THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE

Born at Binghamton, N. Y., 1899. Attended Canisius College & Rensselaer Polytechnic Institute. Served at latter as instructor, 1921-29. Since then has been engaged in development work in one of largest research and engineering organizations. Was ham 1912-15. Started collecting tubes in 1923 and studying tube history in 1932. Has to call in serviceman when anything except a blown fuse develops in his own home set.

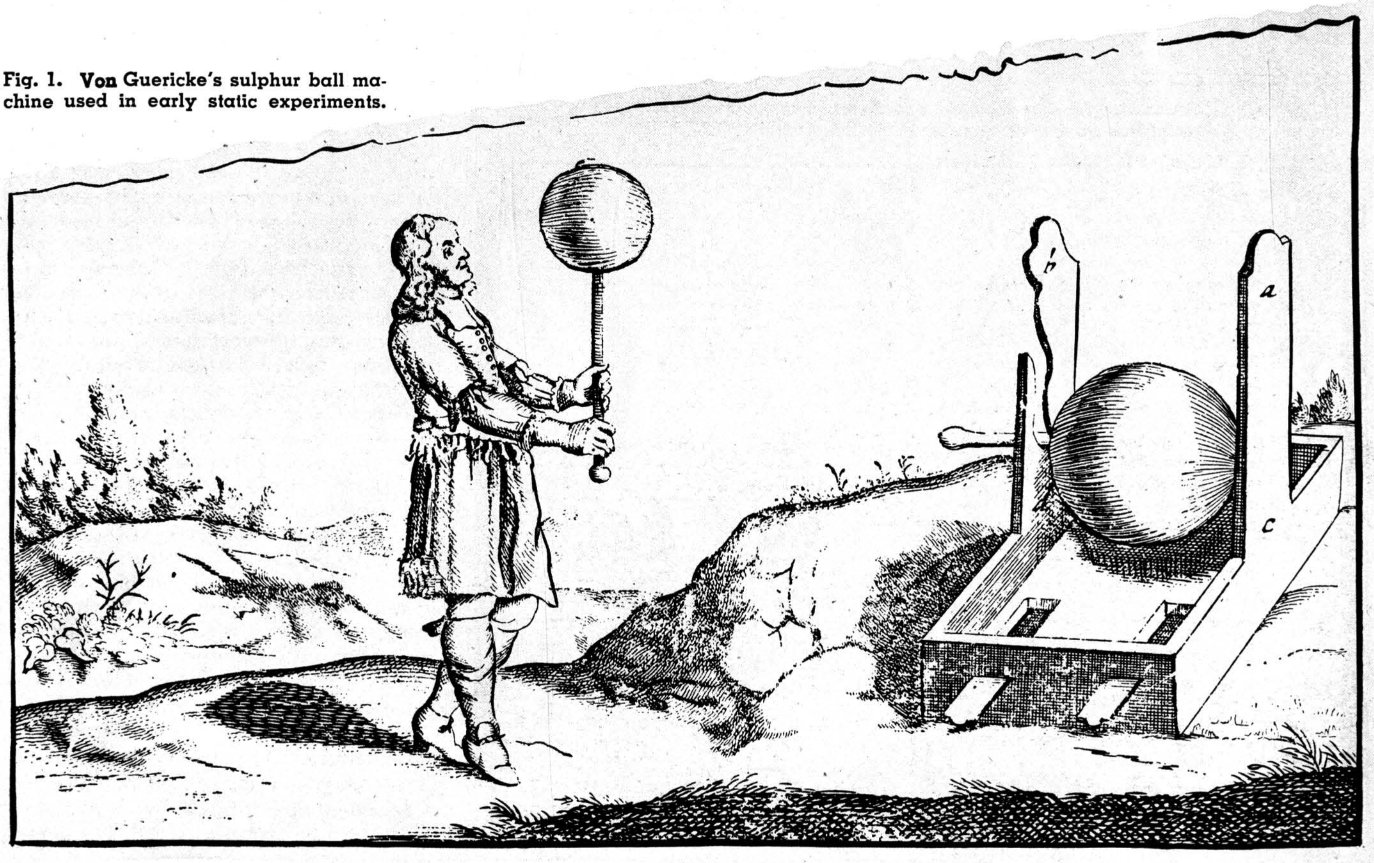
THE modern vacuum tube may well be regarded as the goal toward which scientists were groping for approximately two hundred and fifty years. The early scientists were seeking an explanation of known electrical phenomena, trying to extend the scientific knowledge of the world, and their contributions to later investigations became of great importance. Actually two centuries of scientific research went into building the foundations of the science of thermionics. Another fifty years elapsed before scientists and technical experts produced the tube which in one generation affected everyday living for people all over the world. Around this tube great industries have been built, great fortunes made and lost. In the short space of fifteen years after its first practical application the tiny glow from this tube lighted up endless paths for study in communication, medicine, and other fields. It shed light on some of the darkest mysteries of nature. The culmination of this two hundred and fifty years of tireless searching, studying, and experimenting was the modern Aladdin's lamp, the vacuum tube.

These men of science spent lifetimes spurred on by the conviction that if the electrical phenomena could be understood, this great force in nature might be harnessed and utilized. The solving of the mystery of the combined effects of heat and electricity was one of the greatest challenges science had ever faced. The story of these men who took up the challenge and through sheer heroic persistence mastered the task is a saga as thrilling as any epic of ancient or modern times.

To a great extent we will see that the results attained by scientists and technical experts responsible for the evolution of the vacuum tube reflected the tempo of the ages in which the men lived. In 1672 and the two centuries following, research was geared to a slow pace, partly because of the lack of adequate support for the effort and lack of an efficient system of communication. For what work was done,

Part I of this especially-prepared series of articles giving the complete history and development of the radio vacuum tube.

Fig. 1. Von Guericke's sulphur ball machine used in early static experiments.



long periods might elapse before men in Germany or France appreciated what was being done by a scientist in England, though all might be working on the same problem. Better communications no doubt would have accelerated the study of thermionics.

The period from 1850 to 1880 was notable chiefly for the investigations of men who were duplicating, but with better facilities, the work done by their predecessors in the field.

News of the discovery of the "Edison effect" spread rapidly to other countries. This and further development of the incandescent lamp served as an impetus to stimulate scientific investigation. With the improvement of both transportation and communication at this time we find the picture of research and development quite changed. Sir William Preece visited America. Having heard of the work of the great Edison he witnessed demonstrations of the "Edison effect" and took back to England not only his notes on the demonstration but also samples of the magic lamps. Sir John Ambrose Fleming, who was at that time Electrical Adviser to the Edison Electric Light Company of London, studied Preece's work of repeating the experiments he had seen in America and continued investigation in this field, using the same types of lamps.

By 1895 scientists in the United States, England, and on the Continent had carefully studied the phenomena, seeking an explanation.

Five years later men coping with the problems of the wireless telegraph began to investigate the possible use of this device as a detector of electromagnetic waves.

While we will present evidence that Lee de Forest and his co-workers had conceived the idea of using a heated rarefied gas as a sensitive detecting medium in wireless telegraphy, which idea was later developed into the "Audion," it was actually Sir John Ambrose Fleming who obtained the first patent for the application of a thermionic device, as a rectifier, to wireless telegraphy, in 1904.

Even at this stage of the game few saw the possibilities of the device which was the grandfather of the present day detector, amplifier, and oscillator tubes. Several years later, when highly trained physicist-technicians attacked the problem, having at their command all the facilities which only large capital could provide, the full potentialities of this "bottle" began to be realized.

Who really started the ball rolling toward the modern vacuum tube? As we examine the foundations of the science of thermionics we find that the first stones were placed securely in position by such men as von Guericke, Gray, du Fay, Nollet, Winckler, Bose, von Kleist and their successors. To the casual observer these may be no more than a list of names picked out of a physics book, and placed in chronological order. Viewing the evolution of the vacuum tube from pres-

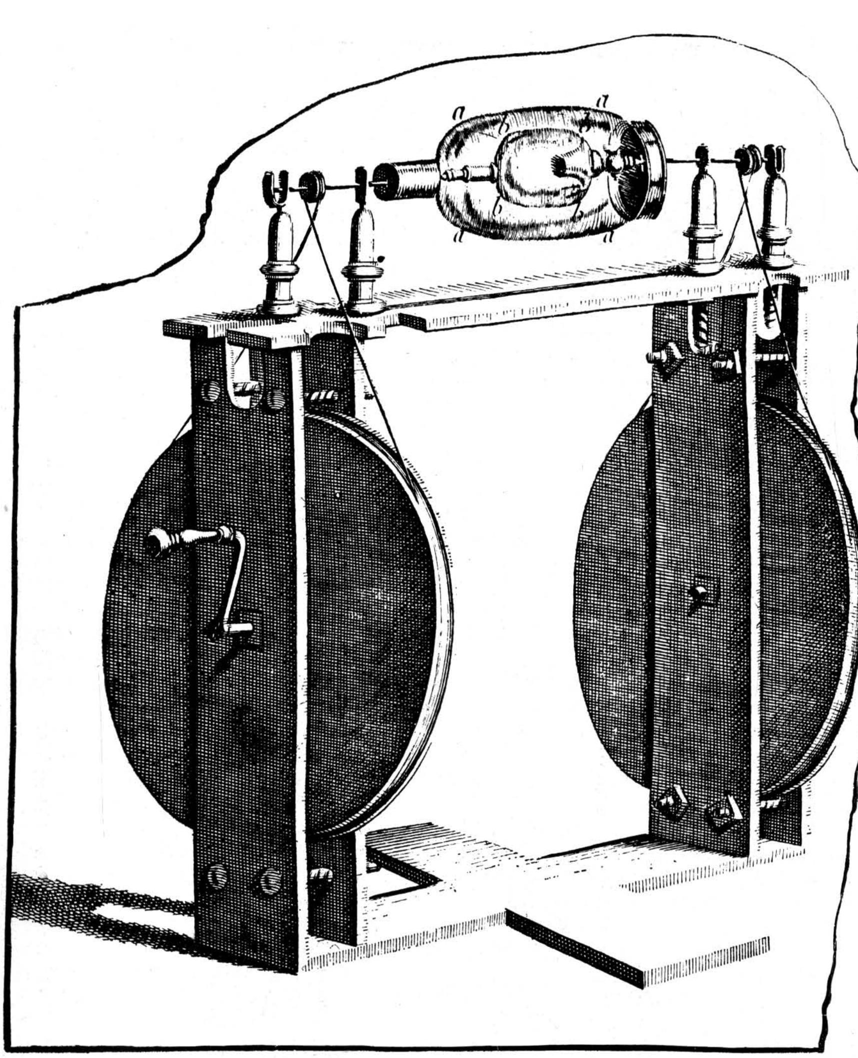
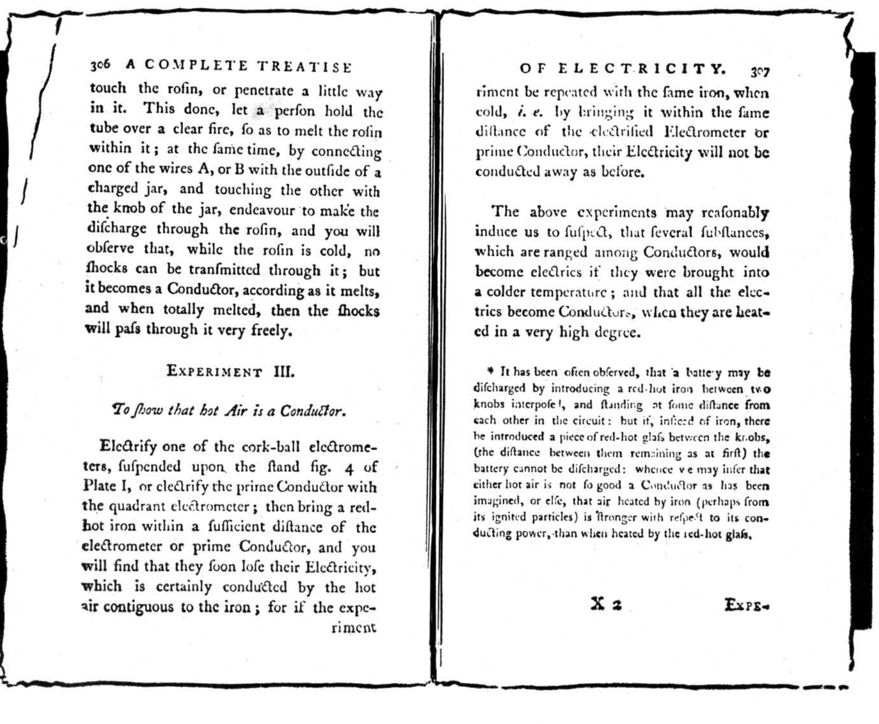


Fig. 2. Cylinder Machine as used by Hauksbee in his early experiments. Note the belt drive to increase speed of rotating elements.

Fig. 4. A reproduction from "Treatise of Electricity in Theory and Practice" (1st edition, London, 1777).



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touch the roſin, or penetrate a little way in it. This done, let a perſon hold the tube over a clear fire, ſo as to melt the roſin within it; at the ſame time, by connecting one of the wires A, or B with the outſide of a charged jar, and touching the other with the knob of the jar, endeavour to make the diſcharge through the roſin, and you will obſerve that, while the roſin is cold, no ſhocks can be tranſmitted through it; but it becomes a Conductor, according as it melts, and when totally melted, then the ſhocks will paſs through it very freely.

EXPERIMENT III.

To ſhow that hot Air is a Conductor.

Electrify one of the cork-ball electrometers, ſuſpended upon the ſtand fig. 4 of Plate I, or electrify the prime Conductor with the quadrant electrometer; then bring a red-hot iron within a ſufficient diſtance of the electrometer or prime Conductor, and you will find that they ſoon loſe their Electricity, which is certainly conducted by the hot air contiguous to the iron; for if the expe-
riment

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riment be repeated with the ſame iron, when cold, *i. e.* by bringing it within the ſame diſtance of the electrified Electrometer or prime Conductor, their Electricity will not be conducted away as before.

The above experiments may reaſonably induce us to ſuſpect, that ſeveral ſubſtances, which are ranged among Conductors, would become electrics if they were brought into a colder temperature; and that all the electrics become Conductors, when they are heated in a very high degree.

* It has been often obſerved, that a battery may be diſcharged by introducing a red-hot iron between two knobs interpoſed, and ſtanding at ſome diſtance from each other in the circuit: but if, inſtead of iron, there be introduced a piece of red-hot glaſs between the knobs, (the diſtance between them remaining as at firſt) the battery cannot be diſcharged: whence we may infer that either hot air is not ſo good a Conductor as has been imagined, or elſe, that air heated by iron (perhaps from its ignited particles) is ſtronger with reſpect to its conducting power, than when heated by the red-hot glaſs.

X 2 EXPEent day knowledge, however, we realize the significance and importance of each man's contribution.

Looking closely at these scientists they begin to live again. We see von Guericke poring over his books, working in his laboratory, proclaiming his discoveries to any one who would listen; Gray, experimenting prodigiously, for years jealously guarding the products of his struggles; du Fay "the interloper," performing his so-called "tricks," an expert at coming to the wrong conclusions; Abbé Nollet, the exhibitionist, in his curled wig and black skull cap, with his black gown barely concealing the richly laced coat and rapier beneath, demonstrating the fruits of his genius with one eye on the gallery of the lords and ladies of the French nobility; and Bose, giving superhuman demonstrations, to the awe and wonder of the populace.

They were all real men, the prototypes of men who played a prominent part in the feverish activity surrounding the final forging of the link between the scientific discovery of the "Edison effect" and its practical applications.

Probably no electrical discovery of major importance ever was made but that the honor of discovering it was claimed for more than one person. The origin of the Leyden jar was claimed for von Kleist, van Musschenbroek, and Cunaeus, and there are those who credit de Romas rather than Franklin with the discovery that lightning is an electrical phenomenon. The invention of the electromagnetic telegraph is ascribed to Steinheil by the Germans, to Wheatstone in England, and to Morse in the United States. Reis, Drawbaugh, Gray, Dolbear, and Bell all claimed the invention of the electrical transmission of speech. In the field of the incandescent lamp we have the conflicting claims of Edison, Sawyer, and Mann. In the field of the thermionic tube we have von Lieben, the de Forest-Fleming controversy, and that of Arnold and Langmuir. The scientific forefront from which these advances flowed truly is of international scope.

In the days of the philosophers these disagreements were largely confined to the annals of scientific societies, but in the past half century the commercial interests at stake have been so large that invention disputes have been the subject of long drawn out actions in the civil courts. This is partly the result of the patent system. Whether in the annals of the learned societies or in the courts of the land, these controversies are productive of a wealth of material for the historian. In modern times, when much development work is done in the research laboratories of large commercial organization, such actions bring out and place on record many of the details of interest which would not otherwise become generally known.

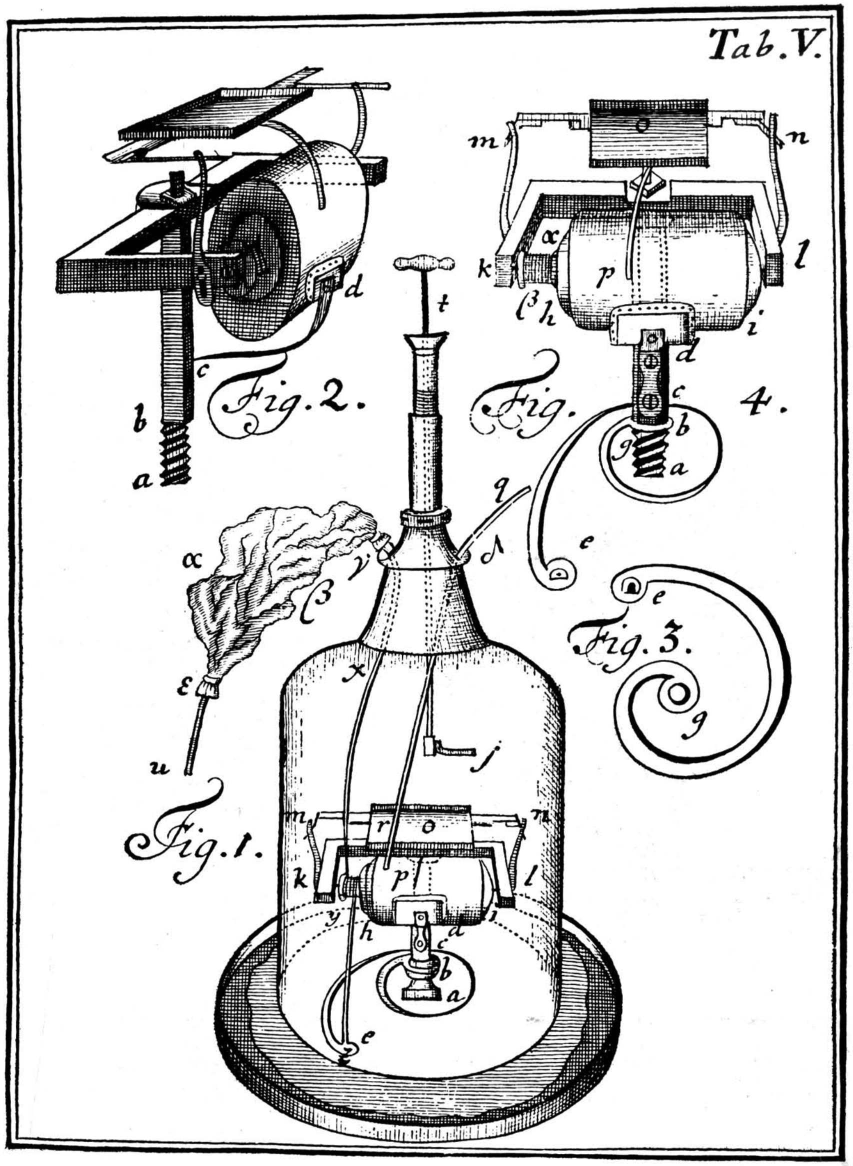

Fig. 3. Details of Winkler's Machine. Fig. 1 shows the machine set up for operation within a vacuum in glass jar.

In the earlier days of which we shall treat it will be seen that a device produced by a philosopher was improved and adapted by those in other countries, and the use of the improved device brought about still further discoveries or resulted in more fruitful work in still a different country. A barrier to this free interchange of knowledge and ideas is found in the language differences involved. That this was recognized in the early days may be seen from the preface to the second edition of Priestley's famous "History and Present State of Electricity," published in 1769. In this work Priestley says:

"It is certainly to be regretted that philosophers have not one common language but neither the theory of language in general, nor the nature and analogies of things to be expressed by it are sufficiently understood to enable us to contrive a new and philosophical one, which might be easily learnt and would be completely adequate to all the purposes of science;—These circumstances make it the more necessary, that there should be in every country, persons possessed of a competent knowledge of foreign languages, who should be attentive to the progress of science abroad, and communicate to their countrymen all useful discoveries as they are made."

In addition to the language barrier it should be realized that the downfall of feudalism and disintegration of the Holy Roman Empire had resulted in sweeping changes in the social and political system of Europe, which were in progress during this period. Countries were torn by internal strife and external war. While this had its bearing on scientific development and research, consideration of it belongs more to the field of social than electrical science. We need consider only the disastrous effect of these factors upon possible intellectual unity. The rise of nationalism frequently resulted in the negation of honestly attributing the truth where truth was due. The resultant dissen-

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tion in the scientific world, however, gives a multi-faceted picture which, even though it sometimes defies evaluation, gives to the historian much additional factual information.

The story of the development of the vacuum tube may be approached along two different paths, one of which leads us through the study of high voltage-heat phenomena, the other the study of high voltage-vacuum phenomena. Much has been written concerning the evolution which took place along this latter path, hence we shall confine ourselves to travel along the former.

Glazebrook's "Dictionary of Applied Physics" defines the word "thermionics" as the term "applied to the phenomena associated with the discharge of electricity from hot bodies." While we usually think of thermionics only in connection with electron emission in vacuo, the term as defined is much broader than that, and includes phenomena taking place under atmospheric conditions, such as the ionization of air by emission from hot bodies, flames, etc., and it is in this broader sense that we shall use the term.

The early work in thermionics is inextricably bound up with the work done by the philosophers of the seventeenth and eighteenth centuries on static electricity, and usually the experiments were conducted in air at atmospheric pressure. Under these conditions ionization phenomena become observable only where high voltages are available, which was the case during this period, the era of so-called *static* electricity. Knowledge in any field becomes greater as the tools available for use in investigation become perfected; hence it will be seen that as better tools and higher concentrations of energy became available, knowledge of thermionics grew apace. This era of static electricity was the era of high voltage.

Beginning around the turn of the nineteenth century with the work of Galvani and Volta the emphases in electrical research shifted to the field of galvanism and voltaic electricity, which was essentially a technique of low impedances. Hence we find little done in the field of thermionics during this era. Not until the tools of galvanism were developed and perfected, and higher voltages and greater energies were available from low impedance sources, could any great amount of work be done in the high impedance field of thermionics.

Early Investigators

The earliest reference in literature to the beginnings of thermionics is to be found in the work of William Gilbert of Colchester, physician to Queen Elizabeth, as recorded in his famous "De Magnete, Magneticisque Corporibus—." In this book[1], in discussing the effect of heat on amber he says:

> "Moreover the spirit of the amber which is called forth is enfeebled by alien heat—"

and later he makes the statement:

> "It is manifest indeed that the effluvia *(charge)* are destroyed by flame and igneous heat; and therefore they attract neither flame nor bodies near a flame."

After Gilbert we find little of importance recorded until Otto von Guericke, Burgomaster of Magdeburg, entered the scene. Von Guericke is one of the few of the early workers to have made contributions to both the paths of research which led to the development of the modern vacuum tube. For, as every high school physics student knows, he was the inventor of the air pump, a device which has proved to be a most useful tool in many branches of research. He also, literally, started the ball rolling, with the invention of the friction type electrostatic generator, the first electrical machine. This machine is shown in Figure 1. It consisted of a globe of sulphur mounted on trunnions and rotated manually. The hand of the operator was used as the friction device. With this machine as a power source von Guericke made many experiments. During the course of his work he observed[2] that a body once attracted by an "excited electric" was repelled by it, and not again attracted until it had been touched by some other object. He also observed that if the repelled (charged) body came near a flame it could again be attracted by the electric without having touched any other body.

While von Guericke was delving so assiduously we know now that over the Alps in Italy similar observations were being made. Some of the members of the Accademia del Cimento, which was founded by the Medici family, and flourished from 1657 to 1667, were making their contributions to the advancement of various branches of human knowledge. We find that they observed[3] that if an electrified amber was presented to a flame it lost its "attractive power," that is, its electric charge.

Over in England Francis Hauksbee published, in 1709, a book[4] of interesting experiments on electricity. He improved on von Guericke's machine by substituting for the heavy sulphur globe a hollow glass globe, with which higher rotational speeds could be attained. A reproduction of an engraving showing Hauksbee's machine, as used in one of his experiments, is given in Figure 2. It will be noted that this machine also uses a pulley and belt drive system to enable the attainment of higher speeds of rotation.

With the work of Hauksbee there came a hiatus in the development of the electrical machine, for what reason we do not know. Many philosophers went back to the use of the glass tube, excited by friction of a piece of cloth, as a source of electricity.

Shortly after Hauksbee's book was published the work of another Englishman, Stephen Gray, began to attract attention. Unfortunately the records of Gray's life and work are hidden in the early annals of the Royal Society. When we first hear of him in 1720, he was about fifty years of age and a pensioner in the Charter House of London. Even then he was described as a crusty and testy old gentleman, to whom life had not been kind. He had no wealthy sponsor in his early years. Truly in his case "Necessity" was the "Mother of Invention." His apparatus was built of materials readily available to the poor. And yet with this crude experimental equipment he determined that the electrical conductivity of bodies depended on the substances composing them, and gave to the world the first practical and useful information on electrical conduction and insulation.

Gray's contribution to thermionics was an indirect one, and consisted of stimulating others. One of these was his co-worker, Mr. Granville Wheeler, who introduced the element of heat into some of his experiments. Another of those influenced by Gray was du Fay, of whom we shall hear more in a short time. Gray's early experimental work was unpublished for some time probably, according to Dr. Desaguliers[5], writing some years after Gray's death, because of his intolerance of opposition and fear of contradiction. In his later years he seems to have changed this attitude, perhaps with the improvement in his economic security which took place. This we deduce from the fact that he contributed a number of papers[6] to the Royal Society, and even while on his deathbed, dictated[7] some of his conclusions to the Secretary of that august body.

Across the Channel in France, Charles François de Cisternay du Fay began, in 1733, his famous work in electricity. At this time he was thirty-five years of age. While it is possible that Gray's temperament prevented philosophers in England from entering the field as competitors, it is evident that neither awe nor fear of this genius crossed the water to frustrate the working of du Fay. As we read of Charles du Fay he becomes a vivid, vital person. To his heritage of culture had been added the gifts of a brilliant mind, keen wit, and charming personality. He used these gifts to win the friendship and co-operation of Gray.

Du Fay's work merited being recorded in the annals of the French Academy. He wrote on every subject considered worthy of public discussion by philosophers. He was the only member of the French Academy who contributed to all six fields into which science was divided by that body. His tastes were catholic and his interests profound.

In the spring of 1733 du Fay learned of the work done by Gray and Wheeler. He immediately set about checking their findings; and determined to continue the experiments along somewhat different lines. During this year and the year following he wrote six Memoires[8] recording his experiences while conducting experiments on electrical phenomena. In one of these Memoires he set forth his theory of electricity, which was known as the two-fluid theory.

It is curious to note that although the electrical machine of von Guericke and Hauksbee must have been known to du Fay and his contemporaries, they did not use it. In all their experimental work they used glass tubes excited by rubbing with silk.

In his Fifth Memoire du Fay describes experiments on the effect of hot air, compressed air, and rarefied air on the electric effect. Another experiment, which was described in his Second Memoire, is especially worthy of note. He observed that the flame of a candle could not be electrified at all, and that it is not attracted by an electrified body. He adds the following:

> "This singularity merits a close examination, in which we will perhaps enter into the question of leakage; but of this we can assure ourselves, for the present, that this (phenomena) is not due to the heat nor to the burning; for a red hot iron and a glowing coal, placed on the glass table, become it (electrified) exceedingly."

Du Fay never examined the effect further, probably because of his interest in other electrical phenomena. He died in 1739 at the age of forty-one and his last Memoire, which was a summary of his concepts of the great phenomenon, was published in 1737.

Du Fay, in December 1733, wrote a brief synopsis of the Memoires which he had published in the annals of the French Academy and sent it to the Duke of Richmond and Lenox for presentation to the Royal Society[9] and to Gray "who works on this subject with so much application and success, and to whom I acknowledge myself indebted for the discoveries I have made, as well as for those I may possibly make hereafter, since it is from his writings that I took the resolution of applying myself to this kind of experiment." This is probably the handsomest recognition of the work of another investigator that has ever been published, and completely won Gray's heart. From that time on Gray and du Fay maintained communication with the greatest of friendliness. It was this which led Fontanelle to remark that he wished that such relations might always typify the intercourse between great nations.

All the experiments of the lonely Gray in England and the spectacular demonstrations of du Fay were soon repeated and publicized by Abbé Jean Antoine Nollet, who might have been as successful in the theater as he was in the field of science.

Nollet, because of his charm and

wit, his talent for simplifying and explaining his theories, entertained the gay French court with his dramatic revelations. The public clamored for the theatricals of the intriguing French philosopher. Contemporary scientists recognized his genius.

Nollet carefully repeated the experiments of du Fay and came to conclusions which contradicted the findings of du Fay, particularly those pertaining to the effect of heat on the electric virtue. Nollet felt[10] that if his friend had lived long enough to study the relationship as exhaustively as he had planned, he would have contradicted himself. Du Fay stated briefly that the application of heat to an electrified tube had little or no effect on the electric virtue. Nollet, after performing many experiments meticulously[11], found that a white hot piece of iron dissipated the virtue very quickly, and that the result was the same when the iron had cooled to a red heat. As the temperature of the iron decreased the dissipation of the virtue was slower. He noted further that when the cooling iron had resumed its brown color, the electricity showed no sign of dissipation.

While Nollet was pursuing his researches in France, scientists in the Germanic states were improving the tools of electrical science.

Johann Heinrick Winckler conceived and brought to execution the idea of using a fixed cushion to provide friction on the electrical machine, instead of the hand of the operator, as originally used by von Guericke and Hauksbee. On March 21, 1745, Winckler communicated to the Royal Society[12] a description of his machine, which is shown in Figure 3. With this device he could obtain much more energy than before. This was later improved by John Canton of England[13], who applied to Winckler's cushion an amalgam of mercury and tin by means of which the excitation was increased.

George Mathias Bose, Professor of Philosophy at Wittemburg, about this time introduced[14] the *prime conductor,* in the form of an iron tube or cylinder, which increased the energy storage capacity of the machine. Figure 3, of Winckler's machine, also shows a prime conductor in the form of a rectangular plate.

About the same time Andreas Gordon, a Scotch Benedictine monk who was Professor of Philosophy at the University of Erfurt, substituted[15] a glass cylinder for the globe used by his predecessors.

With these improved devices much higher voltages could be obtained and greater energies could be stored. By this time the friction type of electrical machine had been developed to nearly its peak; and it seemed as though the time had arrived for some great advance. This came in 1745, when the discovery of the Leyden jar was announced.

The origin of this utilitarian device has been variously attributed to von Kleist, Dean of the Cathedral of Comin in Pomerania; van Musschenbroek, of the University of Leyden; and N. Cunaeus, a burgess of Leyden. It is now established that it was first announced[16] by von Kleist in a letter to Doctor Lieberkuhn, dated November 4, 1745, in which was described an elementary form of the device. His explanation of it was so obscure, however, that it was of little use. Von Kleist felt that the human body contributed part of the force of the jar.

The Leyden Jar, because of the increased energy and storage capacity it provided, was seized upon by the philosophers of all countries as a most versatile and useful tool. Large quantities of energy, with which spectacular experiments could be performed, could be obtained by connecting numbers of these jars together to form what was called a "battery."

The addition of these instrumentalities aided greatly in the progress of research in electrical science.

While this development had been going on, other scientists, such as Delaval, Canton, Watson, and Wilson of England, and Franz Aepinus of Germany were seeking further explanation of the effects of heat on electricity.

While it was customary for the philosophers to repeat experiments made by each other, for the purpose of verification or contradiction, we may attribute the unusual interest in the effect of heat to the fact that in 1756 Franz Aepinus made an important discovery. This celebrated German philosopher reported[17] his results in the study of the tourmaline to the Academy of Sciences and Belles Lettres in Berlin. He found that he could electrify this substance to a high degree by heating it to somewhere between 99½ and 212 degrees Fahrenheit. Up to this time very little was known concerning the necessity of heating the tourmaline to excite electricity.

It is not difficult to understand what followed the publication of his report. Immediately heat was applied by other scientists, not only to the tourmaline, but to all other experiments being conducted. The controversy of the tourmaline stimulated not only the study of this phenomenon but also the exchange of ideas.

Mr. Delaval set forth the results of his studies in this matter in a paper read to the Royal Society on December 17, 1761[18]. Mr. Delaval's explanation of his results was not satisfactory to Mr. Canton, who was similarly interested. Mr. Canton attempted to supply his own explanation of Mr. Delaval's results in a paper which he presented some three months later, on February 4, 1763, to the Royal Society[19].

Mr. Delaval expounded the theory that stones, tourmalines, and similar earthly substances were convertible from electrics to non-electrics by different degrees of heat. Mr. Canton claimed, in his paper, that the substances were conductors when they were cold because they contained moisture (which is the bane of all experiments in static electricity); that when the moisture was evaporated by heat they lost their conductivity; that when they were made very hot, the hot air at or near their surfaces would conduct and the substances only *appeared* to be conductors again. Mr. Canton then proceeded to prove this contention. He says:

> "Hot air may easily be proved to be a conductor of electricity by bringing a red-hot iron poker, but for a moment, within three or four inches of a small electrified body; when it would be perceived, that its electric power would be almost, if not entirely destroyed; and by bringing excited amber within an inch of the flame of a candle, when it would lose its electricity before it had acquired any sensible degree of heat."

We mention this particular incident in the history of thermionics for a very important reason.

Abbé Nollet had performed this same experiment using the heated iron to prove that heat dissipated the electric virtue in a glass tube, arriving at the conclusion that, since the virtue was dissipated, the heat was responsible for the dissipation.

Mr. Canton repeated the experiment to prove that hot air was a conductor of electricity. Since the electric virtue was dissipated, he concluded that hot air was a conductor of electricity.

Apparently, what they found depended on what they were looking for, a condition which is not peculiar to the ancients by any means.

But when Mr. Wilson made experiments[20] discharging electrified tubes by means of heated glass, Mr. Canton, who seemed to be always looking over someone else's shoulder, observed that perhaps Mr. Wilson did not discharge the tubes by means of the hot glass, but rather by means of the heated air on the surface of the material.

In 1777 the next important link in our chain was forged by Tiberio Cavallo. In his book,[21] published in that year, we find instructions for performing an experiment. Because of the significance of the explanatory note which he attaches we are here reproducing (see Figure 4) the pages of his book on which it is given. In reading these pages the student should bear in mind that the "battery" of Cavallo's day was a bank of charged Leyden jars as previously described, and not the chemical device which is today termed a battery.

We see that Cavallo contradicted not only Wilson but Canton. Cavallo realized that some element other than heat or hot air was responsible for the discharge. "Perhaps from its ignited particles" is the keynote of the essential difference between his explanation and that of his predecessors.

The term "thermionic emission" was many years in the future.

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CATHODE-RAY TUBE CHARACTERISTICS

THE electron beam in a cathode-ray tube may be deflected by either magnetic or electric means, but by far the most common type of deflection is electrodynamic. Magnetodynamic deflection is seldom employed for oscillographic purposes since the impedance offered by the deflection coils varies with frequency, varying the deflecting field and therefore producing indications difficult to interpret, according to Du Mont engineers.

Deflection voltage requirements for electrodynamic deflection systems increase directly with increasing accelerating potential. It is thus necessary to investigate the signal voltage available in conjunction with deflection requirements of the cathode-ray tube to be used. At the same time if an amplifier such as, for example, the deflection amplifier provided in a cathode-ray oscillograph is to be used to amplify the signal for deflection of the cathode-ray tube, care must be taken to insure that the output voltage available is sufficient for full-scale deflection of the tube.

All *Du Mont* instruments, it is pointed out, are designed so that the overload point of their deflection amplifiers is off the screen. This consideration is especially important when it is desired to employ commercial oscillograph amplifiers for deflection of a cathode-ray tube different from that provided with the instrument, since in most cases only sufficient deflecting voltage has been provided for the standard tube supplied with the instrument while operating at potentials available in the instrument. If this precaution is not observed, the overload point of the amplifiers is likely to occur on the screen, thereby seriously distorting the unknown signal.

Electrodynamically deflected cathode-ray tubes are manufactured with either one or two plates of a deflecting-plate pair available for external connection. In the former case one plate of each pair is connected within the cathode-ray tube to the second anode. The free plate of each pair is brought out to a connecting terminal for deflection. Such operation is permissible at low accelerating-potentials but, when it is desired to operate a cathode-ray at high accelerating potentials, the high deflecting voltage required is likely to develop an axial as well as radial acceleration to the beam, which may cause a certain amount of defocusing to appear on the screen edges.

When both plates of a deflecting-plate pair are available for external connection, higher accelerating potentials such as are necessary for satisfactory operation of long-persistence screens and for high brilliance, may be used. —30—

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Up to this point we have been concerned with showing a continuity in the study of thermionics. Many scientists not mentioned here were studying the electric phenomena from other angles, and it is true that some considered the factor of heat in some of their experiments. Our purpose has been to show an unbroken chain in the study of the relation of heat and electricity in the early days.

Just as we have traced the foundations of thermionics along the high voltage-heat path, so also we might trace the development along the high voltage-vacuum path, from the work of von Guericke in the development of the air-pump, and the study of the attractive power of electrified bodies in vacuo by Robert Boyle in 1670,[22] and by the Accademia del Cimento.[23]

Following the above, an unbroken chain of experiments with vacuum in connection with electricity may be seen by tracing the observations of Hauksbee,[24] Gray,[25] du Fay,[26] Nollet,[27] Allamand,[28] Ludolph,[29] Hamberger,[30] Waitz,[31] Canton,[32] Watson,[33] Grummert,[34] Wilson,[35] and others.

Up to this time little had been heard from America. Suddenly in the middle of the eighteenth century a voice from this side of the Atlantic was heard.

In 1750 the remarkable discoveries of Benjamin Franklin startled the scientific world. More amazing do the achievements of Franklin appear when we consider his background and contrast it with that of the foreign scientists. Franklin, born in 1709, had very little formal education. At the age of seventeen he arrived in Philadelphia from Boston. He was penniless and had worked for his transportation; at the age of forty he was Philadelphia's leading citizen. Those twenty-three years were spent in work during which time he founded schools and libraries, established a newspaper, organized civic affairs, and founded the Philosophical Society. He always had a desire to study natural sciences but never had the time. Franklin knew nothing of the environment of the European philosopher who spent his time in slow deliberation and contemplation of the causes and effects of the universe.

Yet scarcely five years after he met Doctor Spence and saw his crude electrical experiments in Boston Franklin received world acclaim for his discoveries in electricity. So revolutionary and conclusive were his findings that they almost stunned his contemporaries abroad. His experiments were many, his writings on the subject prolific. At once he was recognized as a genius. He charmed the world with his directness and simplicity, his ability to say "I don't know." With him worked such men as Ebenezer Kinnersley, Thomas Hopkinson, and Philip Sing, all brilliant men.

While they did not contribute directly to the science of thermionics, their work was important enough to make our friends abroad realize that a new era had begun. Their own new date line was "Since the time of Ben Franklin."

The achievements of Ben Franklin are of particular significance today. Thousands of boys in the armed forces are being trained for work in communications. They are required to absorb present day knowledge of radio in the briefest possible time. Many of them have no more technical background than did Franklin. From some of them we may expect inventions and discoveries never thought of by the engineers designing the communications systems. History shows how frequently the men using a device will adapt it to their own needs in ways completely overlooked by the man who, because of his absorption in developing the device, has become a channeled thinker.

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(To be continued)

Pocket VTVM's

(Continued from page 33)

tube need not be electrically shielded.

The circuit is a grid rectification arrangement which functions in the same manner as an input diode rectifier followed by a d.c. amplifier. The input circuit is isolated by means of the 0.02-μfd. mica blocking capacitor (made up of two paralleled 0.01-μfd. units).

The plate-circuit by-pass capacitor C2 (*Aerovox* type 284) is a 0.1 μfd. tubular which acts to by-pass any alternating current passed through the tube interelectrode capacitance.

The initial steady plate current of the tube is bucked out by the single cell B3, which delivers current in the reverse direction through the meter through the zero-set rheostat. This variable resistor must be a midget wire-wound, such as an *I. R. C.* type W-10,000. 10,000 ohms full value is recommended.

This v. t. voltmeter has a normal full-scale deflection of 3 volts RMS which may be multiplied to 30 and to 300 by the input voltage divider R1-R2-R3 which will be seen to consist of the same resistor components as the multiplier in Figure 1. By using a miniature 3-position rotary disc-type switch, the selector mechanism may be kept small in size.

The entire 1Q5-GT instrument may be enclosed within a 4"x5"x2¼" metal chassis pressed into service as a case. The chassis bottom plate completes the enclosure.

Single-Battery Model

The circuit of Figure 4 embodies a unique arrangement for obtaining filament, plate, and bias voltages all from a single *Eveready* No. 773 flat 7½-volt battery. In this hookup, the