# THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

***Part 3 of this series covering the Edison era, illustrating many of his outstanding inventions and the problems encountered.***

IN 1851 Professor Heinrich Buff, of the University of Geissen, published a paper [75] on the electrical conditions existing in flames. He came to the conclusion that gaseous bodies which have been rendered conductive by strong heating are capable of exciting other conductors, solid as well as gaseous, electrically. At that time the incandescent lamp was far in the future, and the experiments reported were made using two small strips of platinum introduced into a glass tube which was closed at one end. Experiments involving heating the tube even to the softening point of the glass gave a negative result, but when the strips of platinum were exposed to the direct action of the flame of a spirit lamp, a current flowed between the strips, the flow being from the hotter of the two strips toward the colder.

Edward Becquerel, illustrious son of an illustrious father, in 1853 began a study of the electrical conductivity of gases. His method was to apply heat externally to a platinum tube, down the axis of which were stretched two parallel platinum wires, maintained at a difference of potential by a low voltage battery. This procedure was varied in some cases by using the tube as one electrode and a platinum rod placed axially in the tube, and supported at one end, as the other electrode. From his experiments with this apparatus, and the measuring equipment which had been developed by the work of the men of whom we have previously spoken, he came to the following conclusions: [76, 77, 78]

*(1) Gases become conductors only at or above the temperature corresponding to red heat, and as the temperature increases so does the conductivity.*

*(2) At such temperatures they are conductors even when a low voltage is applied.*

*(3) The relative dimensions of the electrodes have an effect on the conductivity of the gas, the conductivity increasing rapidly with the surface of the negative electrode.*

*(4) The resistance of the gas varies with the applied voltage, and with the current through it, that is, it does not obey Ohm's law.*

*(5) Below red heat the pressure of the gas has little effect, there being no conduction at low voltages. Above red heat rarefaction of the gas increases the conductivity.*

We know now that these effects noted by Becquerel were due not alone to the fact that the gas was heated, tending to produce ionic conductivity, but also to the fact that the electrodes were heated, whereby thermionic emission was taking place. The results attained by Becquerel do not seem to be widely known, as little credit is given to him in later treatises on the conduction of electricity through gases.

Gustav Wiedemann refused to concede the possibility of gaseous conduction and attempted [79] to explain away Becquerel's results by attributing them to changes in the conductivity of the cement used in sealing the electrodes in place. Blondlot, in 1881, confirmed [80] the results of Becquerel and disproved the contention of Wiedemann.

Fredrick Guthrie, in 1873, repeated Nollet's procedure of more than a century before, of heating iron white hot and testing it for discharging power as it cooled. He found [81] that at white heat an iron ball would retain neither a positive nor a negative charge of electricity, but that at red heat it could retain a negative charge but not a positive one.

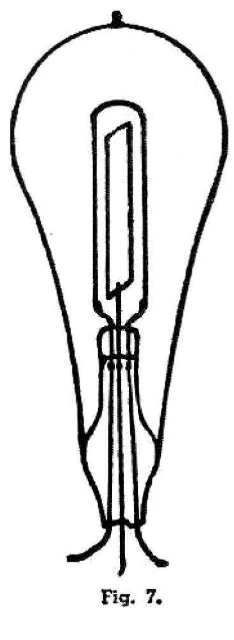


Fig. 7.

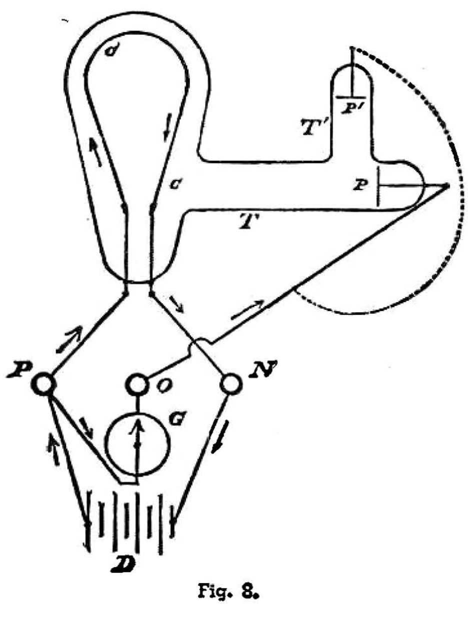



Fig. 8.

### The Edison Effect

In 1879 Thomas A. Edison finally succeeded in "subdividing the electric light" when he brought the incandescent lamp to commercial practicability. He was still at work perfecting it

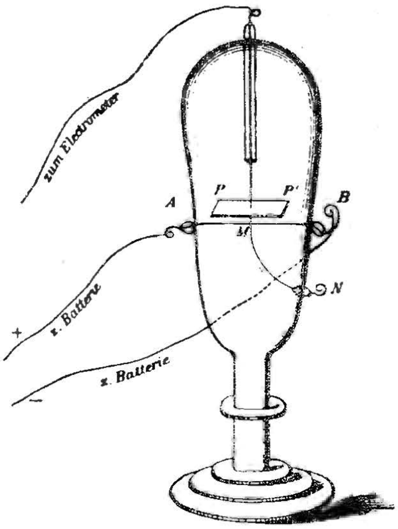



Fig. 9.

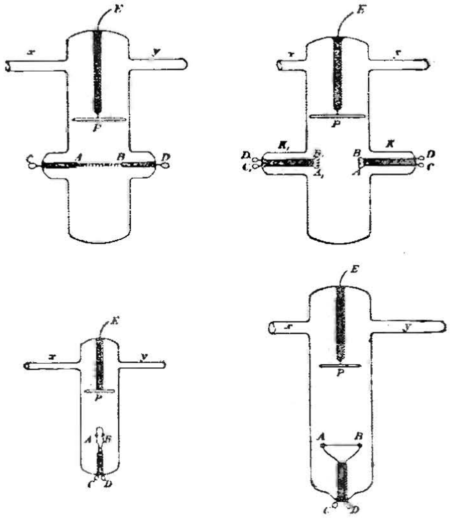


Fig. 10.

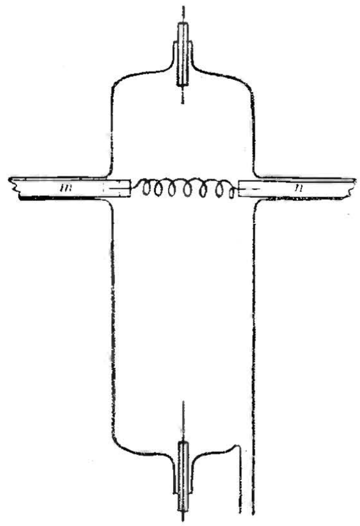


Fig. 11.

some four years later, when he observed and recorded the phenomenon which received the name of the *"Edison effect."*

During his experiments he observed that as the time of operation of his incandescent lamp increased, the light output was reduced by a blackish deposit on the interior of the glass bulb.

In the course of his investigations he noted two other things which were of great importance. The first was that there was frequently to be found on the glass, in the plane of the filament, a line which was not blackened. The second, and this was the more important of the two, was that the leg of the filament which was connected to the positive pole of the circuit was always that which "cast the shadow." It appeared that the opposite side, which was connected to the negative pole, was throwing off minute particles of filament material which traveled outwards and were deposited on the glass everywhere except where the glass was screened by the positive leg of the filament.

In order to study this effect more in detail, Edison had constructed some lamp bulbs containing filaments and, in addition, small metallic shielding plates placed between the legs of the filament. He found [82] that if this plate was connected to the positive end of the filament a current would flow across the vacuous space, but that no current would flow if it were connected to the negative end.

Seemingly the only use which Edison could imagine for this device was as an indicator to show variations of potential on the lighting circuit. In his patent application,[83] filed November 15, 1883, for an "Electrical Indicator," the lamp apparatus used is shown in Figure 7. In this application, however, there is to be found this very significant clause concerning the current across the vacuous space—"This current I have found to be proportional to the degree of incandescence of the conductor or the candle power of the lamp."

Probably because of the work involved in the introduction of the incandescent lighting system, Edison did not have time to carry on further experiments. Even had he done so, and evolved a *"valve"* he would have been at least ten years ahead of his time.

The publication of the *"Edison effect"* aroused interest in many places. In the first paper printed in the first volume of the Transactions of the American Institute of Electrical Engineers, Professor Edwin J. Houston gave "Notes on Phenomena in Incandescent Lamps." In this paper [84] Professor Houston referred to the "peculiar high vacuum phenomena observed by Mr. Edison in some of his incandescent lamps." He then went on.

*"The question is, what is the origin of this current? How is it produced? Since we have within the globe nearly a complete vacuum, we cannot conceive the current as flowing across the vacuous space, as this is not in accordance with our preconceived ideas connected with high vacua."*

Professor Houston described another of Mr. Edison's experiments which appeared to throw no little light on the matter. The apparatus used in this experiment is shown in Figure 8 (which is Figure 3 of Houston's paper). Instead of placing the cold electrode between the legs of the filament, as had previously been done, he placed two cold electrodes as shown at "P" and "P$^1$." Edison found that if the galvanometer was connected to the plate "P" as shown by the solid line, a

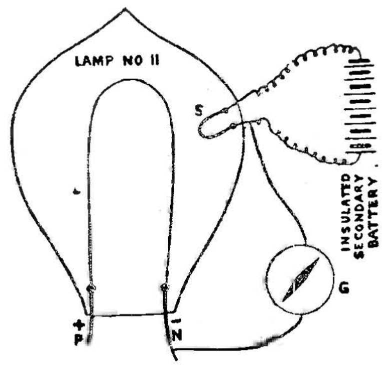



Fig. 12.

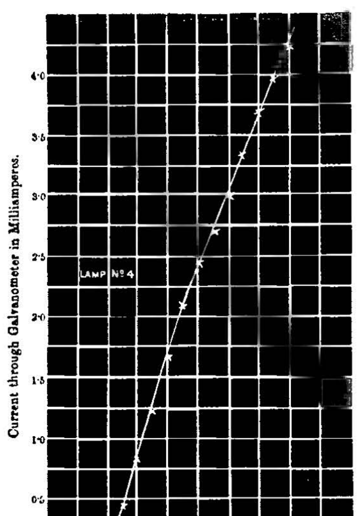



Fig. 13.

current flowed through it, but that this was not the case when it was connected as shown by the dotted line, to "P1." Apparently the current could not flow around a corner.

Among those present, and taking an active part in the discussion which followed the reading of this paper was Sir William Preece, who was extremely interested in the new phenomena. He announced that he intended to exercise his persuasive eloquence upon Mr. Edison to induce Mr. Edison to give him one of these lamps and said:

*"When I go back to England I shall certainly make an illustration before our society there, and then make careful inquiry into it."*

How he succeeded and what he did will be seen later.

Let us now return for a while to Germany. Julius Elster and Hans Geitel, beginning about the year 1880, pursued a series of investigations in that country. The results of these researches were reported in a series of articles beginning in 1882. The first four of these articles[85] deal with the characteristics of flames, particularly with reference to their unsymmetrical conductivity, and in part confirm the earlier work done along these lines. The fifth article[86] which appeared in 1887 is entitled "On the Electrification of Gases by Glowing Bodies." In this article experiments were described involving the use of a glass bulb, which could be exhausted or filled with various gases. Across the inside of this bulb was stretched a platinum wire which could be heated electrically. See Figure 9. Opposite this wire, and very close to it, was placed a platinum plate suspended by a leading-out wire. The vacuum used was described as "the best possible—such as Crookes used in his famous experiments." The results of these experiments of Elster and Geitel indicated that *"Electrified Particles"* were thrown off from the glowing wire uniformly in every direction and that the conductivity was unilateral.

The next paper,[87] published in 1889, is entitled "On the Excitation of Electricity when Galvanically Glowing Wires come in Contact with Heated Gases." In this paper various experiments were described involving the use of glowing platinum wires and glowing carbon filaments in exhausted bulbs, with cold electrodes of platinum placed at various distances from the glowing members. Mention is made of the fact that the carbon filament always excites the cold electrode negatively. The bulbs were so constructed that they could be placed within the poles of a magnet of the horse-shoe type, and the effect of the magnet on the apparent conductivity of the vacuous space was noted.

In the latter part of this paper a theory, first enunciated by A. Schuster, is used to explain the unipolar conductivity. This theory is based on the dissociation of the gas molecules by contact with the glowing body. It is interesting to note that in this paper Elster and Geitel acknowledge that their work was made possible by a grant of American funds, provided by the Elizabeth Thompson Science Fund of Boston.

The last paper of this series was published[89] in 1889 and describes further experiments with various other tubes of the forms shown in Figure 10.

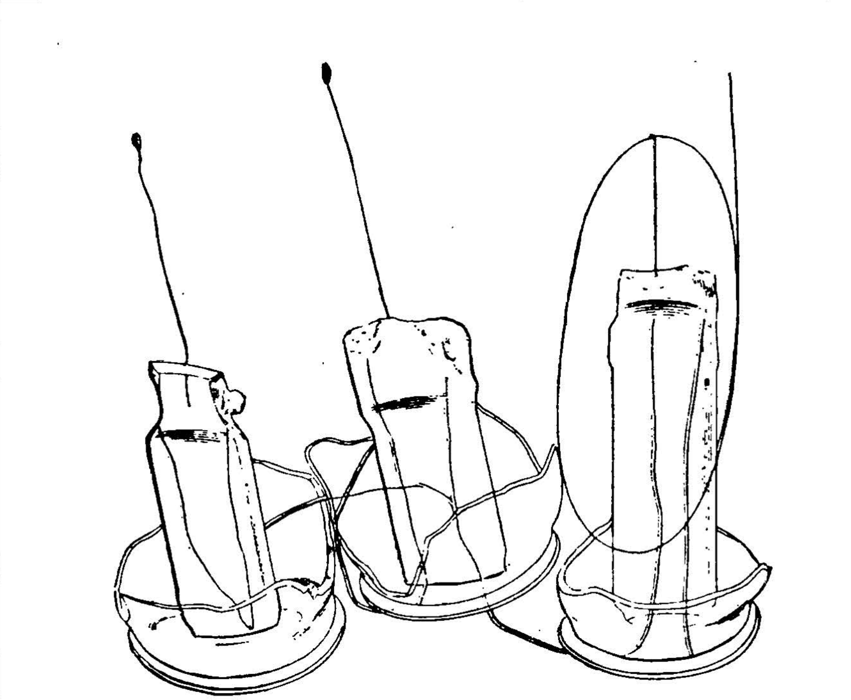


Fig. 14.

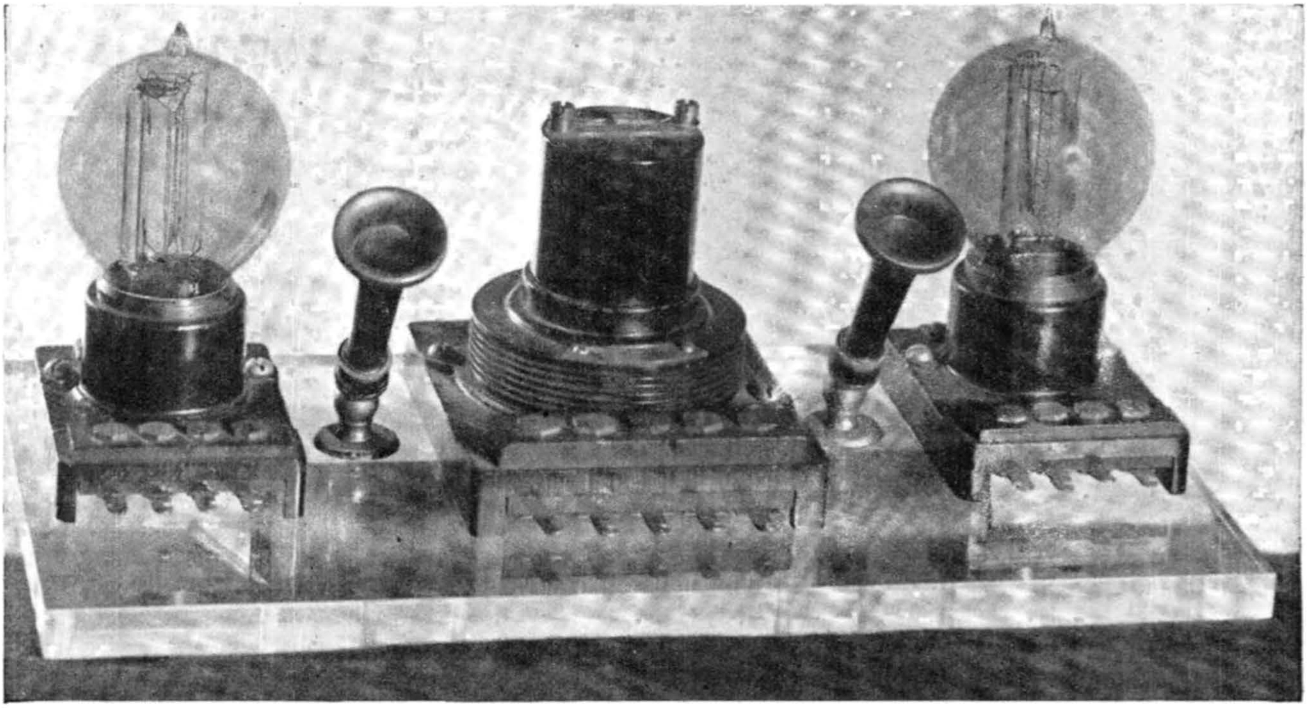
While Elster and Geitel were conducting their investigations another German scientist, William Hittorf, had been for some time working on gaseous conduction. In his work Hittorf made use of high voltages, developed from a large number (2400) Bunsen cells connected in series. This gave about 4000-4500 volts, with which he could observe phenomena of the type seen in the days of static electricity, but which he could reproduce at will, and sustain long enough to permit of taking accurate observations. Hittorf's first paper "On the Conduction of Electricity in Gases" appeared[90] in 1869, his second[91] in 1874, his third[92] in 1879, and his fourth[93] in 1883. In these papers Hittorf describes his work on conduction in rarefied gases, using cold electrodes. It is in his fifth paper, which appeared[94] in 1884, that we first find reference to the use of a cathode which was heated by external means. The apparatus used is shown in Figure 11. He was led to the use of this cathode by the difficulties he experienced with the evolution of gas from the electrodes previously used.

These electrodes became hot, owing to the high energies of the gaseous discharge and the occluded gases which were released impaired the vacuum and affected the discharge. To obviate this difficulty he used a cathode which could be maintained at a high temperature by means which were independent of the discharge. Hittorf's publications are dry, almost repulsive, reading and their value was buried deep in the mass of experimental data which he reported.

The experiments which he performed were essentially those of Becquerel, except that he used higher voltages and better vacua and was able to heat one electrode at a time. He observed that when the spiral platinum cathode was brought to or above a red heat, the conductivity of the gaseous space rose rapidly with the increase of cathode temperature, and that a similar condition was observed if the cathode were made of carbon. He noted[95] (as Becquerel had previously done) that the conductivity increased as the pressure of the gas was lowered.

He also noted that even with the cathode heated by means of an external auxiliary battery it was necessary, in order to maintain the vacuum, to continuously remove, by means of the pump, the gases given off. He observed that the current flowed only when the heated electrode was used as a cathode, at low voltages, that is, that the conductivity of the space was unilateral at those voltages. In this he went a step further than Becquerel, who could not have made such an observation since, due to his experimental arrangement, both his electrodes were heated.

Having thus followed the progress of investigation in Germany up to about 1890, let us now return to England. Early in 1882, after the formation of the Edison Electric Light Com-



**A rather odd but interesting desk set made up of Western Electric antique tubes and sockets.**

pany of London, John Ambrose Fleming (later Sir John Ambrose Fleming) was appointed electrical adviser to the company. He was thus brought into close touch with the many problems which arose in the use of incandescent lamps. He, like Edison, soon noted that when carbon lamps were blackened in service there sometimes was found on the glass, at a point opposite where the filament had finally burned out, a lighter deposit of the black material than was to be seen elsewhere on the glass.

This he termed a *"Molecular Shadow."* His first mention of it comes in a paper read before the Physical Society of London on May 26, 1883.[96] In this paper he observes that the shadow is found only where there is a copper deposit on the inner surface of the glass bulb, never with the ordinary carbon deposit. This paper was a short one, more or less of a summary, to precede a full discussion. The full discussion, however, did not appear until some two years later, on June 27, 1885,[97] which was some time after the discovery of the Edison effect had been announced. In this latter paper he notes that in some cases where only carbon deposit existed he observed the same molecular shadow as in the case of the copper deposit, wherever both legs of the filament were in the same plane, and the filament had burned out due to the development of a hot spot.

Meantime Sir William Preece had returned from America with the fruits of his "persuasive eloquence" in the form of some of Edison's lamps. With these lamps he proceeded to duplicate the experiments he had observed in America and make quantitative measurements of the Edison effect. The results of these experiments were presented to the Royal Society in 1885.[98]

The paper opens by describing the experiments he had witnessed in America and then goes on to describe his own work using Edison's lamps. It is in this paper that we first find mention of *"blue glow"* or *"blue effect"* (due to the ionization of the residual air) which defied explanation for a long time. This appeared when the lamps were operated somewhat above their rated voltage. In the presence of this *blue glow,* Preece observed that current could be made to flow not only from cold to hot electrode, but also in the reverse direction.

He observed that the current was unaffected by the material of which the cold electrode was composed, but increased rapidly with increasing potential across the lamp. That is, he confirmed Edison's observation that this effect was proportional to the degree of incandescence of the lamp, as stated in his patent which had previously been issued.

On February 14, 1890, Fleming gave a Friday evening discourse before the Royal Institution on "Problems in the Physics of an Electric Lamp." [99] He again discussed *molecular shadows* and the reason for their formation. He also reviewed the work of Preece and repeated his experiments. In addition he showed that a single Clark cell would cause a flow of current across the vacuous space if the positive pole of the cell was connected to the cold electrode, but that if the battery was reversed there was no flow of current. This was in agreement with the results attained by Hittorf in 1884, who showed that even a small voltage was sufficient to send a current across the vacuous space, provided the cathode was a high temperature and the positive pole of the battery was connected to the cold electrode (plate).

Fleming also showed that if the cold electrode is heated to incandescence then the current may be made to flow, by the use of the external battery, in either direction through the vacuous space. Fleming did this by means of the apparatus shown in Figure 12. It should be remembered that this same conclusion was reached by Becquerel, with somewhat poorer vacua, in 1853.

These investigations were carried still further and resulted in another paper before the Physical Society of London on March 27, 1896, and entitled "A Further Examination of the *Edison-Effect* in *Glow Lamps.*" [100] In this paper Fleming repeated some of the quantitative experimental work previously done by Preece and gave a curve (See Figure 13) which showed the relation between the potential across the lamps, and the current through the vacuous space. He also announced that even if alternating current was used to heat the filament, that a unidirectional current was obtained in the cold electrode circuit.

The last important work prior to the application of the vacuum tube as a rectifier of high frequency oscillations in wireless telegraphy is recorded in a paper given before the A.I.E.E. in February, 1897, by John W. Howell.[101] This paper was intended as a discussion of the paper by Houston, previously mentioned. It discusses the *Edison-effect* phenomena which occur in lamps when the *"blue glow"* is pronounced, and states that the presence of the blue glow indicates the passage of electric current across the vacuous space. This paper is remarkable in that it is the first to show that currents of more than a few milliamperes may be made to flow across the space

*(Continued on page 75)*

substantial reason for adopting "electronic" as an American all-inclusive term for radio.

Scientists and engineers who have used such care in coining contemporary terms as neutron, magnetron, iconoscope, photo, etc., when they realize the confusion that is now occurring will want to do something about it. Remember, this is the same type of confusion as that between "radio" and "wireless."

*We are not in doubt.* "Radionics" is descriptive of the scope of this science, and, therefore, RADIO NEWS will use "radionic" in preference to "electronic" wherever it is more descriptive.

There may be exceptions where the term "electronic" is used as a trade name or in a direct quotation from an engineering paper, etc. However, with these possible exceptions, "radionics" will be used in the future by this publication.

RECEIVERS that will see, hear and print were predicted for the post-war era by *James L. Fly,* Chairman of the F. C. C. He said that while such a device may seem to be an impossibility now, present developments appear to make the design of a combination television, facsimile and broadcast receiver entirely feasible. Said Mr. Fly, in explaining the prediction . . . "There will be only one service, and separate television. Standard, F.M., facsimile services and separate receivers will all be washed out. I would conjecture that such an instrument will be based upon the best of the developments we have had to date and those that we get out of the war, and it will be a chain operation carried on by relay. Relay problems are pretty well licked now. We have been in the horse-and-buggy days up to now."

That's quite a strong prediction, but it isn't as fantastic as it may sound!

WHICH reminds us, how are so-called radio servicemen to be classified in the days to come? What with new services and new techniques, it seems that some serious thinking should be done by those keenly interested in making their living in the radio industry from the service standpoint and that they decide now as to which phase or portion of the art will offer the greatest personal appeal.

After this decision is made it would be advisable to obtain as much knowledge of that field as possible. There will be hundreds of new radionic and other gadgets, new television receivers, etc., that must be serviced intelligently by someone. Only by carefully planned study, can the serviceman of tomorrow be recognized!

AS we go to press with this issue, we continue the interesting task of preparing our June issue which we believe will be the most outstanding presentation ever made on the activities of the various branches of Aviation Communications. Among the many specially prepared feature articles will be included factual data by the U.S. Army Air Forces, Navy, Marine Corps, Coast Guard, Civil Aeronautics Administration, and the Civil Air Patrol. In addition, there will be a complete analysis of the part that the radio Industry is playing to supply the aviation services with vital equipment. Never before in our history have we found a closer cooperation between Industry and our Military Branches.

One of the highlights of the June issue will be the appearance of an exact replica of the famous *McElroy* code chart which includes every known code, Arabic, Russian, International Morse, American Morse, Japanese, Spanish, Flag Signals, "Q" Signals, and many others. Printed in color—this chart will be well worth keeping by every reader of this important issue.

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**Saga of the V.T.**
(*Continued from page* 29)

at moderate voltages. Howell states that he had measured vacuous currents in an ordinary carbon incandescent lamp, of more than *25 amperes,* which were sufficient to expand the platinum lead-in wires and shatter the glass.

The effects obtained are shown in Figure 14, which is reproduced from Howell's paper. He also showed that in the presence of the *"blue glow"* the Edison-effect current will flow around corners. In the discussion of this paper, Professor A. E. Kennelly said, "It is interesting to observe that a vacuum tube, in the broadest sense of the word, is capable of supplying . . . continuous currents from alternating currents."

Up to this time, it is to be noted, no one except Edison had shown any technical application of the *Edison-effect.* It is probable that Edison did so primarily for the purpose of obtaining patent protection, although Frank J. Sprague, in a letter to William J. Hammer, dated December 27, 1883,[102] praises the arrangement as an extremely sensitive indicator of small changes in voltage at the operating potential of the lamps.

With these experiments we have reached the end of the pure scientific investigation alone in this field. Inventors, making use of this knowledge, were responsible for the next step in development.

This might naturally be expected with the increase in the pace of living. Man's rapidly increasing demands could not wait for complete knowledge before insisting upon practical applications. Man stated his objective, and electrical experts proceeded to clear the path toward that objective.

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Fig. 7. Drawing of Edison effect lamp. Reproduced from U.S. Pat. No. 307031, issued October 21, 1884.

Fig. 8. Edison effect lamp used by Prof. Houston. Reproduced from Trans. A. I. E. E. 1884.

Fig. 9. Tube used by Elster and Geitel in 1887. Reproduced from Annalen der Physik, 1887.

Fig. 10. Tubes used by Elster and Geitel to demonstrate unilateral conductivity. Reproduced from Annalen der Physik, 1889.

Fig. 11. Tube used by Hittorf to demonstrate unilateral conductivity. Reproduced from Annalen der Physik, 1884.

Fig. 12. Tube used by Fleming to demonstrate bi-directional conductivity as unidirectional conductivity. Reproduced from Phil. Mag. 1896.

Fig. 13. Curve showing relation between Edison effect current and lamp voltage. Reproduced from Phil. Mag. 1896.

Fig. 14. Incandescent lamp stems which have been subjected to space currents of 25 amperes. Reproduced from Trans. A. I. E. E. 1897.

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*(To be continued)*

### Electronic Drive
*(Continued from page 12)*

similar application is that of synchronizing the speed of conveyors with that of a material in a plastic state as it emerges from an extruding machine, and for maintaining a fixed relationship between two or more conveyors which must handle the same material. Numerous applications of this type may be found in the rubber industry.

#### Electrical Feed-back Arrangement

Where speed regulation is an essential factor, the electrical feed-back arrangement, utilizing a pilot generator with a suitable circuit, makes it possible to hold the speed of a motor very nearly constant over a wide range of loads.

As in the mechanical arrangement, a full-wave rectifier is used, but a saturable reactor instead of a movable core reactor varies the output of the voltage on the motor.

#### Full Automatic Control (Thy-mo-trol)

Experience with the type of equipment just described has resulted in the development of the Thy-mo-trol system by General Electric. This control in combination with a suitable motor provides a variable-speed drive with features which are not ordinarily found in other conventional drives.

This electronically controlled motor drive was not developed with the idea that it can or will supplant the various other types of mechanical and electrical drives in use today, where such