may be said to have cast a white shadow on the inside of the lamp. Some say that his attention was called to this phenomenon by Mr. William J. Hammer.

It was Edison's practice, during the process of exhausting the air from an incandescent light bulb, to send a current of electricity through the filament in order to eliminate the gas contained in the filament. He noticed that, when he did this, a bluish glow was produced which lasted until a high vacuum had been produced. He wondered if there could be a current existing in the space between the two filaments and if this current carried carbon particles from the filament and, thereby, caused the opaque deposit on the inside of the bulb. To check this, he inserted in the tube a vertical wire between the legs of the filament but not touching them. He further noticed that, when this vertical wire was connected—outside of the lamp of course—to the positive side of the lamp circuit, a current flowed and that when connected to the negative side, no current flowed.

In his patent application, filed November 15, 1883, Edison states:

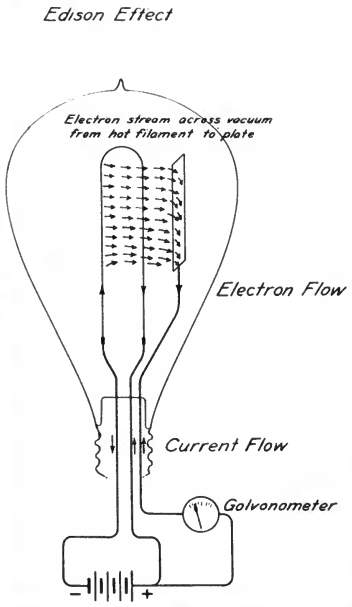
> *"I have discovered that if a conducting substance is interposed anywhere in the vacuous space within the globe of an incandescent electric lamp, and said conducting substance is connected outside of the lamp with one terminal, preferably the positive one, of the incandescent conductor, a portion of 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 candlepower of the lamp."*

On October 21, 1884, Edison was granted a United States patent, #307,031, to use this Edison Effect as a governor to control the output of dynamos or, as we call them today, electric generators. This application to generator control, however, was not successful, due perhaps to the inability at that time in obtaining a sufficiently high and constant vacuum.

Edison's British patent, #2988, to use the Edison Effect for controlling the output of generators, was described in Electrical Review of London in October 1884. The Electrical Review again, in December 1884, carried an account of Edison's exhibit of this new phenomenon at the Philadelphia Electrical Exhibition.

If we refer to the transactions of the American Institute of Elec-

U.S. Pat. 307,031


Edison Effect

trical Engineers, "Notes on Phenomena in Incandescent Lamps," by Professor Edwin J. Houston, as presented at the above mentioned Philadelphia Electrical Exhibition, we find that Professor Houston said: "I have not prepared a paper, but merely wish to call your attention to a matter which I suppose you have all seen and puzzled over. Indeed, I wish to bring it before the Society for the purpose of having you puzzle over it. I refer to the peculiar high vacuum phenomena observed by Mr. Edison in some of his incandescent lamps."

After Professor Houston's remarks, there followed the usual discussion in which William Henry Preece (afterwards Sir William), British electrical and civil engineer, took part.

Later, Mr. Preece prepared a paper on the Edison Effect which was published in the "Proceedings" of the Royal Society for 1885. In fact, the name "Edison Effect," seems to have been first given to this phenomenon by Mr. Preece.

In a written statement prepared in September 1921, Mr. Edison 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 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."**

Unless we understand the lack of knowledge regarding electrical

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* Paper prepared for presentation to Convention of The Association of Edison Illuminating Companies, September 1921.

phenomena which was characteristic of that period, we cannot possibly appreciate this incredible contribution of Mr. Edison.

In 1884, the longest telephone line in the country was 235 miles, from Boston to New York, by overhead line. The alternating current transformer had not yet been invented. Marconi was 10 years old. An international definition of all the electrical units had not yet been agreed upon. The atom was still believed to be the smallest particle of matter, and, in fact, atom means indivisible.

It was not until 1886-87 that Heinrich Rudolph Hertz, German physicist, discovered the Hertzian, electromagnetic, or radio waves on which radio communication is founded.

In 1888, two bright young men, Stone and Webster, graduated in one of the earliest classes in electrical engineering at the Massachusetts Institute of Technology; and they were told by their good professor of electrical engineering that one of them might go into this business of electricity but that there was no future for two of them. Fortunately, they disregarded this advice and founded the well-known Stone & Webster Company.

It wasn't until 13 years later (1897) that Sir J. J. Thomson, British physicist, proved that the Edison Effect was caused by the emission of negative electricity, or electrons, from the hot filament. As a matter of fact, it was 17 years later that O. W. Richardson, British physicist, a Nobel Prize winner, showed that these electrons were emitted solely because of their kinetic energy.

The Edison Effect has afforded us the most convenient and useful source of free electrons for scientific and practical purposes.

Some say that the white streak on the inside of the blackened bulb was called to Mr. Edison's attention by Mr. William J. Hammer. That may well be; and, for the purposes of the story, it will be assumed that such was the case. Mr. Hammer was an unusually intelligent and devoted assistant of Mr. Edison. Having called Mr. Edison's attention to the white streak, his interest in connection therewith evidently ceased.

Now the incandescent light was seven years old, and no one had bothered about the blackening of the bulb. If they had, they must not have succeeded in eliminating it, because there is no reference in the record to any success along these lines. That would come much later.*

But Edison had to find out what made that streak; and in so doing, he became the "Father of Electronics."

Edison kept plastered around his West Orange Works, Laboratory, and Library a quotation, attributed to Sir Joshua Reynolds, that: "There is no expedient to which a man will not resort in order to avoid the real labor of thinking."

To those to whom that name merely brings to mind a great court painter, there will be astonishment that such an individual could be the author of such a philosophy; but it will be remembered that Sir Joshua once wrote a pamphlet of instructions for young painters, and in it he stressed the absolute necessity for a young painter to perfect himself in the art of observation and never to neglect it. It was certainly never neglected by Thomas Edison.

In our next chapter, we will examine the effect which Edison's discovery had upon the great English physicist, Sir John Ambrose Fleming.

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* See "The Incandescent Light, A Review of Its Invention and Application," *by Floyd A. Lewis*, published by the Thomas Alva Edison Foundation.

Chapter 2

FLEMING FINDS APPLICATION FOR THE EDISON EFFECT

Sir John Ambrose Fleming, English physicist, was, in 1882, acting as electrical advisor to the Edison Electric Light Company of London. Like so many others, he had noticed the discoloration of electric light bulbs. His statement about this subject is interesting:

> *"Wondering why the glass bulb grew dark, I started to investigate the matter, and discovered that in many burned-out lamps there was a line of glass that was not discolored. It was as though someone took a smoked glass, drew a finger down it, and left a perfectly clean line behind. I found that the lamps with these strange, sharply-defined clean spaces were covered elsewhere with a deposit of carbon or metal, and that the clean line was immediately in the plane of the hairpin-shaped carbon filament and on the side of the loop opposite to the burned-out point of the filament.*
>
> *"It was obvious to me that the unbroken part of the filament acted as a screen to that particular line of clear glass, and that*

the discharge from the overheated point on the filament bombarded the remainder of the bulb with molecules of carbon or vaporized metal shot out in straight lines. My experiments at the end of 1882 and early in 1883 proved that I was right.

*"Edison in 1883 noticed the phenomenon called 'the Edison Effect', but he could not explain it, nor did he use it in any way. "In October, 1884, Sir William Preece turned his attention to investigation of 'the Edison Effect.' He decided it was associated with the projection of carbon molecules from the filament in straight lines, thus confirming my original discovery. There Sir William Preece let the matter rest, just as Edison had done. He did not satisfactorily explain the phenomenon nor did he seek to apply it. 'The Edison Effect' remained just a peculiar property, a mystery of the incandescent light."**

When Fleming says that Edison did not utilize the phenomenon called the Edison Effect in any way, he is of course wrong, as indicated by the American and British patents noted in a previous chapter, wherein he proposed using the phenomenon as a means for governing the output of electric generators. However, as stated before, the application was not successful.

Fleming's statement that Edison could not explain the Edison Effect is correct. Neither could Fleming nor anyone else at that time. As stated above, the explanation must await the work of Sir J. J. Thomson and O. W. Richardson at a much later period.

Like Edison, Fleming's attention was diverted to other matters; and it wasn't until 1888 that he went back to the Edison Effect.

In that year, he enclosed the negative leg of the carbon filament in a glass bulb and noticed that the bombardment of the electrified particles, i.e., electrons, was stopped. He found that he could vary

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* Radio's 100 Men of Science, *by Orrin E. Dunlap, Jr.*, Harper & Bros., 1944.

the intensity of the bombardment by altering the position of the metal plates. He obtained the strongest current when he enclosed the negative leg of the filament with a metal cylinder. It seemed obvious to Fleming that the metal cylinder was receiving the electrons emitted by the incandescent filament. His great discovery was that the incandescent light, thus altered, could be used for rectifying alternating currents of almost any frequency.

In 1889, Fleming became an electrical advisor to the Marconi Wireless Telegraph Company. Now radio in those days was very much in its infancy; and, in the antenna circuit, it employed a device known as a coherer to detect the radio waves received by the antenna.

This coherer was invented by Edouard Branly, French physicist, accidentally in 1885 when he was testing different theories regarding the carrying of messages over the nerves of the human body. He had discovered that the nerves are not continuous but are formed of neurons existing closely together but not necessarily in contact. By analogy, he constructed the coherer which he demonstrated before the French Academy in 1891. His coherer consisted of a glass tube filled with loose iron filings in a closed circuit with a galvanometer and a battery. When the radio signals, that is, dots and dashes, were led in from the antenna to the coherer, the metallic filings cohered, became a conductor, and allowed the battery to transmit current. By tapping the coherer, the current from the local battery was stopped. This striking of the coherer by hammer to produce decoherence and, therefore, non-conductance automatically followed reception of the radio impulse.

With the coherer in circuit, the only thing the antenna current did was to make the coherer a conductor for the battery current which operated the telephone. When transmitting the familiar dots and dashes of the Morse telegraphic code, the radio wave trains are not continuous. A long wave train was a dash, a short one a dot. The tapper was necessary to destroy conductance at the end of each wave train and thus break the direct current from the battery into dots and dashes which could be heard. It should be noted that the electric energy which actuated the telephone was derived from the direct current of a battery and was not the energy of the radio waves.

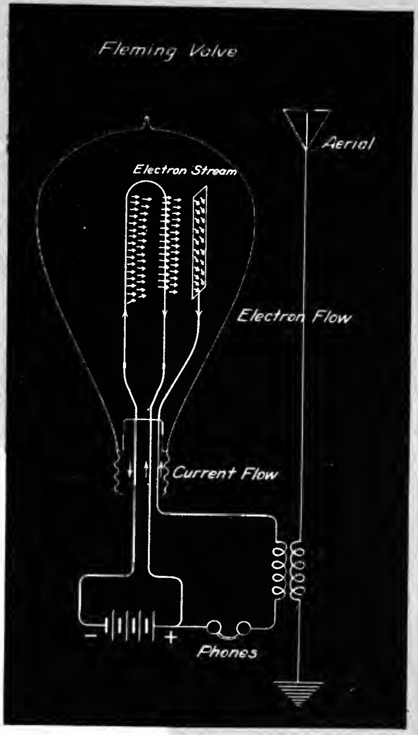
While the coherer did function fairly satisfactorily, the best that can be said about it is that it was better than nothing. Fleming realized this and tried to develop chemical rectifiers as a substitute. Not accomplishing very much along that line, he decided to see what he could do with an incandescent light incorporating the Edison Effect. He substituted the incandescent light with the Edison Effect for the coherer and was delighted to see that his new device rectified high frequency radio currents.

He immediately replaced the metal plate with a metal cylinder, enclosing the whole filament so as to recover all the electrons ejected by the filament. He named this device an oscillation valve, although it did not oscillate, i.e., generate electromagnetic waves of radio frequency.

In this form, Fleming's valve was extensively used by the Marconi Wireless Telegraph Company as a detector of radio waves. It is interesting to note that the discovery of the Edison Effect in 1884 was so far ahead of the times that it was not until 1904 that there was any place to use it.

Fleming applied for a patent in Great Britain on November 16, 1904, but it is not known when he made his discovery of the use of the Edison Effect as a detector.

On February 24, 1897, John W. Howell presented a paper before the American Institute of Electrical Engineers in which he said: "If an alternating current is used to render the filament incandescent,


Fleming Valve
Aerial
Electron Stream
Electron Flow
Current Flow
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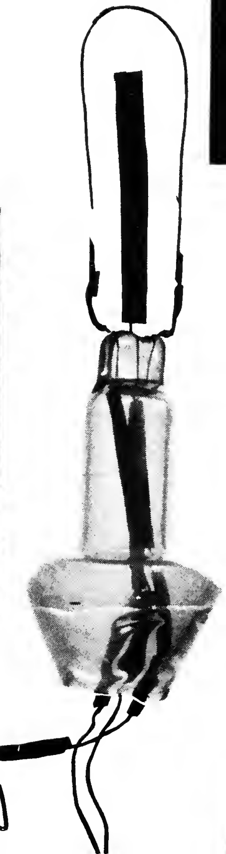
+
Phones



the galvanometer will indicate a current with the connection made to either lamp terminal, because both are equally positive. The current thus produced is a uni-directional one in the galvanometer, and illustrates very well the unilateral conductivity between the incandescent filament and the wire."*

Commenting on this paper, Dr. A. E. Kennelly said: "So far as I know, however, it has been pointed out for the first time in this paper, that an alternating current passed through an incandescent lamp giving the 'Edison Effect' is capable of producing in a branch circuit through a third wire in a lamp, continuous or at least uni-directional currents. Consequently it is interesting to observe that a vacuum tube, in the broadest sense of the term, is capable of supplying not only alternating currents from continuous currents, but also continuous currents from alternating currents."*

In his American Patent #803,684 of November 7, 1905, Fleming claims the ability to rectify high frequency or low frequency alternating currents.

In the disclaimer filed November 17, 1915, by the assignee, Marconi Wireless Telegraph Company of America, the claims are limited to "high frequency alternating electric currents or electric oscillations of the order employed in Hertzian wave transmission."

The application of Fleming's valve sounds quite complicated, but it really isn't. As the radio or electromagnetic waves, initiated by some transmitting station, flow through a receiving antenna, they induce alternating currents of relatively high frequency in the antenna which are carried by a lead-in wire to the radio receiving set. The currents are called alternating because they alternately

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*** American Institute of Electrical Engineers, Vol. XIV, 1897, Courtesy of Dr. Edward L. Bowles of Massachusetts Institute of Technology.**

flow in one direction and then in the opposite. They exert a positive influence when flowing in one direction and a negative influence when flowing in the other. Now if you connected such a current to a telegraph sounder or to a telephone head set or a loud speaker, you wouldn't hear anything; but if you suppress the current flowing in one direction, in effect you rectify or straighten out the current since you only allow it to flow in one direction. Therefore, it becomes what is known as a pulsating direct current, although not a continuous one; and it will operate a telegraph sounder or a telephone.

Fleming connected the lead-in wire from his antenna to the plate circuit; and, therefore, this plate was alternately charged positive or negative, according to which way the antenna current was flowing. When charged positively, it attracted electrons; and a current flowed through space and through the telephone. When charged negatively, the electrons were repelled; and no current flowed. The filament, he connected to ground.

In other words, in effect Fleming's device may be said to have rectified high frequency radio currents; but actually the electrical energy which actuated the telephone was still derived from the battery and not from the energy of the radio waves.

Radio communication gave the Edison Effect its first big boost; in fact, it represents the first successful application of the Edison Effect and, for this reason, it is necessary at this point in the development story to say something about the history of the development of radio.

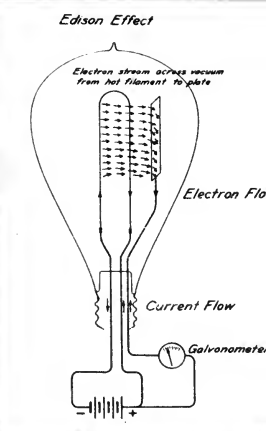
At that time, radio communication wasn't anything to brag about. Early in 1906, the floating drydock, "Dewey," was on its way by tow to Manila, via the Mediterranean. The Navy Department desired to send a radio message to the "Dewey" about the time she was enter-

ing the Straits of Gibraltar. To do this, a radio chain of six or seven cruisers was stretched out across the Atlantic, from the Caribbean to the vicinity of the Straits; and the message was successfully repeated, ship to ship, to the "Dewey." Marconi began commercial service between Glace Bay, Nova Scotia, and Clifden, Ireland, on October 17, 1907.

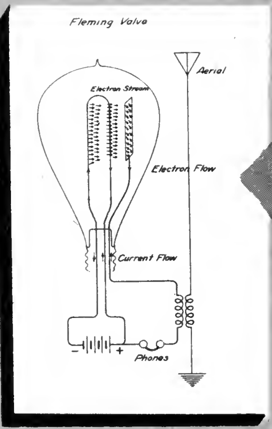
Fleming was an extremely versatile individual, who sometimes operated as a physicist, other times as a professor of electrical engineering, and often as an engineer and inventor.

His discovery that the Edison Effect could be used in connection with the so-called rectification of radio frequencies was an invention or an engineering development of the Edison Effect. Like Edison, he discovered in this instance something; but he explained nothing.

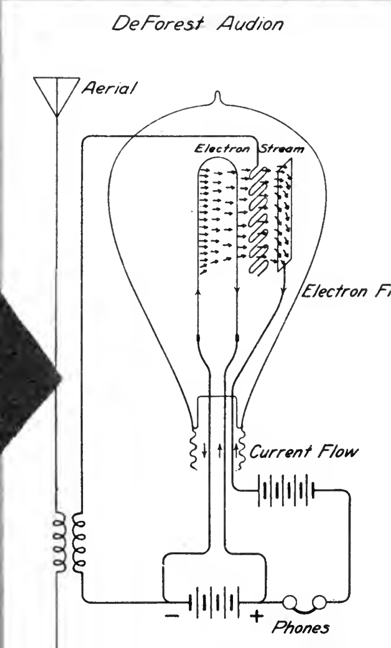
1883


Edison Effect

1904


Fleming Valve

1906


DeForest Audion

Chapter 3

DEFOREST INVENTS THE AUDION

The preceding chapter shows how Fleming transformed the Edison Effect into the Fleming valve, thereby inventing a device to rectify alternating currents. He was not able to explain the reasons for the Edison Effect.

Lee DeForest, who transformed the Fleming valve into the audion, was a graduate engineer with a flair for invention. In looking around for a device to amplify the very weak radio signals received on an antenna, he recalled the Edison Effect and recognized that the Fleming valve had its limitations.

In 1906, he added a grid—a zig-zag piece of platinum wire—between the filament and plate. The result was a circuit consisting of a plate battery, a grid, a filament, and a plate. Fleming's tube could only rectify alternating currents. By adding the grid, DeForest endowed the tube with the additional ability to amplify voltages and also the ability to generate Hertzian or radio waves. According to its use, it is known as a rectifier, amplifier or oscillator. The name, audion, was given this new device by DeForest's assistant, Clifford Babcock; and it was Babcock who conceived the idea of enclosing all of these elements in a glass bulb.

In 1907, the U. S. Patent Office issued to DeForest a patent on his audion.

On the cruise around the world in 1907-08, by the American Fleet, twenty vessels were equipped with DeForest's radio telephone.

The tube works in the following manner: An electric current heats, to incandescence, the filament which emits a stream of electrons or negative particles. Since the metal plate is positively charged by the plate battery, it attracts these electrons. Suspended between the filament and the plate is the grid, which is usually of a mesh-like form.

The grid is inductively connected to the antenna circuit which runs from the antenna to the ground. As a result, the grid, during the reception of a message, becomes alternately positive and negative in varying degrees. Since it is suspended in the electron stream, between the filament and the plate, when it is positive it accelerates the flow of electrons from the filament to the plate and so increases the plate current. When it is negative, it repels some of the electrons (negative particles), thus diminishing or even stopping the plate circuit. Remembering that the telephone is part of the plate circuit, it will be appreciated that the radio signals determine what is heard in the telephones. It is still true, however, that the electrical energy which operates the telephone is derived from a battery or a generator and not from the radio signal. The function of the radio signal is to control or modulate the plate or telephone current through the agency of the grid. With the grid, the expenditure of a very small amount of energy in the grid controls the rate of expenditure of a very much larger amount of energy in the plate circuit.

DeForest's invention happened to be made at a time (1906) when a new phenomenon, the industrial research laboratory, had developed far enough to begin to exercise its tremendous power on the development of American industry.

Both the Bell Telephone Laboratories (Western Electric) and the research laboratory of General Electric were quick to realize and appreciate the tremendous possibilities inherent in DeForest's amazing invention.

Needless to say, the audion displaced the Fleming valve in radio just as the Fleming valve had displaced the coherer.

Chapter 4

THE INDUSTRIAL RESEARCH LABORATORIES TAKE CHARGE

"The function of a detector (rectifier) is to transform radio-frequency oscillations (waves) which cannot produce a note in the telephones over into audio-frequency oscillations which can be heard. . . . The efficiency of a detector . . . is greater for strong signals than it is for weak signals. There is therefore an evident advantage in increasing the strength of a weak radio frequency signal before applying it to the detector tube. In fact, if the amplitude of a weak signal is amplified twenty times before it is applied to the detector tube, the resulting audibility will be as great as would be obtained by applying the signal to the detector tube directly without amplification, and then using an audio-frequency amplifier to amplify the audio-frequency four hundred times.

"Another reason for using radio-frequency amplification is because only two or three stages (degrees) of audio-frequency amplification are feasible. It is difficult to prevent an audio-frequency amplifier having a greater number of stages from howling, and, furthermore, the amplifier is likely to be very noisy because it will amplify noises due to bad contacts, variable batteries, and noisy tubes.

"It is customary to combine radio- and audio-frequency amplification in the same instrument, in which case it is also necessary to include a detector in order to convert the radio-frequency oscillations over into audio frequency. Thus: frequently three tubes and transformers are used to amplify the radio-frequency oscillations, another tube acts as a detector, and two more tubes and transformers (voltage changers) amplify the audio frequency."*

It is evident from the above quotation that the audion is a tube of great versatility, and reference will be made to that fact later. It is further evident that the advent of such a revolutionary device would incite new studies of circuits or hook-ups. It did.

For use with the audion, DeForest invented the feed-back or regenerative circuit, which, figuratively speaking, gave an additional kick to the original radio impulse, much as a small child uses his foot with the right timing to increase the amplitude of his swing.

After years of litigation, DeForest's claim to be the inventor of the regenerative circuit was sustained in the United States Supreme Court in 1934 over the claim of Edwin H. Armstrong.

In October 1912, Lee DeForest, a former Western Electric engineer who had left that company to become an independent inventor, submitted his audion for the consideration of Dr. Frank B. Jewett, then assistant to Western Electric's (Bell Telephone) Chief Engineer. Telephone engineers all over the world had been seeking an amplifier or, as they call it, a "repeater." It was agreed that the Bell engineers would test the audion and see whether or not it was deemed suitable in attacking the problem of long-distance telephony.

"It is true that the audion was a great improvement over other forms of detectors of radio signals, but its amplifying characteristics were decidedly limited, especially when applied to wire telephony.

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* Manual of Radio Telegraphy and Telephony. U. S. Naval Institute, 1927.

The Telephone Company needed a relay or booster of current, yet the audion could operate only on a very low current—one hundredth of a watt. If forced higher than this it caused voice distortion and then broke into a blue glow and ceased to function as an amplifier. The fact that telephone engineers were able to pass one watt of electrical energy through an ordinary telephone transmitter, even though the results were not very satisfactory, caused them to be impatient with the DeForest audion. No one at that time realized that the presence of gas in the imperfect vacuum of the audion was largely responsible for the erratic behavior of the device."*

"The goal of the American Telephone and Telegraph Company engineers was to produce a system of land-wire telephony that would enable telephone conversation between New York and San Francisco. In the latter city was shortly to be held a World's Fair and the telephone industry needed some spectacular achievement as its contribution to the event. The electric current used in telephone wires was incapable of traveling across the continent, since it dissipated or faded out on the way. Amplifiers were needed at intervals along the route to give the fading current new strength to continue its journey. DeForest's audion, despite its defects already noted, gave promise of becoming the answer to the problem. A Dr. H. D. Arnold, in the research department, was now at work upon the problem of producing a better vacuum tube than DeForest had accomplished, hoping thus to get more power out of it and thus also to eliminate disastrous ionization of the gas in the imperfect vacuum."*

Having completed its test and examination, the Bell System purchased DeForest's rights to the audion in the spring of 1913 for wire telephone and telegraph purposes.

The Bell engineers felt that, in order to increase the efficiency of the audion as an amplifier, they would have to redesign both the

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* History of Radio to 1926, *by Gleason L. Archer.*

outer circuit leading into the tube and the inner circuit. They recognized that the chamber, or interior of the tube or bulb, had not been completely evacuated and that they must obtain a much higher vacuum.

The task of improving the audion's efficiency was turned over to Harold D. Arnold, a physicist, who did graduate work at the University of Chicago under Professor Robert A. Millikan, and later entered the research department of the Bell Telephone Laboratories.

He appreciated the necessity for vastly improving the vacuum of DeForest's tube, and this he was able to do after having obtained a superior vacuum pump from Europe.

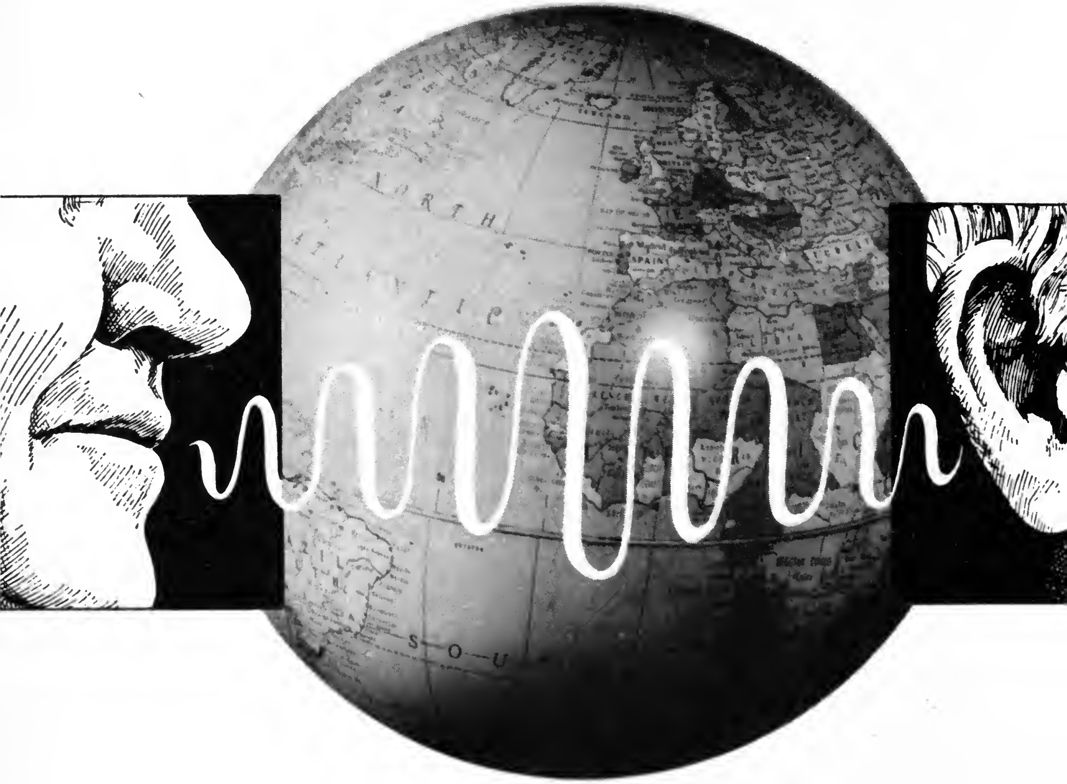
The DeForest audion with which Arnold started was valuable as a detector and amplifier of feeble radio currents. It was, however, incapable of satisfactorily amplifying the feeble but much larger currents of wire telephony.

Arnold, who was one of the earliest scientific workers in thermionics, realized that to improve DeForest's tube he must produce a pure thermionic effect, free of gas complications. In this connection, he recognized the existence and importance of the space charge effect of electrons in the vacuum tube and the necessity for the calculation of the magnitude of this effect and of the methods for its adaptation to commercial purposes.

As a result of Arnold's work on his vacuum tube, together with the results of research which had to be conducted in more than 100 other particulars, long-distance telephone service was extended from New York to Denver late in 1914, and soon after that long-distance telephony was extended from New York to San Francisco.

On September 29, 1915, human speech was transmitted by the Bell System from Arlington, Virginia, to Honolulu, and on October 20, 1915, between Arlington, Virginia, and the Eiffel Tower in Paris.

Unknown to one another, Langmuir of the General Electric Lab-



oratory was also working to improve the DeForest tube, and his success in that respect became public about the same time as Arnold's.

The General Electric Company had inherited the problems of the incandescent lamp when Thomas A. Edison had sold his manufacturing interest in the light and power industry to that company.

The useful life of the carbon filament lamps, as well as that of the tungsten filament lamps which succeeded them, was limited by the gradual blackening of the bulbs which took place during operation. Dr. Irving Langmuir began the study of bulb blackening shortly after he joined the staff of the General Electric Research Laboratory in 1909.

He found that residual gases left in the bulb after exhaust might increase blackening, but that, in the case of the tungsten lamp, even after the most rigorous exhaust, blackening would still take place due to evaporation of the filament, the rate depending on the temperature at which the filament was operated.

This blackening rate determined the filament temperature and hence the efficiency at which the lamp could satisfactorily operate.

He found that evaporation of the tungsten could be retarded by having a substantial pressure of a chemically inert gas* in the bulb and that if, in addition to this, the filament were given the optimum shape (through coiling), the efficiency of the lamp for a given life could be roughly doubled; and so we have the highly efficient gas-filled incandescent lamp of today.

The blackening of bulbs had started Edison on the Edison Effect; and now that Langmuir had finished his work on that problem, he proceeded to see what he could do to improve the Edison Effect as then personified in DeForest's audion tube.

Langmuir had noted that the Edison Effect occurred at a certain vacuum and higher, but that with a poorer vacuum it did not occur. He determined to see what would happen to the Edison Effect with the highest possible vacuum he could attain.

In the course of his work on blackening, he had developed a wonderfully efficient pump for exhausting tubes. He is said to have produced a higher vacuum than ever produced before. Be that as it may, when he started his work on the audion, there remained in the tube one molecule of air out of one-hundred thousand. When he had

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* In actual practice a mixture of nitrogen and argon was used.

finished, there remained in the tube one molecule of air out of ten billion. This was the result of his mercury condensation pump.

In incorporating his new high vacuum in his redesigned audion tube, he raised its voltage to 250 against DeForest's 30 and raised its output to kilowatts from small fractions of a watt. He called his development of DeForest's tube the "radiotron."

Langmuir, in the course of this work, "discovered new laws relating to electronic emission in a vacuum"* and he greatly increased the power of radio tubes by discovering "that electrons in a gas-free space built up a space charge which limits the current"* of the Edison Effect.

"Any acceleration of the velocity of the electron stream increases the (space) current and, vice versa, any slowing down of the rate of flow of electrons decreases the (space) current."**

Langmuir showed 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."*** In other words, the space current depended on the speed of the electrons; and the speed of the electrons depended on the amount of the space charge, the amount of the positive charge on the plate and the amount of the charge on the grid, and also whether the grid charge was positive or negative and the degree of such charge.

Langmuir also showed that the Edison Effect did occur with an ultra-high vacuum and thus settled the argument as to whether or not the Edison Effect could take place under such conditions.

Since Arnold and Langmuir had both, independently, greatly improved the audion, it was natural that each should claim title to the improvements.

After long litigation between the General Electric and the Amer-

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* Radio's 100 Men of Science, *by Orrin E. Dunlap, Jr.*

** Pamphlet by Clayton H. Sharp, presented at convention of Ass'n of Edison Illuminating Co.'s, Sept., 1921, "The Edison Effect and Its Modern Applications."

*** Pamphlet by Clayton H. Sharp.

ican Telephone and Telegraph Companies, the United States Supreme Court held that Arnold's principle of taking DeForest's tube and obtaining a better vacuum so that its range of operation would include high voltages without changing the essential nature of what took place in the tube did not constitute a new invention. The Supreme Court also held that Langmuir's patent did not involve invention and stated further that the effect of high vacuum upon voltages above the point of ionization was already known and that such knowledge was available to practitioners of the art.

Before we leave the subject, a few more words about the fortunes of DeForest.

". . . DeForest and several of the directors of the Radio Telephone Company went on trial in New York City, November 12, 1913, charged with using the mails to defraud the public by selling stock in a company whose only assets were the DeForest patents 'chiefly directed by a strange device like an incandescent lamp, which he called an Audion, and which device had proven to be worthless.' The language of this indictment reveals how completely the prosecuting authorities failed to grasp the significance of DeForest's radio inventions. In the light of subsequent events there is irony indeed in the fact that the Federal District Attorney in his all-seeing wisdom heaped upon the badgered inventor the following epithets of scorn:

" 'DeForest has said in many newspapers and over his signature that it would be possible to transmit the human voice across the Atlantic before many years. Based on these absurd and deliberately misleading statements of DeForest, the misguided public, Your Honor, has been persuaded to purchase stock in his company, paying as high as ten and twenty dollars a share for the stock.' The impassioned District Attorney pleaded that DeForest be sent to the Federal penitentiary at Atlanta. After a trial lasting more than six weeks a jury of twelve men found two of the directors guilty but acquitted DeForest and one of his associates of criminal intent. The Federal judge, in a speech that must later have caused him a measure of chagrin at his own lack of understanding, lectured Lee DeForest severely, reprimanding him as though he were a cheat who had narrowly escaped well-deserved punishment, admonishing him to give up all pretense of being an inventor. The fatuous jurist wound up his homily by advising DeForest to get 'a common garden variety of job and stick to it.' Thus one of the foremost inventors of the age escaped criminal conviction because the twelve men in the jury box had greater ability to perceive the truth than the jurist who presided over one of the most important districts in the Federal judiciary."*

As if that were not enough, on September 20, 1916, the long controversy between the Marconi Company and the DeForest Radio Company over the right of DeForest to manufacture and sell the audion was decided against DeForest by a District Court of the United States.

The Court said:

"Stripped of technical phraseology, what Fleming did was to take the well-known Edison hot and cold electrode incandescent electric lamp and use it for a detector of radio signals. No one had disclosed, nor even intimated, the possibility of this use of a device then long known in another art. Cohering filings, magnets, electrolytes, and sensitive crystals, *at that time,* failed to give any hint of the utility in this art of the Edison lamp. What led Fleming to his result was his adherence to the theory of the 'rectified' alternating currents."**

The court went on to decide that this new use of the Edison device was patentable by Fleming. After discussing the contentions of the defense that DeForest had produced an essentially new device, the court said:

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* History of Radio to 1926, *by Gleason L. Archer.*

** Marconi Wireless Telegraph Co. of America v. DeForest Radio Telephone and Telegraph Co. et al. (District Court, S.D. New York, Sept. 20, 1916) from Federal Reporter, Vol. 236.

"DeForest had long been proceeding on a theory different from that of Fleming. Having read Fleming's article, he began to experiment with the incandescent lamp. He probably doubted its efficacy at first, but within a very short space of time—perhaps a week, perhaps a month—he changed his mind, and, discovering that Fleming was right, wrote his solicitor, after he had filed his application for No. 824,637, that the 'new receiver is the best yet.' Thereafter he used the language of the incandescent lamp, and in an address on October 20, 1906, before the American Institute of Electrical Engineers, really described fundamentally the Fleming lamp detector, although using phraseology which has since become Audion vocabulary. Thus the physical ocular fact is that in the alleged infringing P. N. device, the Fleming detector, and not the Bunsen burner, is used, and the broad claim No. 1 of the Fleming patent is infringed, precisely the same as if a patented crystal had been placed in some old or new type of circuit with a local battery—such, for instance, as the Weagant and Armstrong circuits.

"In respect of claim 37 defendants' device does not escape because the circuit outside the vessel is divided into two branches, nor because Fleming's detector of a 'continuous current' was a galvanometer and DeForest's is a telephone long well known in the art. DeForest in his three-electrode Audion has undoubtedly made a contribution of great value to the art, and, by the confession of judgment in respect thereof, defendant company may enjoy the just results of this contribution; but, on the other hand, Fleming's invention was likewise a contribution of value, and is to be treated liberally, and not defeated, either by unconfirmed theory or by association in apparatus, where later developments have taught how other useful adjuncts can be employed."*

"The conclusion was that the DeForest invention had infringed

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* History of Radio to 1926, *by Gleason L. Archer.*

that of Fleming, hence that he could not manufacture the three-electrode audion without the consent of the Marconi Company, the owners of the Fleming patent."**

In reading over the court's decision, one cannot escape the feeling of regret that the court did not express more appreciation of DeForest's remarkable development of Fleming's two-electrode tube. It is true that the court did say: "DeForest in his three-electrode Audion has undoubtedly make a great contribution to the art. . . ."* DeForest did more than that. He took Fleming's two-electrode detector and rectifier and made it into a monumental detector, rectifier, and amplifier. He gave to Arnold and Langmuir a tube which, under these later developments, became the cornerstone of the modern art of electronics. It is evident that the court had no conception of what a brilliant contribution DeForest had made by adding the grid to Fleming's tube, and it is difficult to understand why the court was guilty of this omission.

This decision, however, did not affect the right to use the audion for telephonic purposes, for which wire line rights A. T. & T. paid DeForest $50,000 in 1913.

In 1914, DeForest sold his radio rights to the telephone company for $90,000 retaining certain limited rights in connection with the use of the audion by amateurs.

In 1917, the telephone company, with its eye on radio telephony, purchased for $250,000 from DeForest "all the still outstanding rights under his patents, and under all his applications issued and to be applied for during the next seven years. Among these latter were the then pending feedback or regenerative audion patents"** which, as has been noted before, were adjudged in favor of DeForest in 1934.

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* Marconi Wireless Telegraph Co. of America v. DeForest Radio Telephone & Telegraph Co. et al, (District Court, S.D. New York, Sept. 20, 1916) from Federal Reporter, Vol. 23.

** History of Radio to 1926.

Chapter 5

THE ELECTRON

In the history of invention and development of much modern equipment, we find an interweaving of invention and discovery, scientific activity and development engineering. The history of the electronic tube is typical of this interweaving.

This idea has been very well expressed by Mr. J. R. Pierce: "Modern technology is made possible by some understanding of basic scientific laws or principles. Sometimes this understanding has come in the train of practical application; for instance, thermodynamics was strongly inspired by the empirical invention of the steam engine. In later times this order has come to be reversed. The most recent important contribution of physics to technology, the atomic bomb, is the outgrowth of long years of patient unraveling of nuclear physics; it would never have been made through mere garret inventing.

"The development of electronics had combined both of these prods to progress; its scientific foundations and its applications have been closely intertwined, and each has inspired the other. To explain the electron tube as the outgrowth of years of science for its own sake would be to under-estimate the importance of such a contribution of genius as Lee DeForest's invention of the audion, on which all our television, radio and long-distance telephony depend. On the other hand, much of our present detailed understanding of applied electronics has grown out of more basic studies, some aspects of which were available long before DeForest hit upon his invaluable invention without, perhaps, fully understanding its operation."*

The earliest use of the word, electron, appears to be its employment, in 1858, by William C. Richards, who wrote a poem ascribing telegraphy—then a comparatively recent invention—to the inflence of a sprite which he called the electron. Perhaps Richards was influenced by Thales of Miletus, 640-546 B.C., a Greek sage and philosopher, who believed that everything had a soul, including of course the magnet and amber. The Greek word for amber was "elektron."

In 1891, G. Johnstone Stoney, a British physicist, employed the word to characterize a fundamental particle of electricity.

In 1897, Joseph John Thomson proved the existence of the electron.

The effects of the electron were first observed and studied in partially evacuated glass tubes.

Heinrich Geissler (1814-1879), a German glass blower, who later became a physicist, experimented with air (vacuum) pumps which he used to exhaust the air from long glass tubes with an electrode sealed in each end. He noticed that when high voltage was applied to the electrodes the air which still remained in the partially exhausted tube glowed.

In 1878, Sir William Crookes experimented with tubes which

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* Scientific American, October, 1950—"Electronics," *by J. R. Pierce.*

were essentially Geissler's. He observed that the glow decreased with an increase of vacuum and almost disappeared with high vacuum; but, at this point, the tube wall opposite to the negative electrode began to shine. When he placed metal targets in the tube, they cast a shadow on the glowing spot. As a result, he concluded that the negative electrode was emitting particles which travelled in a straight line. He also found that the stream of particles or the ray could be deflected by a magnetic field. He established the fact that the brilliance of the glow varied with the different materials upon which the ray impinged.

In 1895, Jean Perrin, a Frenchman, deduced from the action of the ray in a magnetic field that the particles were negatively charged.

In 1897, Thomson started his investigation into the nature of these negatively charged particles. "He cut the cloud of charged particles down to a well-defined beam by passing them through two lined-up apertures, and to this stream he applied both an electric and a magnetic field.

"Now the two kinds of field act on a charged particle in different ways. An electric (electrostatic) field, created by a voltage between two sheets of metal, urges a negative particle toward the positive electrode whether the particle is moving or not. The electric force involved in the particle's attraction toward the electrode is proportional to the charge on the particle times the strength of the electric field. A magnetic field, on the other hand, exerts a force on a charged particle only if the particle moves across the magnetic lines of force. Hence the speed of the particle now enters the calculation; the force deflecting it is proportional to the speed of the particle times the charge on the particle times the strength of the magnetic field. When either a magnetic or an electric field bends the path of a particle, the amount of bending varies inversely as the mass of the particle.

"Thomson applied these facts to measure the physical properties of the particles. He first measured the deflection caused by a magnetic field of known strength. Since he knew the strength of the field, he was able to calculate the relation between the particle speed and the ratio of the charge of the particles to their mass. He then balanced the deflecting effect of the magnetic field by an electric field. This additional information told him the velocity of the particles. He could then calculate the ratio of charge to mass for the particles; that is, how much electricity they carried per pound. He found that this ratio of charge to mass was the same for all the particles, and that the particles were remarkably light. They were much electricity and little matter.

"Although Thomson's experiment showed that these new particles, now called electrons, were very much alike, it was not yet demonstrated that they were all the same. To do this, it was necessary to measure the charge carried by the particles, and this was done in a number of ways. The most decisive was a series of experiments begun in 1909 by Robert A. Millikan, then at the University of Chicago. He caught electrons by ones, twos and threes on tiny drops of oil and measured the forces exerted on them by an electric field. Millikan's experiments showed conclusively that all electrons have exactly the same charge. Clearly all electrons must also have the same mass, for Thomson had shown that all electrons have the same ratio of charge to mass."*. . . .

By 1926, H. Busch, a German physicist, had proved that an electron stream could be focussed by magnetic and electric fields much as a beam of light is focussed by lenses. This marks the beginning of electron optics which has resulted in television and in the electron microscope.

The atoms of all matter contain electrons, and there are several methods of obtaining free electrons to work with.

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* Scientific American, October, 1950—"Electronics." *by J. R. Pierce.*

". . . In a gas-discharge tube the process by which electrons are knocked out of the negative electrode is very complicated and roundabout. The free, moving electrons in the tube run into molecules or atoms of gas. When the collision is sufficiently violent, an electron may be knocked out of the molecule, which is thereby left with a net positive charge. This positive ion is attracted toward the negative electrode of the tube. On finally striking that electrode, it can knock one or more electrons out of the metal.

"Electrons can be knocked out of a metal or other substance by electrons as well as by positive ions. This is called secondary emission, the 'secondary' electrons being the electrons knocked out, as distinguished from the primary electrons which do the knocking. One primary electron may produce several secondary electrons. This process is of great technological importance. Equally important is the release of electrons by radiation such as light or X-rays, a phenomenon called photoelectric emission and employed in the photoelectric cell.

"But the form of electron release that has perhaps the greatest technological importance is thermionic emission, which means the escape of electrons from hot metal."* . . .

Thomas Edison discovered the best source of thermionic emission, namely, the Edison Effect. This was the source of the current observed by Mr. Edison in the discovery of current flow through a highly exhausted space.

"The free electrons in a metal are in continual motion. As the temperature of the metal is raised, the motion speeds up. If the metal is heated sufficiently, the electrons become so agitated as to boil right out past the barrier at the surface.

"That barrier is important. Electrons must move very fast indeed to escape from tungsten, the metal of which incandescent lamp fila-

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* Ibid.

ments are made; tungsten filaments must be heated white-hot to give much thermionic emission. In 1904 the German physicist A. R. B. Wehnelt discovered that if a metal is coated with certain substances, electrons can escape from it at much reduced temperatures. Later, through work at the Bell Telephone Laboratories and elsewhere, it became clear that oxides of barium and strontium are the most suitable coatings, and these are now almost universally used."* . . .

In the booklet on the invention and development of the incandescent light, published by the Thomas Alva Edison Foundation, attention was called to the work of Dr. William D. Coolidge in the development of the incandescent light. Dr. Coolidge succeeded in making tungsten, a resistant brittle metal, into a pliable wire which was capable of being drawn down to only 1/6th the diameter of a human hair. This ductile tungsten filament created a veritable revolution in the construction of incandescent lights and electron tubes.

X-RAY TUBE

Having succeeded in ductilizing tungsten, Coolidge turned his attention to x-ray tubes.

The x-ray tube had become quite standardized for fifteen years and consisted essentially of two electrodes, an aluminum cathode and a platinum anode or target. The x-ray output was limited by the melting point of the platinum which was strongly heated by electron bombardment. Coolidge successfully replaced the platinum with the much higher melting ductile tungsten and so, other conditions being the same, substantially increased the x-ray output.

The operation of the tube was, however, dependent upon the pressure of its gas content and, as this was subject to rapid and unpredictable changes, the control was difficult.

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* Ibid.

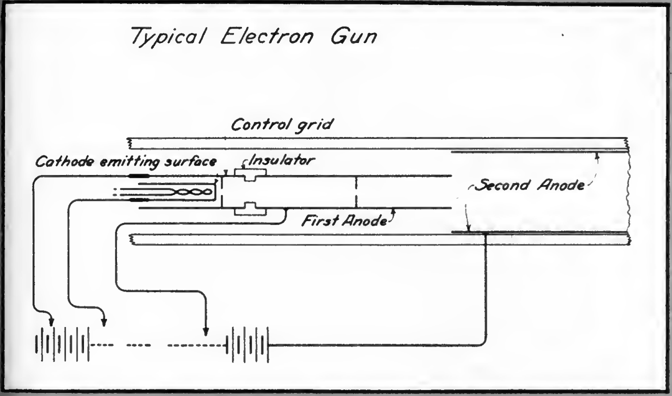
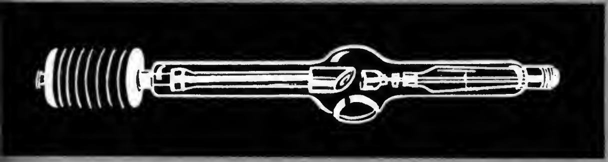
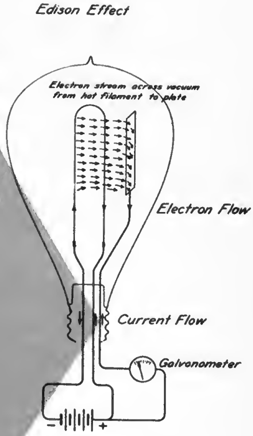


Fig. 1—Electron Gun (R.C.A.)





Encouraged by Langmuir's discovery that the Edison Effect persisted and was even favored by the absence of gas, Coolidge was able to develop a successful hot cathode, high vacuum x-ray tube. This eliminated the control difficulties inherent in the earlier form and made possible the development of tubes for much higher voltage.

"The term 'electron gun' is fairly new and is used to describe the part of the cathode ray tube which comprises the arrangements for generation, concentration, control, and focusing of the electron beam. Fig. 1 (page 45) shows a typical modern gun. The tubular cathode with a flat emitting surface is indirectly heated. The emitting surface is coated with some oxide preparation. The grid (control electrode) sleeve surrounds the cathode and has a circular opening just opposite the cathode emitting area. An insulator is inserted between the grid and an auxiliary anode, the latter often being called the first anode. The electrostatic field created by the potential applied to the first anode penetrates the grid opening and draws the emitted electrons into the beam. The beam enters the first anode and passes through a central aperture. The purpose of this aperture, called the masking aperture, is to cut off some of the peripheral portions of the beam similar to a stop in a photographic lens. Then the beam enters the region of the field produced by the difference of potentials between the first and second anodes. The second anode is usually in the form of a cylinder surrounding the first anode. It may be either a separate electrode or it may be in the form of a conducting coating on the inside of the glass tube. In this field a strong focussing action takes place, which gives the electrons a radial velocity component directed towards the axis of symmetry of the beam. The radial momentum acquired by the electrons is sufficient to bring them after a flight through the equipotential space of the main body of the bulb to a focus at the screen."* as in the case of the kinescope tube.

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* Television, July, 1936, RCA Institute Technical Press—"Theory of Electron Gun," *by I. G. Maloff and D. W. Epstein.*

TELEVISION

"The name 'kinescope' has been applied to the cathode ray tube used in the television receiver to distinguish it from ordinary cathode ray oscilloscopes because it has several important points of difference; for instance, an added element to control the intensity of the beam. Fig. 2 (opp. p. 49) gives the general appearance of the tube. Fig. 3 (opp. p. 49) is a cross-section view of one of these tubes, showing the relative position of the electrodes, especially the cathode and its surrounding assembly, which is usually referred to as the 'electron gun.' "*

This electron gun is, however, slightly different from the one already described. The first anode is still a cylinder but it has two apertures instead of one in order to better limit the angle of the emerging electron beam. The second anode, instead of being another tube, is the metallized portion of the inside surface of the neck of the kinescope tube. "The purpose of the second anode is to accelerate the electrons emerging from the electron gun and to form the electrostatic field to focus them into a very small, threadlike beam.

"The focussing is accomplished by an electrostatic field set up by potential differences applied between elements of the electron gun and the gun itself and the metallized portion of the neck of the kinescope.

"The lines of force of the electrostatic field, between properly shaped electrodes, force the electrons of the beams to move toward the axis, overcoming the natural tendency of electrons to repel each other. This action is analogous to the focussing of light rays by means of optical lenses."*

The iconoscope tube, the invention of Dr. Vladimir Zworykin, is the pickup or transmitting tube for television.

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* Television, July 1936, RCA Institutes Technical Press—"Description of an Experimental Television System and the Kinescope," *by V. K. Zworykin.*

Fig. 2—Kinescope (R.C.A.)

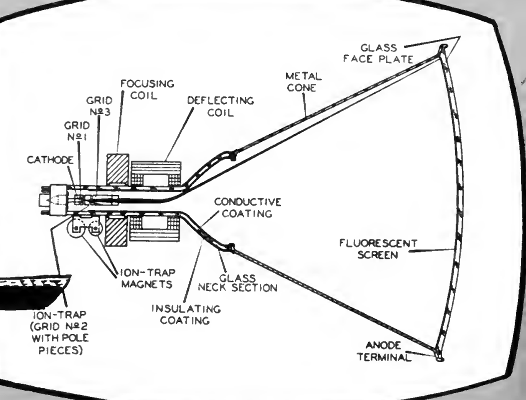

Fig. 3—Cross-Section Kinescope (R.C.A.)

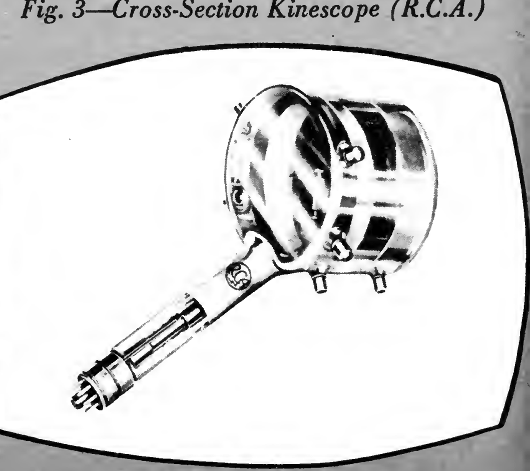

Fig. 4—Iconoscope (R.C.A.)

"This beautiful development, the iconoscope, made television practical. Zworykin is certainly the father of electronic television."*

"On the transmitting end this device took the form of a virtual artificial electric eye. The device was named iconoscope, the name being derived from two Greek words signifying 'image observer.' The photograph of this device is shown on Fig. 4 (opp. page).

"It consists of two principal parts enclosed in an evacuated glass bulb. The first part is the photo-sensitive mosaic, consisting of a metal plate covered with a great number of miniature photo-electric cells, insulated from the plate and each from the other. The function of the mosaic is similar to that of the retina of the eye. It transforms the energy of the light from the image into electrical charges and stores them until they can be transformed point by point into electrical impulses and transmitted. This transformation is accomplished by an electron beam scanner, the nerve of this electric eye.

"To complete the analogy of the iconoscope with the human eye, we shall mention that it possesses an electrical memory, because with a good dielectric the charges of the mosaic can be preserved for a considerable length of time.

"To fully understand the operation of the photo-sensitive mosaic of the iconoscope, it is best to consider the circuit of a single photoelectric element in the mosaic, as shown in Fig. 5 (opp. p. 50). Here is represented such an element, and its capacity to a plate common to all the elements, which hereafter will be called the 'signal plate.' The complete electrical circuit can be traced starting from the cathode to condenser element, then to resistance, source of e.m.f., and back to the anode. When light from the projected picture falls on the mosaic, each element emits electrons, and thus the condenser element is positively charged by the light. The magnitude of this charge is a function of the light intensity. When the electron beam which scans the mosaic strikes the particular element, that element receives electrons from the beam and may be said to have become

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* Dr. Wm. D. Coolidge in a letter to the author.

discharged. This discharge current from each element will be proportional to the positive charge upon the element.

“Fig. 6 (opp. page) gives an idea of conditions on the surface of the mosaic. Here the shaded picture represents the electrical charges accumulated by the individual elements of the mosaic due to the light of the projected image. Although the background of this image is of uniform density, the corresponding charges at a given instant are not uniform but vary, as shown on the left part of this picture. The highest charge occurs just before the exploring beam has discharged the elements. After the beam has passed the charge is momentarily near its equilibrium condition and begins to increase throughout the whole scanning period, attaining its maximum value again just before the scanning by the beam.

point of the picture, releases practically instantaneously the energy stored there during the whole 1/24th of the second. The electrical impulse created on the opposite side of the mosaic energizes the

“The electron beam, in neutralizing the charge of a particular

amplifier. . . .

“The schematic diagram of a complete electrical circuit for the iconoscope is shown in Fig. 7 (opp. p. 53). Here the two parts of the photo-element, shown on Fig. 5 (opp. page), are entirely separated. The cathodes are in the shape of photo-sensitive globules on the surface of the signal plate and insulated from it. The anode or collector is common and consists of a silvered portion on the inside of the glass bulb.

“The capacity of each individual element with respect to the signal plate is determined by the thickness and dielectric constant of the insulating layer between the elements and the signal plate. The discharge of the positive charge of the individual elements is accomplished by an electron beam originating in the electron gun located opposite the mosaic and inclined at 30° to the normal passing through the middle of the mosaic. Both mosaic and electron

Circuit of a single photo electric element

ERRATA SHEET

On page 50 delete lines 14 to 18 inclusive and substitute:

"The electron beam, in neutralizing the charge of a particular point of the picture, releases practically instantaneously the energy stored there during the whole 1/24th of the second. The electrical impulse created on the opposite side of the mosaic energizes the amplifier. . . .

Fig. 6—Conditions on Surface of Mosaic

(R.C.A.)

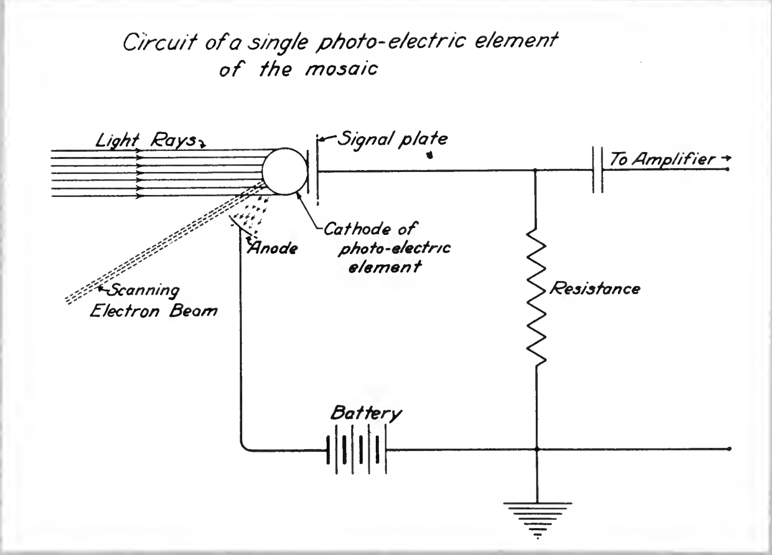


Fig. 5—Circuit of Single Photo-Electric Element

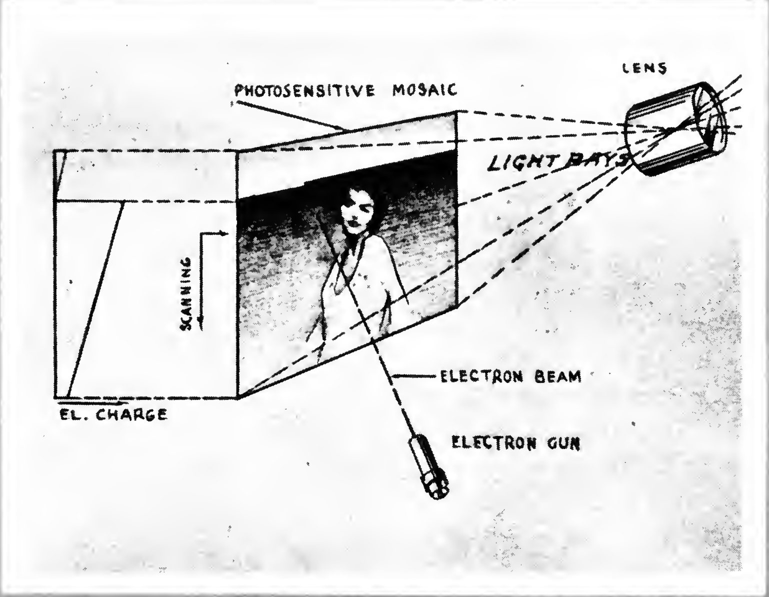


Fig. 6—Conditions on Surface of Mosaic

(R.C.A.)

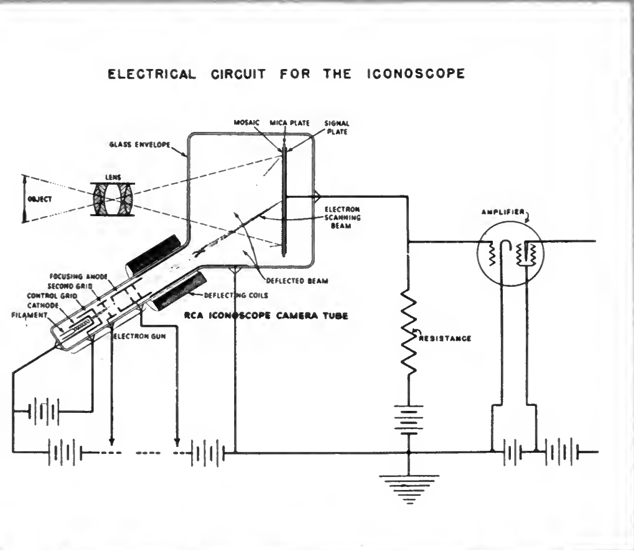


Fig. 7—Diagram of Iconoscope and Circuit

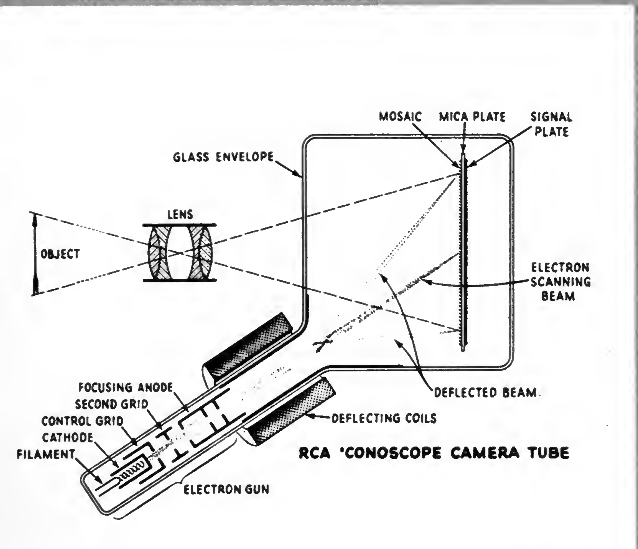
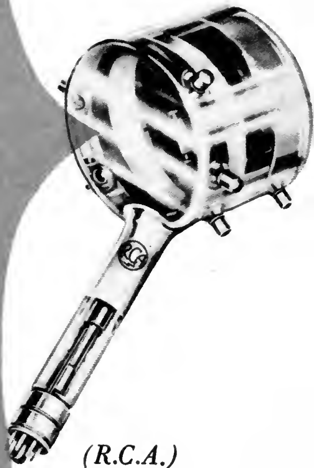


Fig. 8—Diagram of Iconoscope



(R.C.A.)

gun are enclosed in the same highly evacuated glass bulb. The inclined position of the gun is merely a compromise in the construction in order to allow the projection of the picture on the surface of the mosaic.

"The resolution of the iconoscope is determined by both the size and number of picture elements in the mosaic, and the size of the scanning electron beam. In practice, however, the number of individual photo-elements in the mosaic is many times greater than the number of picture elements, which is determined entirely by the size of the scanning spot.

"The requirement of uniformity, which at first glance appears quite difficult to obtain, is solved by the help of natural phenomena. It is known that such a common material as mica can be selected in a thin sheet of practically ideal uniform thickness and it therefore serves as a perfect insulating material for the mosaic. The signal plate is formed by a metallic coating on one side of the mica sheet. The mosaic itself can be produced by a multitude of methods, the simplest of which is a direct evaporation of the photo-electric metal onto the mica in a vacuum. When the evaporated film is very thin it is not continuous, but consists of a conglomeration of minute spots or globules quite uniformly distributed and insulated each from the other. Another possible method is that of ruling the mosaic from a continuous metallic film by a ruling machine.

"Although the initial method of formation of the photo-sensitive mosaic was the deposition of a thin film of alkali metal directly on an insulating plate, subsequent developments in the photo-cell art resulted in changes in the methods of formation of the mosaic. The mosaic which is used at present is composed of a very large number of minute silver globules, each of which is photo-sensitized by caesium through utilization of a special process.

"Since the charges are very minute the insulating property and dielectric losses should be as small as possible. Mica of good quality satisfies this requirement admirably."*

The electron gun is quite similar to the one first described except, in the iconoscope, the anode is a long cylinder with three apertures aligned on the same axis with the cathode and control element. The second anode consists of the metallized inner surface of the neck as well as part of the surface of the tube. This second anode also serves as a collector for photo-electrons from the mosaic. The components of the gun are shown on Fig. 8 (opp. p. 53). "The first anode usually operates at a fraction of the voltage applied to the second anode, which is approximately 1,000 volts.

"The focussing is accomplished by an electrostatic field set up by potential differences applied between parts of the electron gun, and between the gun itself and the metallized portion of the neck of the iconoscope.

"The deflection of the electron beam for scanning the mosaic is accomplished by a magnetic field. The deflection coils are arranged in a yoke which slips over the neck of the inconscope. The scanning is linear in both vertical and horizontal directions and is caused by saw-tooth shaped electrical impulses passing through the deflecting coils and generated by special tube generators."*

This ends the description of the early and historic tubes used in the development of electronic television. Needless to say, great improvements have been made since the period they represent.

RADAR

During the last war, the public became aware of the fact that a new branch of electronics had been developed prior to the war and known as radar. Radar is just another application of electronic tubes, embodying the Edison Effect.

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* **Television, July, 1936, RCA Institutes Technical Press—"Television,"** *by V. K. Zworykin.*

In this country, radar was mostly pioneered by Dr. A. Hoyt Taylor and his associates at the Naval Research Laboratory, Anacostia, D. C.

The Naval Research Laboratory was built in 1923, when Congress followed the recommendation of the Edison Naval Consulting Board that the Navy Department should establish a research laboratory. It was fitting and appropriate that such an enormous and vital extension of the art of electronics should have been made at a laboratory conceived in the mind of Thomas A. Edison.

In this connection, it should be noted that radar in this country is distinctly an American invention. Radar in England appears to have been principally the work of Sir Robert Alexander Watson-Watt. Both the American and the British independent achievements in radar stem from the experiments participated in by Taylor and Young of the Naval Research Laboratory, working with Dr. Gregory Breit and Merle A. Tuve of the Carnegie Institution, in measuring the height of the Kennelly-Heaviside layer of radio reflection.

Chapter 6

THE EDISON METHOD

Thomas A. Edison discovered that an unexplainable phenomenon existed inside of an incandescent light. Workers all over the world, whether they were inventors, physicists, engineers, scientists, or what, had the same opportunity to discover this phenomenon; but they didn't.

Edison discovered this phenomenon at a time when the electron was unknown. He discovered this phenomenon at a time when the schools were still teaching that an atom was the smallest unit of material.

"Mr. Edison is deserving of great credit for his discovery and publication of the fact that electric current could flow through the vacuous space of one of his highly exhausted lamps.

"Prior to that, we had known—or thought that we did—that no current could flow through a vacuum.

"Today, you can see the Edison Effect operating in, and making possible, our whole family of vacuum tubes, including of course the x-ray tube.

"Other men have studied the Effect, and many have, in various ways, applied the underlying principle; but it was Mr. Edison's work which opened the door to this whole field."*

It was Mr. Edison who discovered the best source of free electrons as distinguished from the captive electrons which produce the electric current in all wiring.

The development of the Edison Effect furnishes an interesting commentary on the change, or perhaps evolution, of the ways and means of dealing with material problems since the date of that discovery.

The chain of events was started by an inventor who often displayed, as he did in this instance, all the keenness of mind and all the great powers of observation so often, but not always, associated with a scientist.

In the next step we see a physicist, Fleming, actually working as an application engineer.

In phase three, a graduate engineer and inventor, DeForest, makes his contribution, among other reasons, because he lived and was educated during the early appearance of engineering schools in this country.

In the fourth or final phase, Arnold, Langmuir and Coolidge, each a combination of scientist and engineer so typical of the personnel of first-class industrial research laboratories, make their contributions which were possible because they were the products of modern technological education.

But there is more to it than that.

Organization of scientific effort started, not in universities but in voluntary societies, where amateurs in natural philosophy engaged in experimentation. Typical of these societies were the Acca-

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* Personal letter from Dr. William D. Coolidge to the Executive Director, Thomas Alva Edison Foundation dated 11 July, 1950.

demia del Cimento (The Experimental Society), Florence 1657, the Royal Society 1662, and the Academie des Sciences, Paris 1666.

"The development of science in the seventeenth century and, indeed, in much of the eighteenth, was the work of the scientific societies rather than of the universities. These societies assumed responsibility for the progress of science and developed the experimental method, which found no welcome in the universities of that period, steeped as they were in the spirit of tradition."*

Martha Ornstein says:

> *"It was the unmistakable and magnificent achievement of the scientific societies of the seventeenth century, not only to put modern science on a solid foundation, but in good time to revolutionize the ideals and methods of the universities and render them the friends and promoters of experimental science instead of the stubborn foes they had so long been."***

The rise of the industrial research laboratory is a phenomenon which reminds one of the rise of the scientific societies in the seventeenth and eighteent centuries. Both arose outside of universities. The one, at least at its inception, usually enjoyed the support of a prince or a sovereign. The other represents a self-supporting art. How indispensable the industrial research laboratory has become to industry may be realized when it is learned that one company announced recently that forty per cent of its current sales consists of new products developed by its laboratory in the past decade.

Edison appears to have started the first organized industrial research laboratory at Menlo Park in 1876. When he moved to Orange (now West Orange), the first thing he did was to build another laboratory.

Present-day electronic tubes are clearly the development of in-

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* Reprinted by permission from THE PATH OF SCIENCE, *by C. E. Kenneth Mees,* Published by John Wiley & Sons, Inc., 1946.

** The Role of Scientific Societies in the Seventeeth Century, *by Martha Ornstein,* University of Chicago Press, 1938.

dustrial research laboratories, which are engaged in everything from pure research to engineering development and application engineering. One exception appears to be the development of the magnetron (radar) tube by the University of Birmingham, England.

"The progress of the electronic art through the past two decades has been of such magnitude it is difficult to assess it in technical terms. The applications in communications, in industry, in applied science and in medicine are so various, that even to list them is a formidable task. It is simpler to cast the review in terms of the common denominator of all electronic development, the electron tube itself."*

In 1930, 59 active tubes were listed in the "RCA Tube Handbook." In 1950, the RCA handbook noted 689 types.

"Production of tubes has reached well into the billions. Well over three billion receiving tubes have been made in the U. S. A. alone. Receiving-tube sales averaged about 50 million annually from 1930 to 1935. Since the war the rate has been 200 million or more annually. During the war even higher figures were reached. One series alone, the proximity-fuse tubes, achieved a total production of 130 million."*

The fact is that all of the research and development in connection with vacuum tubes, thermionic tubes, electronic tubes, or whatever you may call them, was founded on the discovery of the Edison Effect by Thomas A. Edison.

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* Electronics, April 1950, a McGraw-Hill publication. ("Electron Tubes 1930 to 1950")

Acknowledgments and Bibliography

Acknowledgment is made to Dr. William D. Coolidge and to Dr. Karl T. Compton for reviewing the manuscript of this booklet; to Mr. Norman R. Speiden, Curator of the Edison Museum, for drafting work; and to Mr. Joseph S. Wheelan for reduced photographs of the drafting diagrams and pictures of electronic tubes.

Acknowledgement is also made to the Radio Corporation of America for permission to use diagrams and photographs in connection with the material on television.

Appreciation is expressed for permission to make quotations from the following:

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LETTER TO EXECUTIVE DIRECTOR, THOMAS ALVA EDISON FOUNDATION, FROM DR. WILLIAM D. COOLIDGE, July 1950

FILES OF THOMAS A. EDISON

Purposes of

The Thomas Alva Edison Foundation

The THOMAS ALVA EDISON FOUNDATION, INC., was created to keep alive and active, for the benefit of present and future generations, the inspiration and genius exemplified in the life, accomplishments, and ideals of Thomas A. Edison and thereby to stimulate research and educational activities for the more effective advancement of human welfare.

The Foundation was established in June 1946 to assist, encourage and conduct investigation, research and discovery in the arts, science, industry and the conduct of public affairs and government, particularly in the fields in which Thomas Alva Edison made such notable inventions and distinguished contributions, and to which he devoted his life; to foster and develop means and methods to reduce to practical use the results of such investigation, research and discovery, and to provide for the teaching and dissemination of knowledge and the publication of data of all kinds; and to establish or maintain, in whole or in part, charitable, scientific, literary or educational activities, agencies, institutions or corporations, or aid any such activities, agencies, institutions or corporations already established.

At the present time the Foundation is engaged in three principal activities.

The Laboratory and Library of Mr. Edison at West Orange, New Jersey, are open to the public. The Exhibition Room has been extensively equipped with exhibits of Mr. Edison's work, and the display of Edisonia is constantly being enlarged. Schools are encouraged to include a guided tour of these activities in their schedules of field trips for student groups.

Each fall and winter the Foundation sponsors the Edison Lecture Series. During each series, distinguished speakers present addresses on various facets of our modern industrial state and, particularly, Mr. Edison's connections therewith. These lectures have set a high standard in explaining industry's position and have received an enthusiastic response.

The Foundation also has under way a study of Mr. Edison's technique in order to arouse, through publications, a greater interest in the art of invention. To this end, booklets describing Mr. Edison's principal inventions are being published. The Foundation is making a point of bringing the stories of these inventions up to date so as to show the almost incredible effect of Mr. Edison's original inventions on today's industry and, also, because they provide excellent examples of what happens to an invention when it becomes subjected to modern technological development. An attempt is being made to write these booklets in a vein which will appeal to students of the sciences and to foremen and skilled workers in the shops throughout the country.

Through the publication of the booklets, the Foundation hopes to set forth the technique Mr. Edison used so that others may follow in his footsteps and, in conjunction with the lecture series, to educate the American public on the fundamentals of our present industrial civilization.

Plans are being formulated to expand the Foundation's usefulness into other activities within the scope of its objectives as funds become available.

For the support of existing and proposed activities, donations and bequests will be gratefully received by the Foundation. For those who wish to make the Foundation a beneficiary under their wills, the following form is suggested:

> *"I hereby give and bequeath to the THOMAS ALVA EDISON FOUNDATION, INC., incorporated June 1946 in the State of Delaware, having an office at the Edison Foundation Center, Main Street and Lakeside Avenue, West Orange, New Jersey, the sum of ...."*

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