NATIONAL ACADEMY OF SCIENCES
OF THE UNITED STATES OF AMERICA
BIOGRAPHICAL MEMOIRS
VOLUME XXI—FOURTH MEMOIR

BIOGRAPHICAL MEMOIR

OF

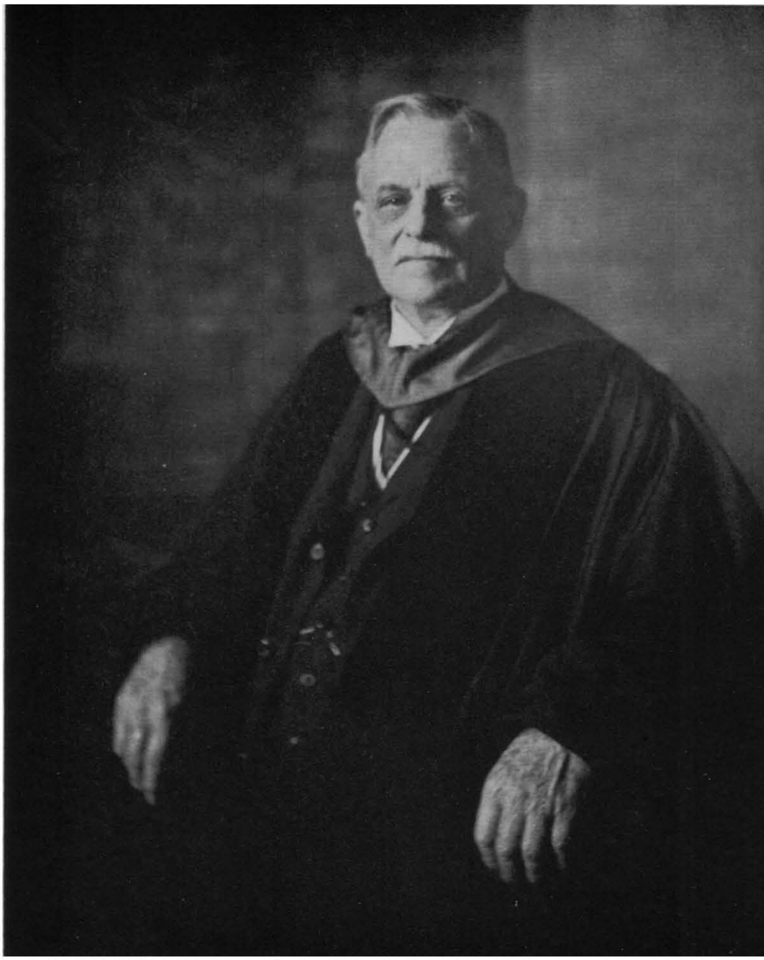
ELIHU THOMSON

1853–1937

BY

KARL T. COMPTON

PRESENTED TO THE ACADEMY AT THE AUTUMN MEETING, 1939



Elihu Thomson

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For one destined to apply his genius largely toward harnessing electricity for the work and comfort of man, the decade beginning with 1850 was a timely period in which to be born. The preceding half century had witnessed the fundamental discoveries which underlie the utilization of electricity, and imaginative minds had begun to direct these discoveries into the broad channels of practical and commercial employment.

In the development of the electrical art this first half of the Nineteenth Century was a remarkable fifty years, and because it provided the foundation for the practical achievements which came in the second half, a review of it helps to give perspective to this memoir on Elihu Thomson.

The century opened auspiciously with Volta's discovery of the voltaic cell, and with the demonstration by Nicholson and Carlisle of electrolysis. In 1820 Oersted announced his discovery that an electric current has the power to deflect a magnetic needle. In this same year Ampere brilliantly elucidated Oersted's discovery by giving mathematical expression to the forces produced by electric currents. Six years later Ohm announced the formulation of his law that current is proportional to the electromotive force, and twenty years later Gauss and Weber invented an acceptable system of electrical and magnetic units.

Meanwhile, Faraday had begun the epocal researches which were to lay the foundations of electrical engineering. In 1821 he had succeeded in making a wire revolve about a magnet and a magnet about a wire, and ten years later, almost simultaneously with Henry in America, he made the great discovery underlying almost all electrical machinery—electromagnetic induction. This led him to the mechanical production of a steady electric current by revolving a copper disc between the poles of a magnet. Here, at last, in embryo, was the machine which ultimately would generate in one year in the United States alone 120 billion kilowatt hours of electric power.

Minds with a practical bent were quick to follow the road which Faraday and Henry had pointed out, but they found the going slow. By 1850, the electric motor had been demonstrated, the commutator had been devised, the electric arc had been experimentally used for lighting, and efforts had been made to drive boats, buggies, and locomotives by electricity. But the conquest of electric power was still thwarted by practical difficulties; only in the form of the telegraph and a few other devices had electricity been put to work effectively. Efforts to obtain a reliable mechanical source of electric power languished.

It was during this stage in the development of the electrical art that Elihu Thomson was born in 1853, and it was not until he had embarked upon his professional career at the tender age of 17 and was ready to join the creative thrust that the drive toward economic utilization of electric power had really begun to gain ground rapidly. In 1875, five years after Gramme had built his ring-wound armature, and along with Siemens had made the dynamo a practical machine, Thomson had built a dynamo and by 1879 he had invented and patented a three-coil arc dynamo—the first three phase generator. He thus early took prominent place in the brilliant group, including Brush, Edison, Siemens, Stanley, Tesla, Van Depoele, Weston, and others, which was to solve the problem of generating adequate current. The electrical tide was approaching its flood and Thomson was ready—with consequences enormously important to the development of the electrical industry.

The young man who thus auspiciously began his career in Philadelphia was born in Manchester, England, on March 29, 1853, of a Scotch father, Daniel, and an English mother, Mary Rhodes. Elihu was the second son of the family which ultimately was to total eleven children, six boys and five girls. Four years after Elihu's birth, the panic of 1857 struck England and his parents, moved by the resulting scarcity of work, decided to emigrate to America, which they did in 1858, settling in Philadelphia. Elihu early showed signs of exceptional ability. When his parents felt the appropriate time had arrived for them to teach him his alphabet, they were astonished to discover that the youngster, now five years old, not only knew the letters but could recite the alphabet both forwards and backwards.

Elihu's father was a gifted mechanician and his work led naturally to Elihu's interest in technical and industrial arts. As he himself has recalled,

"A great many of the industrial establishments, on account of my father's work as engineer and machinist, were open to me. I was thus able to witness as a boy many of the industrial processes going on, both in chemical work and also in mechanical constructions, in which I was always interested even from the start. The literature which was available to me at home was chiefly the 'Imperial Journal of Arts, Sciences and Engineering', of which there were two volumes, which I studied actively. Evidently my tastes had already been formed and were, perhaps, to a certain degree, hereditary, intensified by my father's occupation and that of several of my uncles, who followed mechanical pursuits. I was constantly endeavoring to imitate, in a small way, the processes and operations which I saw going on around me. Thus, at about the age of ten or eleven, I constructed small models of cupola furnaces with fan blowers for furnishing the blast and actually succeeded in melting cast iron, hoping to be able to get enough iron to make castings. In this, I was not successful, as the iron melted was not in sufficient quantity to run into a mold. I was, however, always interested in what was going on around me, such as the laying of water pipes and gas pipes in the streets, the building of sewers, etc., spending hours in watching the operations. I remember that I was constantly imitating on a small scale, or by drawings, operations mostly of an engineering nature which I saw going on about me. What I couldn't actually make, I contented myself by drawing. During the latter part of the period of the Civil War, I often visited the Philadelphia Navy Yard and operated a donkeyengine during the noon hour, so that the men need not stop work. This engine was used for the boring out of the propeller holes of two ships then under construction in the yard. One was an iron-clad cruiser called 'The Tonawanda' belted with four inches of iron on a wooden hull, and the other was a high powered ship intended for chasing blockade runners and named 'The Chattanooga'. As a boy of about fourteen years of age, I had access to a large chemical works, where sulphuric, nitric and hydrochloric acid were made, and where paints and pigments were a large portion of the production. Needless to say, I understood the processes from my own chemical reading."[1]

Elihu entered the public schools of Philadelphia at the age of six and by the time he was eleven years of age, he was ready to enter the Boys' Central High School. Under existing regulations, he could not be accepted until he was thirteen, and because Elihu was not particularly strong, his parents seriously considered the recommendation of the grammar school principal that he give up studying entirely for two years and attempt to build up his physique. To this suggestion Elihu reacted promptly and violently, telling his parents that he would as soon die as to give up his books. The parents capitulated, and young Thomson embarked on a period of reading and a program of gadget making and youthful experimentation. He built a static machine from a wine bottle, small condensers, Leyden jars, a pair of telegraph instruments, and voltaic cells, and he assembled a collection of chemicals adequate to carry out many processes and reactions.

In February, 1866, he was finally admitted to the Central High School, even though he lacked several weeks of having attained the required age. Four years later he was graduated as fourth honor man and accepted employment in a commercial laboratory where analyses were made of iron ore and other minerals. He remained in this post for about six months and then returned to Central High School in the fall as "Adjunct to the Department of Chemistry" at a salary of $500 per year.[2]

One of the senior professors whom he assisted in this post was Edwin J. Houston, who held the chair of Physical Geography and Natural Philosophy, and the two were soon engaged in collaborative investigations which led to a long partnership. The first publication growing out of their research was a paper "On a New Connection for the Induction Coil," contributed by Professor Houston to the June, 1871, issue of the *Journal of the*

[1] From an unpublished letter, dated January 26, 1933, in the files of the National Academy of Sciences.

[2] The Philadelphia Period in the Life of Professor Elihu Thomson by John Louis Haney. *The Barnwell Bulletin* of Central High School, February, 1939.

Franklin Institute. The paper contained an account of Thomson's observations of sparks drawn from grounded waterpipes during the operation of a nearby induction coil. Although he did not recognize the significance of the evidence at the time, he had clearly observed the propagation of electrical waves through space. When, in 1875, Edison announced a new "etheric" force which he described as non-electrical, Professor Thomson was primed to dispute his conclusions, for he wrote later

"I had proposed to Houston that we carry on these experiments and show definitely that the so-called 'etheric' force that Edison had announced in the papers was merely an electrical phenomenon. At this time I took upon myself the enlargement of the scale of the experiments, so as actually to obtain a very definite result. This was carried out, as follows, in 1875. A 6-inch spark Ruhmkorff coil was set up with one terminal connected by a wire about 5 feet long to a large tin vessel mounted on a glass jar on the lecture table. When the coil was in operation, sparks were allowed to jump across the terminals of the coil itself, these sparks being about 1½ inches to 2 inches long and having the character of condenser sparks. When the coil was in action, I explored the whole building throughout the several floors and then went up to the top of the building to the observatory, where Professor Snyder had charge of the astronomical instruments. It was found that tiny sparks could be obtained from metal objects wherever they were, in the cases or outside, from the door-knobs or from apparatus, by the simple expedient of shading from the light and detecting the tiny sparks with a pointed pencil by applying it, say, to the door-knob. I recognized clearly that this was a manifestation of electric waves passed through space, and I also understood that a system of communication might readily be based thereon." [3]

A description of this experiment was communicated to the Franklin Institute by Professor Houston and printed in its *Journal* for January, 1876. With the exception of Joseph Henry's experiments, which were unpublished, here was the first experimental demonstration of the validity of Maxwell's theory, and here, too, was an example of Professor Thomson's extraordinary intuition anticipating the wireless transmission of signals over a decade before Hertz demonstrated electro-

[3] Unpublished notes of Professor Thomson in the files of J. A. McManus, General Electric Company, Lynn, Mass.

magnetic waves and twenty odd years before Marconi received his patent on "telegraphy without wires".

Again in Thomson's nineteenth year, the *Journal of the Franklin Institute,* August, 1871, carried an account, written jointly by Thomson and Houston of further original work by Thomson. This paper, "On the Change of Color Produced in Certain Chemical Compounds by Heat," was a pioneer discussion of this phenomenon. His next important paper, "On the Inhalation of Nitrous Oxide, Nitrogen, Hydrogen, and other Gases and Gaseous Mixtures" appeared in the *Philadelphia Medical Times,* November 15, 1873, and foreshadowed his later work on the use of helium in diving and caisson work.

By 1877 Thomson was swinging into his full stride. He had received the Master of Arts degree from his institution and been appointed Professor of Chemistry and Mechanics. His capacity to work productively in a variety of fields had been amply demonstrated by creative work in both chemistry and physics, and by such avocational activities as lens grinding and the construction of a pipe organ with electropneumatic key action. He had, during a series of successful lectures at the Franklin Institute, anticipated the system of electric-welding he was later to patent, he had conceived the idea of a cream separator, and he had described the operation of tuning one electrical circuit to another.

Thomson regarded his "more serious interest in electrical applications" [4] as beginning in 1878 with a series of tests on dynamos then in commercial use. This report had been preceded in the *Journal of the Franklin Institute* by papers on the relaying of the telephone and on "A New System of Electric Lighting and a New Form of Electric Lamp," and it was followed in 1879 by "Circumstances Influencing the Efficiency of Dynamo Electric Machines" published jointly with Professor Houston in the *Proceedings* of the American Philosophical Society. This paper, as did the report to the Franklin Institute, emphasized the advantage of low internal resistance in a dynamo as compared to the resistance of the external circuit.

[4] "Pioneer Investigations on Dynamo Machines Fifty Years Ago," by Elihu Thomson. The *Journal of the Franklin Institute,* July, 1928.

It was in 1879 that he and Houston built a dynamo with three-phase winding. This machine, patented in 1880 and now at the Smithsonian Institution, was known as the "bakery machine" because of its use for lighting a large bakery in Philadelphia. "This is the machine," Thomson once noted, "upon which the Thomson-Houston Electric Company was based. . . . I think this is a very important invention, inasmuch as the great power generators of today are three-phase dynamo machines with three-phase armature winding. . . ." [5]

Having made fundamental improvements in the dynamo, Thomson and Houston, prompted by the commercial application of arc lighting by Brush, rapidly rounded out a complete and reliable arc-lighting system. They devised a constant current regulator (1881), an air blast method to extinguish or prevent the arc tending to occur when an electric circuit is opened (1882), and the magnetic blow-out (1883) which employs a magnetic field to extinguish an arc.

Of this arc-lighting development Dr. Dugald C. Jackson, the well-known electrical engineer, has said:

"Arc lighting has largely been superseded by later forms of electrical illumination, but I am personally inclined to put forward this invention of the automatically regulated dynamo for arc-lighting service as one of Thomson's most important, on account of its influence on his own work and the development of his opportunities. The invention was made when he was still in his twenties. It was carried through substantially on his own responsibility except for meager financial aid, and drew out at this early age, at least in some degree, those qualities of originality, courage, resourcefulness, far-sighted thinking and powers of experiment which were so notably the foundation for his distinguished and productive career." [6]

For similar reasons I have dwelt in detail on Professor Thomson's Philadelphia days, particularly on his work at Central High School. By the time he resigned from the school in 1880, he had unmistakably demonstrated his wide-ranging genius, and in his

[5] Unpublished notes of Professor Thomson in the files of J. A. McManus, General Electric Company, Lynn, Mass.

[6] Address of Dugald C. Jackson at the meeting in commemoration of the life and work of Elihu Thomson, February 16, 1939. In the files of the American Philosophical Society, Philadelphia.

work there are to be found the seeds of his later achievements. Here it was, too, that he developed his life-long interest in education and that fondness for teaching which led him throughout his life to cherish the title "Professor" above all others. Of his early developed gifts as a teacher there is direct testimony from Dr. Edwin W. Rice, Jr., a student of Professor Thomson's during the Central High days, later his assistant, and ultimately the President of the General Electric Company.

"To me he has been 'My Professor' ever since I first met him away back in the year 1876 in the Central High School of Philadelphia. He was a youthful professor of chemistry in his twenty-third year and I was a young student of fourteen. I was full of eagerness to learn; he was equally keen to teach. My discovery of Professor's genius occurred years before he had become famous; before he had started on his career of invention which was to astonish the world. He was at that time an obscure young teacher unknown to the world, but to me he was as wonderful then as he is today. I therefore feel that I may have a good claim to call him 'My Professor'. The High School was to me a wonderful new world; full of books and bottles; of magnets and batteries, and topped by a great dome containing a marvelous telescope. It was there, as I have said, that I first met Professor Thomson. On my side it was a case of love at first sight, and what a discovery; what a mine of knowledge, ready to be explored, as willing to give as I was to receive its richness. It is my recollection, that there was no question that I asked to which I failed to obtain a satisfactory reply, expressed in language that I could understand. It was to me a new and glorious experience! Encouraged by his friendly attitude I summoned up courage to waylay him at recess, and my joy knew no bounds on the occasion when he invited me to remain after school and continue our talk and to be shown some new scientific discovery. . . ." [7]

Professor Thomson resigned from Central High School to become "electrician" for the American Electric Company, a firm organized early in 1880 at New Britain, Conn., to control the Thomson-Houston patents. Two years later Thomson, at the suggestion of Charles A. Coffin of Lynn, Mass., formed the Thomson-Houston Company to take over the assets of the New

[7] "My Professor," by Edwin W. Rice, Jr. Elihu Thomson, Eightieth Birthday Celebration at the Massachusetts Institute of Technology, March 29, 1933. The Technology Press, Cambridge, Mass.

Britain Company, and in 1883 the business was moved to Lynn. With Coffin assuming the burden of finance and management, Thomson was free to give undivided attention to research and technical development, and for the first time he was able to surround himself with competent assistants. The result of this happy arrangement was one of the most extraordinary records of technical achievement in the history of the electrical industry.

Founded in the period when Edison was demonstrating the commercial possibilities of electricity with his "Jumbo" dynamos, the company grew rapidly. In 1884 it employed 184 workers, but by 1892, when it was merged with its competitor, the Edison General Electric Company of Schenectady, the number had grown to 4000.[8] The result of the merger was the General Electric Company, with Coffin as President and Rice, who had been manager of the Lynn plant, as Vice-President and Technical Director. Not the least of Professor Thomson's contributions to the success of this great industrial organization was his demonstration of the value of industrial research.

Returning to the record of Professor Thomson's inventions, we find him in 1885 applying his magnetic blowout to lightning arresters. This fundamental method of breaking electric currents became the foundation for automatic circuit breakers and for controllers of electric cars and trains.

The basic idea of his lightning arrester derived from an accurate knowledge and study of scientific phenomena involved in the discharge of electricity through gases. A transmission line, of course, has to be insulated from the earth by insulators adequate to prevent spark-over at the voltages used. If, however, the line is struck by lightning or an abnormally large electric surge passes through it, a spark may pass around the insulation, and it is a peculiarity of sparks through air that when once the insulation of the air is broken down by a spark there is literally no limit to the amount of current which can flow. Thus these sparks frequently cause serious short circuits.

Professor Thomson's discovery consisted in placing the in-

[8] "Professor Thomson and the Development of the Lynn Electrical Industry" by J. A. McManus, Tercentenary edition "Greater Lynn," June 1929, Lynn Chamber of Commerce.

sulator between the poles of a magnet, with the result that the spark or arc which might be produced was acted on by electrical forces in such a way as to elongate it in the form of a bow which became more and more extended until it finally became so long that it went out. This principle is of just as great importance today as ever and is the foundation of many recently improved schemes for the switching of very large currents.

Again in these early days and long before the importance of it was understood, Thomson had outlined the now universally used method of transmitting alternating current by transformers. He had written out a description of the system in 1878 and set up a working model at the Franklin Institute in 1879, but his patent application was not filed until 1885. After an unusually strenuous history in the Patent Office because of interferences with the work of Gaulard, Gibbs, Brush and others, the patent did not issue until 1902. When it did issue it covered every alternating current distribution system in the country, and it is not surprising, therefore, that the courts subsequently held the patent invalid.

One of the reasons why Thomson delayed his application for this celebrated patent on alternating current distribution was his fear that the system would be dangerous when reduced to practice; the insulation of the transformer might break down and the high voltage of the primary would appear in the secondary circuit. It was not until he discovered in 1885 a way to avoid the danger, chiefly by grounding the secondary in the transformer, that he was willing to see the distribution system put into use.

In the further development of alternating current machinery he devised constant current transformers embodying the magnetic leakage shunt (1889), and a movable secondary (1894), which could be adjusted, in relation to a fixed primary, to give constant current output. Again, in the direction of increasing the power capacity of transformers, he obtained patents in 1890 covering the cooling of transformers by oil immersion and by air. He further called attention to the deleterious effect of moisture in the oil, an effect the full significance of which experts of insulation are only now beginning adequately to realize.

I pass now to two of the most important and characteristic of Professor Thomson's discoveries. The first of these is that process of electrical welding (1886), whereby the welded surfaces were fused and united by the heat developed on account of the resistance in the contact between them. This method of welding has come into enormous use in industry and the indications are that it will be even more used in the near future. As examples in widely different fields may be mentioned the welding of seamless metal tubing, the attachment of filaments and other electrodes in incandescent lamps and vacuum tubes, and the fastening together of many of the parts of automobiles. In the former of these applications it may be interesting to know that a single manufacturer had manufactured, a few years ago, about 24,000 miles of bedstead tubing by this process in a single year.

Professor Thomson described the genesis of this invention as follows:

"While preparing a lecture on Electricity (one of a course of five) at the Franklin Institute at Philadelphia, early in 1877, I had the temetery to pass the discharge of a Leyden battery through the fine wire secondary of a Ruhmkorff induction coil, while the primary coil of quite coarse wire had its terminals resting together in contact. As the Ruhmkorff was my own, one I had made, I could take the risk of breaking down the insulation. On the passage of the condenser spark of about 35 mm. length, a bright flash appeared at the ends of the heavy primary in contact, and I afterward found them firmly welded together.

"This suggested to me the possibility of electric welding, and later, about 1885, as soon as opportunity afforded, I built the first electric welder,[9] using a transformer to step down to a very short and heavy secondary between the terminals of which, by suitable clamps, the pieces to be welded were held in juxtaposition or contact. The first trials of this apparatus were highly successful, and welds were made not only between pieces (bars) of the same metal, but many different metals were so united."

Professor Thomson was not the first to utilize an arc in welding. There was some previous art, such as that of Slavianoff

[9] "Electric Welding," by Elihu Thomson, the *Electrical World,* December 25, 1886.

and DeMeritens, but the DeMeritens patent, which was fundamental, was bought on advice of Professor Thomson by the Thomson Electric Welding Company in the early days, and had arc welding developed within the life of the patent, that company would have controlled the arc as well as the electric resistance welding art.

Again, one of Professor Thomson's most fundamental discoveries was the principle of dynamical repulsion between a primary and secondary coil. This can be demonstrated by a variety of interesting lecture experiments, most of which were suggested and shown first by Professor Thomson himself. One of these experiments still serves as a spectacular demonstration for popular science lectures and for elementary classes in physics. A vertical wire coil is surrounded by a spool of wire through which a large current can be passed upon throwing a switch. A metal ring which slips easily over this core is dropped around it from above. Immediately upon closing the circuit this ring is shot up into the air by the repulsive action of the electric current produced in the ring and the primary current in the coil. This scientific observation was developed by Professor Thomson into an alternating current repulsion motor which is nothing more nor less than our present repulsion induction motor.

In connection with this discovery the following quotation from the *Electrical World* of May 28, 1887 is of interest:

"It is, as yet, too early to assign to its proper place and limit the part which the alternating current will take in the electric arts. It has started on its career with most rapid strides, and it now only remains to devise means for its accurate measurement, regulation, and distribution. Certain it is that Professor Thomson's brilliant paper cannot fail to act as a powerful stimulus to those whose attention is now absorbed in the direction indicated, and the fruits of which will soon be noted. We hope that at a later meeting of the Institute Professor Thomson will give to the world his practical results, which he has only hinted at in the present paper."

In the field of electrical measuring instruments, he invented the "inclined-coil" instrument (1895), and the Thomson integrating wattmeter (1889). It is this latter meter which is now almost universally used for measuring amounts of electric current used. In 1890 this instrument was exhibited in Paris and a prize of 10,000 francs for meters was divided between Thomson and Aron.

He next turned to the investigation of high-frequency phenomena. Already he had conceived the notion (1876), as I have mentioned, of tuning electric circuits, an operation fundamental to modern communication systems, and he had observed the propagation of electrical waves through space. In 1890 he patented a dynamo operating at frequencies 30 to 40 times greater than any previous machine. This led him to design high-frequency transformers. While working in this field he discovered (1893) a method of producing still higher frequency alternating current from a direct current arc, by shunting the arc with inductance and capacity, thus discovering the method which played such an important role in wireless transmission up until its virtual replacement by electronic tube devices. This interesting method of producing alternating currents was independently developed and applied to wireless telegraphy by Poulsen, and is therefore generally known as the Poulsen arc. During these high frequency investigations he made the important discovery that the insulating power of oils at these high frequencies is very much greater than at the ordinary low commercial frequencies, if this insulating power is measured in terms of the path at which a spark will pass.

After Röntgen announced his discovery of X-rays in 1895 Professor Thomson immediately began a series of experiments with them, the foundation for which had been laid by his previous experiments, beginning in 1891, on electric discharge through gases. In 1897 he made the first application of stereoscopic principles to X-rays, a great step forward in the medical use of X-rays for clinical purposes. He also made many improvements in the design of X-ray tubes, including the double-focus tube and a cooled-target tube. Along with these experiments he took a lively interest in the physiological effects of X-rays, going so far as to expose one of his fingers until a definite burn resulted.

Among his many other electrical inventions should be noted his resistance electric furnace patented in 1894, and a dynamo-static machine (1900) by which it was possible to obtain high-frequency discharges suitable for vacuum-tube apparatus.

As I have already suggested, Professor Thomson did not confine his activity exclusively to electrical science. Jointly with his first colleague, Houston, he invented and patented (1881) a continuous cream separator, the precursor of the ultra-centrifuge of today. In the field of steam engineering he secured a patent in 1903 on a "fluid pressure engine" of very high efficiency. This engine was later taken up by German engineers and reappeared under the name of the Stump Uniflow Engine.

Again in 1894 he devised a muffler for automobiles antedating the Maxim silencer and in many respects similar in principle. This muffler was based upon the sound scientific principle of dividing up an impulse or sound wave so that it should traverse a number of paths of unequal length in such a way that when these divided impulses all came together again, they would be out of phase and partially neutralize each other so as to take away or spread out the shock of the initial impulse. I can only mention further in the field of automotive engineering that Professor Thomson devised numerous types of gas and oil engines or improvements in their construction.

Professor Thomson began his career as a teacher of chemistry and he continued active in this area throughout his life. I have mentioned his early paper on the inhalation of gases and his suggestion that helium and nitrogen be used in deep sea diving. He early observed the transformation of ordinary carbon into graphite. In the nineties he published a series of papers on the uses of liquid air, and in 1906 published an article with the modern-sounding title "Alcohol and the Future of the Power Problem."[10] A patent granted to him in 1902 shows a method of forming hollow cylinders of quartz by the action of an arc drawn up through a bed of granular quartz. This was the beginning of his extended researches directed toward producing quartz disks for telescope mirrors. In a paper read before the American Philosophical Society in November, 1929, he described how he became convinced of the desirability of constructing these mirrors of quartz:

[10] *Cassier's Magazine*, August 1906.

"It is now about thirty years since I made the first experiment, comparing a small slab of fused quartz or fused silica with a similar slab of glass, as a preliminary to further work. I formed on the surface of each of these a slightly concave surface, and then used well-known optical tests to show whether the figure was maintained under different conditions. The experiment was, naturally, imperfect, but I felt sure of the result. On having the two mounted so that I could have a distinct and clear image of a small artificial star, when used with an eye-piece as a telescope is used, I found that by instantaneous application of a moderate heat or a small flame on the back of the glass slab, the image went immediately all to pieces, as we may say; that is, it scattered; the definition was gone. A similar treatment of the quartz slab showed very little change, and not until the back of the quartz had become quite hot was there a semblance of the disturbance such as occurred with the glass. This experiment, modest as it was, convinced me that there was one material suitable for the making of astronomical reflectors that would avoid many of the difficulties of construction and operation inherent with the glass mirror telescopes."

He subsequently made mirrors for a small telescope at the Mount Wilson Observatory and undertook, at the request of the late George Ellery Hale, to prepare a huge fused quartz disk for the Mount Palomar 200-inch telescope.

"Through months and years of painstaking work, Dr. Thomson and his co-workers succeeded in producing larger and larger quartz disks for astronomical purposes, several of which have already been useful for the purposes intended. With every increase in size, however, new difficulties arose which he surmounted until at length quartz disks of five feet in diameter were actually secured. Here progress toward success appeared to be approaching an asymptote. While no difficulties ahead appeared unconquerable, time and cost began to impose harsh limits so that with many misgivings, it appeared expedient to revert to the more familiar and less expensive process of casting glass, if a sufficiently large disk for the 200-inch mirror were to be produced without undue postponement.

"It is now common knowledge that a large disk of Pyrex glass honeycombed to relieve excess weight was finally cast at the Corning Glass Works in March, 1934. Since Pyrex has a lower coefficient of expansion than the ordinary borosilicate glass, the finished product should show a considerable gain in performance in the direction to which Dr. Thomson devoted so much of his energy, even though the result must unfortunately fall short of the high ideal he had set. It is perhaps fair to remark that he was very reluctant to forego further work in the fusing-of-quartz process for he was still confident that the mischievous obstacles which crept in with each increase in size were by no means insurmountable." [11]

In the summer of 1858, when 5 years of age, Thomson had seen Donati's comet and in 1867 he witnessed spectacular meteor showers. These early observations prompted his abiding interest in astronomy. In 1878 he published an account of a method of grinding and polishing glass specula, and in 1899 he began the construction of a telescope for his private observatory, including the difficult task of making the optical parts for the 10-inch reflector. In later years he published nearly a score of papers on astronomical subjects ranging from discussions of zodiacal light to solar eclipses.

Still other scientific byways of Professor Thomson's interest were the earth sciences. He published on "The Nature and Origin of Volcanic Heat," and in his last appearance before the American Academy of Arts and Sciences in 1933, he read a paper on "The Krakatau Outbreak." The eruption of this volcano in Java occurred when he was a small boy in Philadelphia, and had incited the curiosity which he always exhibited. He had watched for evidences, in the brilliant sunsets, of the volcanic ash in the upper atmosphere and had, I am informed, recorded his observations. At a much later date he hired as a research assistant the sole survivor of the catastrophe and induced him to record his personal observations of the event. In his paper before the Academy he reported on this record, upon the history of the eruption and upon his own boyhood observations of its effects. Coupled with these more formal observations were his love of mountain climbing and his activities as an amateur naturalist.

With all this intensive activity, Professor Thomson lived a rich family life. He was married on May 1, 1884, to Mary L.,

[11] "The Astronomical Contributions of Elihu Thomson," a paper read by Harlan T. Stetson at the meeting in commemoration of the life and work of Professor Thomson, February 16, 1939. In the files of the American Philosophical Society, Philadelphia.

daughter of Charles Peck of New Britain, Conn., and of this union there were four sons, Stuart, Roland D., Malcolm and Donald T. In 1916 Mrs. Thomson died, and on January 4, 1923, he was married to Clarissa, daughter of Theodore F. Hovey of Boston. He had a charming home at 22 Monument Avenue, Swampscott, Mass., two of the striking features of which were his excellent shop and observatory. One of his most notable characteristics was his deep and understanding interest in children.

During his life he received wide recognition for his achievements. His honorary degrees included an A.M. from Yale in 1890, a Ph.D. from Tufts College in 1894, a D.Sc. from Harvard University in 1909, and from the University of Manchester, England, in 1924, and the LL.D. from the University of Pennsylvania in the same year.

Among the many medals and prizes he received were: the John Scott Legacy Medal and Premium of the Franklin Institute; the Rumford Medal, 1902, of the American Academy of Arts and Sciences; the Hughes Medal, 1916, of the Royal Society of Great Britain; the Edison Medal, 1910, of the American Institute of Electrical Engineers; the Elliott Cresson Medal, 1912, of the Franklin Institute; the John Fritz Medal, 1916, given by the founder of engineering societies; the Lord Kelvin Medal, 1924, of the English engineering societies; the Franklin Medal, 1925, of the Franklin Institute; the Faraday Medal, 1927, of the Institution of Electrical Engineers, London; the Grand Prix at the Paris Expositions of 1889 and 1900, and the Grashof Medal, 1935, of the Verein Deutscher Ingenieure. He was made Officier et Chevalier de la Legion d'Honneur in 1889.

Of his many affiliations with societies the following may be noted: Fellow of the American Association for the Advancement of Science, American Institute of Electrical Engineers (President, 1889-90), American Chemical Society, American Philosophical Society, National Academy of Sciences, American Academy of Arts and Sciences, Institution of Civil Engineers of Great Britain, and honorary member of the Franklin Institute and Institution of Electrical Engineers of Great Britain. Among the important offices he held was the presidency, succeeding

Lord Kelvin in 1908, of the International Electrotechnical Commission.

Behind all his astonishingly varied interests, stood a man who had complete faith in the efficacy of the scientific method, and who in all his activities, vocational and avocational, was a shining exemplar of the scientific spirit. Something of his own view of his methods was incorporated in an address delivered by him in 1899 as vice-president and chairman of the physics section of the American Association for the Advancement of Science, in which he said:

> "The development in the field of research by experiment is like the opening of a mine, which, as it deepens and widens, continually yields new treasure but with increased difficulty, except when a rich vein is struck and worked for a time. In general however, as the work progresses there will be needed closer application and more refined methods. In most fields of research the investigator must be ready to guide the trained mechanic and be able himself to administer those finishing touches which often mark the difference between success and failure. There must be in his mental equipment that clear comprehension of the proper adjustment of means to ends which is of such great value in work in new fields. He must also learn to render available to science the resources of the larger workshops and industrial establishments. . . . Scientific facts are of little value in themselves. Their significance has a bearing upon other facts, enabling us to generalize and to discover principles, just as the accurate measurements of the position of a star may be without value in itself, but in relation to other similar measurements of other stars may become the means of discovering their proper motion. We refine our instruments, we render more trustworthy our means of observation, we extend our range of experimental inquiry and thus lay the foundation for future work with the full knowledge that although our researches cannot extend beyond certain limits, the field itself is even within those limits inexhaustible."

Observation and experimental inquiry were his chief reliances; he apparently did not resort to the mathematical or analytical methods that most scientists and engineers use who tackle problems as complex as he solved. He was not, like Steinmetz, a gifted mathematician; he seemingly did not need to employ mathematical analysis because his teeming mind leapt to correct conclusions without it.

His powers of observation he carried into every walk of life, and no one could be with him for ten minutes without being impressed and stimulated by his perception and by his wide-ranging knowledge of natural phenomena. He could best be described by saying that he was a brilliant natural philosopher who was held in equally high esteem by practical engineers and by academic scientists.

Perhaps the most eloquent testimony to his scientific contributions may be found in the widespread appreciation today of the value of research in industry. Professor Thomson was one of the first in America to recognize the importance of research, both fundamental and practical, to our industrial progress. This was a contribution that may transcend any of his scientific discoveries.

I have spoken of his devotion to education. His long association with the Massachusetts Institute of Technology affords a specific example. He became a lecturer in electrical engineering at this institution in 1894, and from then until his death he maintained with it the closest sort of relationship. He was elected a life member of the corporation in 1898, was acting president from 1920 to 1923, and for many years was a member of the executive committee of the corporation. He likewise served Harvard University as a lecturer and as a member of several of its visiting committees.

In other ways he never ceased to teach. His friend, Dr. Richard C. Maclaurin, President of M. I. T. from 1909 to 1920, observed:

"Throughout his life he has not only done great things himself but shown an intense desire to help all who are struggling earnestly with scientific problems. He has proved an inspiration to an ever-widening circle of engineers and others who have intrusted him with their secrets and sought his help in overcoming their difficulties. They have done this, knowing that they had only to ask in order to get the full benefit of his imagination and his power, and that they need have no misgivings that he would take any advantage of their confidence or any credit for their work, for he has no touch of selfishness."

From my own association with him I can validate Dr. Maclaurin's tribute. He combined in a most remarkable way the constructive powers of the inventor, the intuition and imagination of the great scientist, and the kindly balance of the ideal philosopher, teacher and friend. Perhaps no inventor save Edison has brought more renown to our country or contributed so much to its recent material progress. His life encompassed the development of the electrical industry, and he will long be remembered as one of those who brilliantly extended and applied the primary discoveries of Faraday and the other pioneers in the science of electricity.

He died on March 13, 1937, in his eighty-fourth year.

Key to Abbreviations Used in Bibliography

Elec. Eng.—Electrical Engineering
Elec. Rec.—Electrical Record
Elec. Rev.—Electrical Review
Elec. World—Electrical World
Electr. & Elec. Eng.—Electrician and Electrical Engineer
Eng. Mag.—Engineering Magazine
Eng. Mech.—English Mechanic
Gen. Elec. Rev.—General Electric Review
Journ. Franklin Inst.—Journal Franklin Institute
Phila. Med. Times—Philadelphia Medical Times
Trans. Amer. Electro-Therapeutic Assn.—Transactions American Electro-Therapeutic Association

SELECTED LIST OF THE PUBLICATIONS * OF ELIHU THOMSON

1873

On the Inhalation of Nitrous Oxide, Nitrogen, Hydrogen and Other Gases and Gaseous Mixtures. Phila. Med. Times, November 15.

1876

Electrical Phenomena. Journ. Franklin Inst., April, Vol. 101, pp. 270-4.

1877

Method of Grinding Glass Specula. Eng. Mech., XXVII, 1878.

1878

Report of Committee on Dynamo Electric Machines. Journ. Franklin Inst., May and June 1878, Vol. 105, pp. 289-303, Vol. 105, pp. 361-77.

A New System of Electric Lighting, and a New Form of Electric Lamp. Journ. Franklin Inst., October, Vol. 106, pp. 251-3.

1886

Welding by Electricity. Electrician (London), September 17, Vol. 17, p. 392.

Electrical Welding. Elec. World, December 25, Vol. 8, pp. 307-9.

1887

Electric Welding. Journ. Franklin Inst., May, Vol. 123, pp. 357-70.

Novel Phenomena of Alternating Currents. Electr. and Elec. Eng., June, Vol. 6, pp. 211-15.

* The American Philosophical Society has in its files in Philadelphia an extensive list of papers by and about Professor Thomson.

1888

Electric Wave and Phase Indicator for Alternating and Undulatory Currents. Elec. World, January 28, Vol. 11, pp. 39-40.

Safety Devices with Transformers. Electrician (London), March 16, Vol. 20, p. 520.

Phenomena of Magnetic Propagation. Elec. World, October 27, Vol. 12, pp. 220-2.

1889

Note on the Recalescence of Iron. Elec. Rev., April 26, Vol. 24, p. 471.

On Recalescence in Steel and Its Relation to Expansion, Magnetization and Hardening. Elec. World, May 25, Vol. 13, p. 295.

Magnetism in Its Relation to Induced E.M.F. and Current. Elec. World, June 1, Vol. 13, pp. 315-16.

1890

Safety and Safety Devices in Electric Installations. Elec. Eng., March, Vol. 9, pp. 95-8.

Phenomena of Alternating Current Induction. Elec. Eng., April 9, Vol. 9, pp. 212-14.

Loss by Hysteresis. Elec. Eng., April 30, Vol. 9, pp. 295-6.

1891

Induction of Alternating Currents and Induction Coils. Journ. Franklin Inst., August, Vol. 132, pp. 81-101.

Physiological Effects of Alternating Currents of High Frequency. Elec. Eng., March 11, Vol. 11, pp. 304-5.

Notes on Alternating Currents at Very High Frequency. Elec. Eng., March 11, Vol. 11, p. 300.

The Electric Arc and Its Use in Lighting. Elec. World, February 28, Vol. 7, pp. 166-70.

Phenomena of Alternating Currents of Very High Frequency. Elec. World, April 4, Vol. 17, p. 254.

Oil Insulation for High Tension Transformers. Elec. Eng., April 15, Vol. 11, p. 440.

Discussion on the Phenomena of Currents of High Frequency. Elec. Eng., April 22, Vol. 11, p. 474.

Practical Aspects of Electrical Welding. Elec. World, June 6, Vol. 17, pp. 421-2.

Constant Current Transformers. Elec. World, July 4, Vol. 18, p. 9.

1892

Induction by High Potential Discharge. Elec. Rev. March 18, Vol. 30, pp. 348-50.

Further Experiments with Condenser, Spark and Air Jet. Elec. Rev., April 15, Vol. 30, p. 493-5.

High Potential Transmission. Elec. World, March 26, Vol. 19, pp. 214-15.

1893

Single Phase Alternating Motors. Elec. Eng., March 15, Vol. 15, pp. 272-3.

1894

Effects of High Frequency Electrical Discharges Passed Through the Body. Trans. Amer. Electro-Therapeutic Assn., September 27.

How the Carbon Brush Came into Use. Elec. Eng., October 3, Vol. 18, p. 265.

1896

Stereoscopic Roentgen Pictures. Elec. Eng., March 11, Vol. 21, p. 256.

Dielectric Strength of Oils in Alternating Potentials. Elec. Eng., February 12, Vol. 21, pp. 160-61.

A Proposed Standard Tube for Producing Roentgen Rays, Double Focus Tube. Elec. World, April 18, Vol. 27, p. 426.

Diffusion and Opalescence with Roentgen Rays. Elec. World, April 25, Vol. 27, p. 452.

Roentgen Rays Act Strongly on the Tissues. Elec. Eng., November 5, Vol. 22, p. 534.

1897

Roentgen Ray Burns. Elec. Eng., April 14, Vol. 23, p. 400.

Roentgen Ray Diffusion Phenomena. Elec. Eng., June 23, Vol. 23, pp. 699-700.

1899

Possibilities of Liquid Air. Eng. Mag., May, Vol. 17, pp. 197-205.

The Field of Experimental Research. Science, August 25, Vol. 10, pp. 236-45.

Apparatus for Obtaining High Frequencies and Pressures. Elec. World, October 14, Vol. 34, pp. 576-8.

1906

Alcohol and the Future of the Power Problem. Cassier's Magazine, August, Vol. 30, pp. 310-12.

The Nature and Origin of Volcanic Heats. Science, August 10, Vol. 24, pp. 161-6.

1909

The Electric Arc and Recent Advances in Arc Lighting. Elec. Rec., June.

1922

Silica Glass or Fused Quartz. Gen. Elec. Rev., February 1923, Vol. 26, pp. 68-74.

1927

Helium in Deep Sea Diving. Science, January 14, Vol. 65, pp. 36-8.

A Suggestion or Hypothesis Concerning the Zodiacal Light. Science, October 21, Vol. 66, pp. 376-8.

The Pioneer Investigations on Dynamo Machines Fifty Years Ago. Journ. Franklin Inst., July 1928, Vol. 206, pp. 17-25.

The United States Patents of Elihu Thomson

A list of Professor Thomson's patents is more significant as an index of his important work than is a bibliography of his publications. Consequently the total list of nearly 700 is presented here as obtained from J. A. McManus, Professor Thomson's secretary. I have ventured to star those which seem to me to be the most important.—*The Author.*

No.	*Title*	*Date*
177,124	Street Railway Rail Fastener	May 9, 1876
183,031	Relays and Sounders	Oct. 10, 1876
*219,157	Dynamo Electric Machine	Sept. 2, 1879
220,287	Regulator for Electric Lamps	Oct. 7, 1879
220,507	Galvanic Battery Cell	Oct. 14, 1879
220,508	Regulator for Electric Lamp	Oct. 14, 1879
220,948	Proc. & App. for Storage of Electricity	Oct. 28, 1879
*223,557	Dynamo Electric Machine	Jan. 13, 1880
223,646	Regulator for Electric Lamps	Jan. 20, 1880
*223,658	Arm. & Com. for Mag. El. Machines	Jan. 20, 1880
*223,659	Aut. Adj. for Com. Brushes on Mag. Electric Machines	Jan. 20, 1880
232,910	Dynamo Electric Machine	Oct. 5, 1880
*233,047	Dynamo Electric Machine	Oct. 5, 1880
*238,315	Cur. Reg. for Dynamo Electric Machines	Mar. 1, 1881
*239,659	Centrifugal Creamer	Apr. 5, 1881
*242,488	Com's for Dynamo El. Machines	June 7, 1881
250,175	Electro Magnetic Device	Nov. 29, 1881
250,463	Electric Lamp	Dec. 6, 1881
*253,958	Electric Lamp	Feb. 21, 1882
255,824	System of Electric Distribution	Apr. 4, 1882
256,605	Electric Lamp	Apr. 18, 1882
258,684	Electric Arc Lamp	May 30, 1882
261,067	Electric Arc Lamp	July 11, 1882
261,790	Electric Arc Lamp	July 25, 1882
*265,936	Means for Preventing Flashing between Electric Conductors	Oct. 10, 1882
265,937	Reg. for Dynamo Electric Machines	Oct. 10, 1882
265,993	Electric Arc Light	Oct. 17, 1882
269,605	Dynamo Electric Machine	Dec. 26, 1882
*269,606	Dynamo Electric Machine (Reg. for)	Dec. 26, 1882
*271,947	Com. for Dynamo Electric Machines	Feb. 6, 1883
*271,948	Electric Current Regulator	Feb. 6, 1883
272,353	Electro-Magnetic Retarding Device	Feb. 13, 1883
*272,920	Electric Arc Lamp	Feb. 27, 1883
*273,496	Air Blast Attachment for Commutators of Dynamo Elec. Mchs.	Mar. 6, 1883
274,413	Electric Arc Lamp	Mar. 20, 1883
275,289	Safety Self-Closing Shunt Switch for Elec. Light Circuits	Apr. 3, 1883
275,290	Safety Self-Closing Shunt Switch for Elec. Light Circuits	Apr. 3, 1883
281,416	Dynamo Electric Machine	July 17, 1883
*283,167	Electric Com. or Switch	Aug. 14, 1883
283,168	Electric Lamp	Aug. 14, 1883
283,437	Electric Lamp	Aug. 21, 1883
289,589	Safety Device for Electric Arc Lamps	Dec. 4, 1883
294,094	Dynamo Electric Machine	Feb. 26, 1884
294,095	El. Power Distributing System	Feb. 26, 1884

No.	*Title*	*Date*
295,836	Double Carbon Arc Lamp	Mar. 25, 1884
296,569	Dynamo Electric Machine	Apr. 8, 1884
296,799	Dynamo Electric Machine	Apr. 15, 1884
297,194	Electric Arc Lamp	Apr. 22, 1884
297,195	Electric Arc Lamp	Apr. 22, 1884
297,196	Electric Arc Lamp	Apr. 22, 1884
297,197	Electric Arc Lamp	Apr. 22, 1884
297,198	Electric Arc Lamp	Apr. 22, 1884
297,199	Electric Arc Lamp	Apr. 22, 1884
297,200	Electric Arc Lamp	Apr. 22, 1884
297,201	Electric Arc Lamp	Apr. 22, 1884
302,960	Electric Lamp	Aug. 5, 1884
302,961	Focusing Electric Arc Lamp	Aug. 5, 1884
302,962	Electric Arc Lamp	Aug. 5, 1884
302,963	Reg. for Dynamo Electric Machines	Aug. 5, 1884
303,762	Electric Arc Lamp	Aug. 19, 1884
303,898	Electric Lamp Mechanism	Aug. 19, 1884
*305,413	Electric Lamp Mechanism	Sept. 16, 1884
306,118	Electric Arc Lamp	Oct. 7, 1884
306,119	Electric Arc Lamp	Oct. 7, 1884
307,818	Aut. Cut-out for El. App.	Nov. 11, 1884
307,819	Cut-out for Electric Arc Lamps	Nov. 11, 1884
320,017	Cut-out for Electric Circuits	June 16, 1885
320,018	Electric Lamp	June 16, 1885
*321,461	Electric Lighting System	July 7, 1885
*321,463	Electric Switch	July 7, 1885
*321,464	Lightning Arrester	July 7, 1885
*322,138	System of Electrical Distribution	July 14, 1885
322,139	System of Electrical Distribution	July 14, 1885
*323,975	Dynamo El. or El. Dynamic Machine	Aug. 11, 1885
323,976	Aut. Com. Adj. for Dynamo Electric Machine	Aug. 11, 1885
324,501	Reg. for Dynamo Electric Machines	Aug. 18, 1885
324,502	Electric Arc Lamp	Aug. 18, 1885
*327,039	Safety Device for Electric Circuits	Sept. 29, 1885
*333,573	Dynamo Electric Machine	Jan. 5, 1886
335,158	Incandescent Electric Lamp	Feb. 2, 1886
*335,159	System of Electric Distribution	Feb. 2, 1886
335,160	Incandescent Electric Lamp	Feb. 2, 1886
335,547	Electric Motor	Feb. 2, 1886
335,548	Switch or Turn-off for Electric Circuits	Feb. 2, 1886
338,208	Aut. Cut-out for Electric Lamps	Mar. 16, 1886
*339,079	Reg. for Dynamo Electric Machines	Mar. 30, 1886
339,714	Electric Switch	Apr. 13, 1886
344,692	Holder for Incandescent Lamps	June 29, 1886
345,334	Electro Magnetic Motor	July 13, 1886
345,335	Socket for Incandescent Lamps	July 13, 1886
345,336	Commutator Brush	July 13, 1886
*347,140	Apparatus for Electric Welding	Aug. 10, 1886
*347,141	Apparatus for Electric Welding	Aug. 10, 1886
*347,142	Electric Welding	Aug. 10, 1886
349,912	Compound Wound Dynamo Electric Machine	Sept. 28, 1886
350,955	Cut-out App. for Electric Lamps	Oct. 19, 1886
350,956	Aut. Compensator for Magnets	Oct. 19, 1886
350,957	Electro Magnet	Oct. 19, 1886
350,958	Distribution of Electric Currents	Oct. 19, 1886
353,179	Regulator for Electric Currents	Nov. 23, 1886
353,180	Reg. for Dynamo El. Machines, Motors, etc.	Nov. 23, 1886

No.	*Title*	*Date*
354,272	App. for the Distribution of Electricity by Means of Secondary Batteries	Dec. 14, 1886
354,273	Reg. for Dynamo Electric Machines	Dec. 14, 1886
354,274	Induction Coil	Dec. 14, 1886
356,902	Arm. for Dynamo Electric Machines	Feb. 1, 1887
356,903	Electric Arc Lamp	Feb. 1, 1887
358,131	Pump for Producing High Vacua	Feb. 22, 1887
360,122	System of Electric Distribution	Mar. 29, 1887
360,123	Electro Magnetic Cut-off	Mar. 29, 1887
360,124	Automatic Cut-off	Mar. 29, 1887
*360,125	System of Electric Distribution	Mar. 29, 1887
363,183	Electric Switch	May 17, 1887
363,184	Automatic Commutator Adjuster	May 17, 1887
*363,185	Alternating Current Electric Motor	May 17, 1887
*363,186	Alternating Current Motor Device	May 17, 1887
365,553	Electric Arc Lamp	June 28, 1887
367,469	System of Electric Distribution	Aug. 2, 1887
367,470	Reg. for Dynamo Electric Machines and Motors	Aug. 2, 1887
367,471	Coupling Compound Wound Dynamo Machines	Aug. 2, 1887
367,866	Coupling Dynamo Electric Machines	Aug. 9, 1887
369,754	Dynamo Electric Machine or Motor	Sept. 13, 1887
*370,572	Electric Arc Lamp	Sept. 27, 1887
370,573	Re. Device for Alternating Current Circuits	Sept. 27, 1887
372,501	System of Electric Distribution for Alternating Currents	Nov. 1, 1887
373,108	Electric Motor	Nov. 15, 1887
375,022	Electric Welding	Dec. 20, 1887
375,784	Apparatus for Electric Welding	Jan. 3, 1888
376,120	Dynamo Electric Machine or Motor	Jan. 10, 1888
377,217	Alternating Current Motor and Regulating Device	Jan. 31, 1888
381,441	Electric Meter	Apr. 17, 1888
381,442	Electro-Mechanical Device	Apr. 17, 1888
381,443	Electric Meter	Apr. 17, 1888
382,335	Alternating Current Dynamo Electric Machine	May 8, 1888
382,336	Alternating Current Regulator	May 8, 1888
385,022	Apparatus for Electric Welding	June 26, 1888
385,384	Joining Pipes by Electricity	July 3, 1888
385,385	Electrically Welding Chains and Links	July 3, 1888
385,386	Direct Electric Welding Machine	July 3, 1888
385,647	Electric Meter	July 3, 1888
386,441	Apparatus for Electric Welding	July 17, 1888
387,123	Flue for Electric Transformers	July 31, 1888
389,265	Thermal Device for Varying Electric Resistance of Currents	Sept. 11, 1888
389,779	Direct Welding Dynamo Electric Machine	Sept. 18, 1888
390,318	Alternating Current Dynamo	Oct. 2, 1888
391,437	Electrical Potential Differentiator	Oct. 23, 1888
392,765	Dynamo Electric Machine	Nov. 13, 1888
393,040	Electric Light Pole	Nov. 20, 1888
394,892	Portable Electric Welding Apparatus	Dec. 18, 1888
395,018	Electric Meter	Dec. 25, 1888
396,009	Forming, Brazing and Welding of Metals by Electricity	Jan. 8, 1889

No.	Title	Date
396,010	Electric Forging	Jan. 8, 1889
396,011	Electric Welding	Jan. 8, 1889
396,012	Apparatus for Electric Welding and Working Metals	Jan. 8, 1889
396,013	Electric Pipe Joining and Pipe Work	Jan. 8, 1889
396,014	Electric Metal Working	Jan. 8, 1889
396,015	Electric Riveting	Jan. 8, 1889
397,616	Regulating and Motive Device for Alternating Currents	Feb. 12, 1889
398,912	Manufacturing Screws and Bolts by Electricity	Mar. 5, 1889
398,913	Electric Welding Machine	Mar. 5, 1889
398,914	Electric Metal Working and Welding Machine	Mar. 5, 1889
399,800	Dynamo Electric Machine	Mar. 19, 1889
399,801	Alternating Current Inductor	Mar. 19, 1889
*400,515	Apparatus for Regulating Current or Potential in Secondary of Transformers	Apr. 2, 1889
*400,516	Method of Regulating Current or Potential in Secondary of Transformers	Apr. 9, 1889
400,971	Alternating Current Electric Motor	Apr. 9, 1889
400,972	Induction Coil and Self-Inductive Apparatus	Apr. 9, 1889
400,973	Armature for Dynamo Electric Machines	Apr. 9, 1889
*401,085	Lightning Arrester	Apr. 9, 1889
401,608	Distribution of Electric Currents	Apr. 16, 1889
401,803	Electric Meter	Apr. 23, 1889
403,157	Method of Electric Welding and Shaping of Metals	May 14, 1889
403,707	Process of Electric Soldering, Brazing & Welding	May 21, 1889
403,708	Method of Electric Welding and Brazing	May 21, 1889
406,010	Electric Meter	June 25, 1889
407,844	Alternating Current Electric Motor	July 30, 1889
409,714	Induction Coil	Aug. 27, 1889
410,468	Reactive and Induction Coil	Sept. 3, 1889
413,292	Electric Measuring Instrument	Oct. 22, 1889
413,293	System of Electrical Distribution	Oct. 22, 1889
413,294	Conduit for Electrical Railways	Oct. 22, 1889
414,266	Iron-Cased Induction Coil for Alternating Current Transfer	Nov. 5, 1889
415,305	Electric Welding Clamp	Nov. 19, 1889
415,747	Electric Meter	Nov. 26, 1889
415,748	Electric Meter	Nov. 26, 1889
415,749	Electric Transformers	Nov. 26, 1889
416,350	Electric Meters	Dec. 3, 1889
416,762	Induction Coil, Transformer, etc.	Dec. 10, 1889
418,198	Method of Making Collars on Axles by Electricity	Dec. 31, 1889
418,249	Lightning Arrester	Dec. 31, 1889
420,306	Electric Transformer	Jan. 28, 1890
421,207	Cut-out for Incandescent Lamps	Feb. 11, 1890
421,208	System of Distribution for Alternating Currents	Feb. 11, 1890
422,550	Compound Insulating Layer for Electric Coils	Mar. 4, 1890
422,999	Field Magnet for Dynamos	Mar. 11, 1890
423,965	Electric Valve Controller	Mar. 25, 1890
423,966	Method of Electric Soldering, Cementing, etc.	Mar. 25, 1890

No.	*Title*	*Date*
423,967	Apparatus for Electric Soldering and Cementing	Mar. 25, 1890
425,470	Distribution of Electric Currents	Apr. 15, 1890
425,588	Cut-out	Apr. 15, 1890
425,640	Guard for Electric Railway Trolleys	Apr. 15, 1890
426,082	Safety Connection	Apr. 22, 1890
426,348	Dynamo Electric Machine	Apr. 22, 1890
428,647	Turn-off for Alternating Current Circuits	May 27, 1890
*428,648	Casing for Induction Coils	May 27, 1890
428,649	Electric Meter	May 27, 1890
*428,650	Alternating Current Magnetic Device	May 27, 1890
428,651	System of Electrical Distribution	May 27, 1890
428,652	Incandescent Lamp Socket	May 27, 1890
428,653	Guard Wire Protector and Lightning Arrester for Electric Railways	May 27, 1890
428,704	Electric Switch	May 27, 1890
428,705	Regulator for Dynamo Electric Machines	May 27, 1890
430,326	Electro-Magnetic Cut-out for Electric Lamps	June 17, 1890
430,327	Regulator for Dynamo Electric Machines	June 17, 1890
430,328	Alternating Current Motor	June 17, 1890
430,357	Electric Arc Lamp	June 17, 1890
431,414	Electric Railway Conductor	July 1, 1890
432,581	Frog for Overhead Wires	July 22, 1890
432,651	Method of Working Metals by Electricity	July 22, 1890
432,652	Welding or other Dynamo	July 22, 1890
432,653	Method of Welding Pipes by Electricity	July 22, 1890
432,654	Electric Meter	July 22, 1890
*432,655	Dynamo Electric Machine	July 22, 1890
432,656	Manufacture of Bands, Rings, etc. by Electricity	July 22, 1890
434,488	Electric Power Transmission	Aug. 19, 1890
434,489	Electric Power System	Aug. 19, 1890
434,530	Process of and Apparatus for Forming and Welding Metals by Electricity	Aug. 19, 1890
434,531	Induction Discharge Protector for Welding Apparatus	Aug. 19, 1890
434,532	Process of Electric Welding	Aug. 19, 1890
434,961	Section Insulator for Overhead Electric Conductors	Aug. 26, 1890
435,870	Suspending Device for Overhead Electric Conductors	Sept. 2, 1890
438,204	Electric Motor	Oct. 14, 1890
438,656	Electric Motor	Oct. 21, 1890
438,657	Process of Electric Welding	Oct. 21, 1890
438,658	Electric Welding of Pipes	Oct. 21, 1890
440,662	Electric Arc Lamp	Nov. 18, 1890
440,663	Electric Arc Lamp	Nov. 18, 1890
440,664	Method of Electric Welding	Nov. 18, 1890
440,665	Trolley Arm for Electric Railways	Nov. 18, 1890
*444,678	Lightning Arrester	Jan. 13, 1891
444,925	Electric Arc Lamp	Jan. 20, 1891
444,926	Method of Electric Welding	Jan. 20, 1891
444,927	Method of Electric Welding	Jan. 20, 1891
444,928	Method of Electric Welding	Jan. 20, 1891
444,929	Incandescent Electric Lamp	Jan. 20, 1891
444,930	System of Distributing and Metering Electric Energy	Jan. 20, 1891

No.	*Title*	*Date*
444,931	Electric Meter	Jan. 20, 1891
444,946	Method of Electric Welding	Jan. 20, 1891
446,483	Electric Railway Conductor	Feb. 17, 1891
447,383	Electric Arc Lamp	Mar. 3, 1891
447,384	Dynamo Electric Motor or Generator	Mar. 3, 1891
448,279	Electric Lighting System	Mar. 17, 1891
448,280	Electric Meter	Mar. 17, 1891
*448,894	Electric Meter	Mar. 24, 1891
449,356	Manufacturing Chains by Electric Welding Process	Mar. 31, 1891
449,357	Burr Preventer for Electric Welding Machines	Mar. 31, 1891
449,715	Electric Arc Lamp	Apr. 7, 1891
449,836	Method of Electric Welding	Apr. 7, 1891
450,687	Railroad Gate Crossing for Overhead Lines	Apr. 21, 1891
451,345	Method of Electric Welding	Apr. 28, 1891
452,951	Armature for Dynamo Electric Machines or Motors	May 26, 1891
454,090	Transformer	June 16, 1891
454,671	Lightning Arrester	June 23, 1891
454,672	Lightning Arrester	June 23, 1891
*454,673	Lightning Arrester	June 23, 1891
454,782	Lamp Cut-Out and System	June 23, 1891
454,890	Apparatus for Removing Inductive Effects from Electric Lines	June 30, 1891
455,420	Method of Electric Welding	July 7, 1891
455,421	Securing Metal Bands on Wooden or other Articles	July 7, 1891
455,905	Automatic Hammer	July 14, 1891
456,172	Method of Measuring Electric Currents	July 21, 1891
457,036	Electric Motor for Street Cars	Aug. 4, 1891
458,025	Electric Arc Lamp	Aug. 18, 1891
*458,115	Method of Electric Bending and Straightening	Aug. 18, 1891
458,646	Electric Motor	Sept. 1, 1891
*459,422	Dynamo Electric Machine and Motor	Sept. 15, 1891
459,423	System of Electrical Distribution	Sept. 15, 1891
460,765	Composition for Insulating Material	Oct. 6, 1891
461,144	Electric Arc Lamp	Oct. 13, 1891
461,526	Adjustable Transformer	Oct. 20, 1891
461,856	Mode of Making Tools	Oct. 27, 1891
*462,338	Incandescent Lamp	Nov. 3, 1891
462,339	Incandescent Lamp	Nov. 3, 1891
462,973	Brush Holder for Dynamo Electric Machines	Nov. 10, 1891
463,671	Armature Core for Dynamo Electric Machines	Nov. 24, 1891
463,761	Section Insulator and Lightning Arrester for Electric Railroads	Nov. 24, 1891
463,762	Electric Arc Interrupter	Nov. 24, 1891
464,595	Lightning Arrester	Dec. 8, 1891
*465,078	Method of Controlling Alternating Current Induction	Dec. 15, 1891
467,318	Commutator for Dynamo Electric Machines and Motor	Jan. 19, 1892
468,119	Electric Switch	Feb. 2, 1892
468,120	Method of and Means for Interrupting Electric Currents	Feb. 2, 1892
468,121	Dynamo Electric Machine	Feb. 2, 1892
468,122	System of Electric Distribution	Feb. 2, 1892

No.	*Title*	*Date*
468,123	System of Electrical Distribution	Feb. 2, 1892
468,497	Lightning Arrester	Feb. 9, 1892
470,221	Electric Railway	Mar. 2, 1892
470,721	Lightning Arrester	Mar. 15, 1892
*471,155	Alternating Current Motor	Mar. 22, 1892
476,330	Safety Device for Electric Motors	June 7, 1892
476,331	Dynamo Electric Machine	June 7, 1892
476,967	Manufacture of Axes	June 14, 1892
478,145	Electric Arc Lamp	July 5, 1892
478,722	Distribution of Electric Currents	July 12, 1892
480,392	Method of Electric Soldering	Aug. 9, 1892
481,878	System of Telephony	Aug. 30, 1892
482,209	Induction Coil for Electric Meters	Sept. 6, 1892
482,397	Ventilating Armatures for Dynamo Electric Machines	Sept. 13, 1892
483,700	Armatures for Dynamos and Motors	Oct. 4, 1892
485,239	Regulator for Dynamo Electric Machines	Nov. 1, 1892
485,669	Continuous Current Transformer	Nov. 8, 1892
486,916	Electrical Transformer	Nov. 29, 1892
487,302	Method of Electric Welding	Dec. 6, 1892
488,585	Electric Arc Lamp	Dec. 27, 1892
489,046	Electric Arc Lamp	Jan. 3, 1893
490,178	Electric Circuit Breaker	Jan. 17, 1893
490,376	Armature for Dynamo Electric Machines or Motor	Jan. 24, 1893
490,839	Thermal Circuit Closer	Jan. 31, 1893
493,313	Dynamo Electric Machine	Mar. 14, 1893
*493,314	Lightning Arrester	Mar. 14, 1893
493,739	Electric Arc Lamp	Mar. 21, 1893
495,071	Compressed Air Apparatus	Apr. 11, 1893
495,714	Lightning Arrester	Apr. 18, 1893
*495,853	Lightning Arrester	Apr. 18, 1893
496,019	Electric Soldering	Apr. 25, 1893
496,020	System of Electric Distribution	Apr. 25, 1893
496,455	Electric Lighting System	May 2, 1893
496,456	Commutator for Dynamo Electric Machines	May 2, 1893
496,710	Friction Coupling for Dynamos or Motors	May 2, 1893
496,918	Safety Connection for Induction Coil Systems	May 9, 1893
497,361	Commutator Brush Holder for Dynamo Electric Machines	May 16, 1893
497,838	Safety Appliance for Systems of Electric Distribution	May 23, 1893
498,327	Pole Piece for Dynamo Electric Machines	May 30, 1893
500,629	Electric Switch	July 4, 1893
*500,630	Method of and Means for Producing Alternating Currents	July 4, 1893
500,631	Rheostat	July 11, 1893
501,114	Lightning Arrester	July 11, 1893
501,172	Manufacture of Incandescent Electric Lamps	July 11, 1893
501,546	Automatic Chain Welding Machine	July 18, 1893
501,547	Shaping and Spinning Metals by Electricity	July 18, 1893
502,022	Electric Measuring Instrument	July 25, 1893
502,330	Fusible Cut-Out	Aug. 1, 1893
502,788	Regulator for Electric Generators	Aug. 8, 1893
503,445	Method of Winding Coils for Dynamo Electric Armatures	Aug. 15, 1893
506,383	Cut-Out	Oct. 10, 1893

No.	*Title*	*Date*
508,646	System of Electrical Distribution	Nov. 14, 1893
508,647	Electric Lighting System	Nov. 14, 1893
508,648	Lightning Arrester	Nov. 14, 1893
508,649	Protection for the Insulation of Dynamo Electric Machines	Nov. 14, 1893
508,650	Electrical Transformer	Nov. 14, 1893
508,651	Contact Apparatus	Nov. 14, 1893
508,652	Electric Cut-Out	Nov. 14, 1893
508,653	Insulating Composition	Nov. 14, 1893
*508,654	Cooling Transformer	Nov. 14, 1893
508,655	Electrical Transformer	Nov. 14, 1893
508,656	Electric Arc Lamp	Nov. 14, 1893
508,657	Reactive Coil	Nov. 14, 1893
508,658	Dynamo Electric Machine or Motor	Nov. 14, 1893
508,659	Leading-In Wire for Incandescent Lamps	Nov. 14, 1893
508,660	Detector for Electric Current Meters	Nov. 14, 1893
508,661	Electric Meter	Nov. 14, 1893
508,662	Indicating Apparatus for Electric Circuit	Nov. 14, 1893
509,499	Regulator for Dynamo Electric Machines	Nov. 28, 1893
511,375	Method of and Means for Compounding Dynamo Electric Machines	Dec. 26, 1893
511,376	Electric Measuring Instrument	Dec. 26, 1893
512,848	Chain Making Machine	Jan. 16, 1894
513,349	Means for Neutralizing Self Induction in Alternating Circuits	Jan. 23, 1894
*513,602	Electric Furnace	Jan. 30, 1894
516,666	Electric Railway System	Mar. 20, 1894
516,845	Method of Constructing Commutators for Dynamos or Motors	Mar. 20, 1894
*516,846	Regulation of Alternating Currents	Mar. 20, 1894
*516,847	Means for Regulating Alternating Currents	Mar. 20, 1894
516,848	Armature Winding	Mar. 20, 1894
*516,849	Alternating Current Electric Motor	Mar. 20, 1894
516,850	Electrical Transformer	Mar. 20, 1894
518,290	Armature for Dynamo Electric Machines	Apr. 17, 1894
*518,291	Mode of Cooling Electric Motors	Apr. 17, 1894
519,076	System of Electrical Distribution	May 1, 1894
520,809	Means for Preventing Arcing in Electric Power Stations	June 5, 1894
520,810	Electric Reciprocating Motor	June 5, 1894
*520,811	Electric Meter	June 5, 1894
*521,684	Meter for Recording Measurements of Electric Power	June 19, 1894
521,685	Electric Meter	June 19, 1894
522,241	Alternating Current Dynamo Electric Machine	July 3, 1894
522,865	Current Interrupter for High Potential Circuits	July 10, 1894
523,019	Commutator for Dynamo Electric Machines	July 17, 1894
523,695	Electro Expansion Device	July 31, 1894
523,696	Dynamo Electric Machine	July 31, 1894
525,034	Electric Arc Lamp	Aug. 28, 1894
525,035	Electric Arc Lamp	Aug. 28, 1894
525,369	Electric Lighting System and Apparatus	Sept. 4, 1894
526,169	Electric Apparatus (Motor)	Sept. 18, 1894
528,188	Electric Transformer	Oct. 30, 1894
529,429	Electric Incandescent Lamp	Nov. 20, 1894

No.	*Title*	*Date*
532,838	Electric Welding Apparatus	Jan. 22, 1895
532,839	Electric Meter	Jan. 22, 1895
533,931	Dynamo Electric Machine	Feb. 12, 1895
533,932	Carbon for Arc Lamps	Feb. 12, 1895
*534,730	Means for Operating Drills	Feb. 26, 1895
534,731	Method of and Means for Preventing Magnetic Leakage	Feb. 26, 1895
537,498	Incandescent Electric Lamp	Apr. 16, 1895
537,499	Electric Measuring Instrument	Apr. 16, 1895
537,500	Electric Measuring Instrument	Apr. 16, 1895
537,501	Electric Measuring Instrument	Apr. 16, 1895
539,453	Carbon Brush	May 21, 1895
539,454	Carbon Brush	May 21, 1895
539,886	Electric Meter	May 28, 1895
540,035	Brush Holder for Dynamo Electric Machines	May 28, 1895
542,295	Transformer for Alternating Current Systems	July 9, 1895
542,662	Electric Arc Lamp	July 16, 1895
*542,663	Electric Measuring Instrument	July 16, 1895
543,198	Electric Current Distributor	July 23, 1895
543,950	System of Electric Distribution	Aug. 6, 1895
544,396	Winding of Dynamo Electric Machines or Motors	Aug. 13, 1895
545,111	Means for Synchronizing Electric Motors	Aug. 27, 1895
545,554	Alternating Current Generator or Motor	Sept. 13, 1895
548,406	Dynamo Electric Machine	Oct. 22, 1895
550,464	Dynamo Electric Machine	Nov. 26, 1895
550,733	Electric Safety Device	Dec. 3, 1895
551,799	Electric Arc Lamp	Dec. 24, 1895
554,321	Electrical Measuring Instrument	Feb. 11, 1896
555,130	Electric Welding Indicator	Feb. 25, 1896
555,131	Electric Riveting	Feb. 25, 1896
555,191	Electric Motor	Feb. 25, 1896
555,590	Monocyclic Generator	Mar. 3, 1896
560,379	Electric Measuring Instrument	Mar. 19, 1896
563,895	Rotary Transformer	July 14, 1896
*564,806	Process of Producing Gas	July 28, 1896
571,463	Controlling Electric Arcs	Nov. 17, 1896
574,123	Electric Arc Lamp	Dec. 29, 1896
*575,772	Roentgen Ray Tube	Jan. 26, 1897
*578,430	Electric Meter	Mar. 9, 1897
580,020	Process of Producing Gas	Apr. 6, 1897
580,475	Electric Riveting Apparatus	Apr. 13, 1897
581,873	Electrical Transformer	May 4, 1897
583,955	Carbon Holder for Arc Lamps	June 8, 1897
*583,956	Producing Stereoscopic Pictures by Roentgen Rays	June 8, 1897
*583,957	Electrostatic Influence Machine	June 8, 1897
587,024	Rectifier	July 27, 1897
587,883	Device for Examining Jewels by Roentgen Rays	Aug. 10, 1897
590,653	Shielding Device for Electric Meters	Sept. 28, 1897
590,654	Electric Measuring Instrument	Sept. 28, 1897
591,898	Damper for Electric Measuring Instruments	Oct. 19, 1897
*591,899	Regulating Roentgen Ray Tubes	Oct. 19, 1897
595,419	Method of and Apparatus for Converting Electric Currents	Dec. 14, 1897
595,420	Electric Arc Lamp	Dec. 14, 1897

No.	*Title*	*Date*
596,190	Induction Wattmeter	Dec. 28, 1897
602,922	Electric Arc Lamp	Apr. 26, 1898
602,963	Distribution of Electric Currents	Apr. 26, 1898
610,928	Electrostatic Measuring Instrument	Sept. 20, 1898
*617,546	Controlling Elec. Motors and Trains	Jan. 10, 1899
625,816	System of Electrical Distribution	May 30, 1899
627,155	Electrostatic Measuring Instrument	June 20, 1899
631,343	System of Electric Metering	Aug. 22, 1899
634,965	Electrical Measuring Instrument	Oct. 17, 1899
635,159	Electric Meter	Oct. 17, 1899
635,880	Summation Meter	Oct. 31, 1899
635,881	Electric Meter	Oct. 31, 1899
642,176	Internal Combustion Engine	Jan. 30, 1900
*645,675	High Potential Apparatus	Mar. 20, 1900
646,476	Carbon Brush	Apr. 3, 1900
647,168	Safety Appliance for Electric Circuits	Apr. 10, 1900
649,015	Current Interrupter	May 8, 1900
654,367	System of Distribution	July 24, 1900
655,032	Rectifying Alternating Currents	July 31, 1900
656,680	System of Electrical Distribution	Aug. 28, 1900
656,681	Circuit Breaker	Aug. 28, 1900
659,716	Adjusting Reluctance of Mag. Circs	Oct. 16, 1900
659,717	Contact Device	Oct. 16, 1900
*664,190	Alternating Current Elec. Motor	Dec. 18, 1900
665,486	Dynamo Electric Machine	Jan. 8, 1901
666,161	Elec. Metal Working Apparatus	Jan. 15, 1901
666,162	Transforming Apparatus for Elec. Metal Working	Jan. 15, 1901
667,106	Electric Arc Lamp	Jan. 29, 1901
667,107	Electric Arc Lamp	Jan. 29, 1901
669,291	Current Interrupter	Mar. 5, 1901
669,670	Electrical Measuring Instrument	Mar. 12, 1901
669,737	Gas Engine	Mar. 12, 1901
*669,738	Vapor Generator	Mar. 12, 1901
671,249	Rectifier	Apr. 2, 1901
*676,344	Reg. Device for Alt. Cur. Circuits	June 11, 1901
678,066	Electric Arc Lamp	July 9, 1901
678,916	Electric Arc Lamp	July 23, 1901
684,883	Power Transmitting Device for Engines	Oct. 22, 1901
686,558	Apparatus for Manufacturing Tubes, Pipes, etc.	Nov. 12, 1901
687,588	Steering Mechanism for Automobiles	Nov. 26, 1901
688,558	Ignition Tube	Dec. 10, 1901
691,017	Gas or Oil Internal Combustion Eng	Jan. 14, 1902
691,675	Manufacture of Electrical Condensers	Jan. 21, 1902
*695,127	Insulated Conductor	Mar. 11, 1902
695,870	Electrical Lighting System	Mar. 28, 1902
696,518	Gas or Oil Engine	Apr. 1, 1902
*698,156	System of Electric Distribution	Apr. 22, 1902
Re. 11,997	Insulated Conductor	May 27, 1902
701,965	Electric Meter	June 10, 1902
*702,038	Regulation of Speed & Power Engines	June 10, 1902
706,612	Electric Meter	Aug. 12, 1902
712,106	Electric Meter	Oct. 28, 1902
712,620	Electric Meter	Nov. 4, 1902
712,741	Apparatus for Transferring Elec. Energy	Nov. 4, 1902
712,742	Alternating Current Meter	Nov. 4, 1902

No.	*Title*	*Date*
713,023	—Electric Meter	Nov. 4, 1902
715,901	—Controlling Electric Arcs	Dec. 16, 1902
716,311	—Electrical Conductors	Dec. 16, 1902
723,076	—Rectifier	Mar. 17, 1903
723,189	—Rectifying Alternating Currents	Mar. 17, 1903
723,502	—Internally Fired Engine	Mar. 24, 1903
723,503	—Internally Fired Engine	Mar. 24, 1903
725,798	—Multiple Rate Meter	Apr. 21, 1903
726,233	—Multiple Rate Metering	Apr. 21, 1903
726,593	—Electric Control Mechanism	Apr. 28, 1903
727,713	—Means for Accentuating Elec. Contacts	May 12, 1903
727,714	—Electric Arc Lamp	May 12, 1903
729,449	—Induction Motor Armature	May 26, 1903
729,811	—System of Electric Metering	June 2, 1903
732,908	—Driving Mechanism for Automobiles	July 7, 1903
733,093	—Means for Regulating the Power of Automobiles	July 7, 1903
735,621	—Electrostatic Motor	Aug. 4, 1903
735,683	—Vapor Burner	Aug. 4, 1903
739,564	—Regulator for Vapor Generators	Sept. 22, 1903
*740,203	—Fluid Pressure Engine	Sept. 29, 1903
*741,388	—Steam or Similar Engine	Oct. 13, 1903
744,130	—Electric Arc Lamp	Nov. 17, 1903
745,465	—Transparent Refractory Observation Plate	Dec. 1, 1903
751,028	—Means for Extinguishing Electric Arcs	Feb. 2, 1904
755,815	—Electric Arc Lamp	Mar. 29, 1904
758,157	—Means for Preventing Arcing Between Commutator Brushes	Apr. 26, 1904
*761,111	—Production of Tubes from Refractory Material	May 31, 1904
768,636	—Driving Mechanism for Self Propelled Vehicles	Aug. 30, 1904
*773,827	—Roentgen Ray Tube	Nov. 1, 1904
774,118	—Roentgen Ray Tube	Nov. 1, 1904
*775,586	—Valve Mechanism	Nov. 22, 1904
777,867	—Photometric Apparatus	Dec. 20, 1904
*778,286	—Manipulation of Refractory Material	Dec. 27, 1904
779,189	—Power Generating Apparatus	Jan. 3, 1905
779,190	—Static Influence Electric Machine	Jan. 3, 1905
781,035	—Commutation of Electric Currents	Jan. 31, 1905
781,921	—Gas or Fuel Engine	Feb. 7, 1905
781,922	—Hydrocarbon Burner	Feb. 7, 1905
783,651	—Transformer for Electric Metal Working Apparatus	Feb. 28, 1905
789,463	—Reactive Coil	May 9, 1905
792,087	—Thermo-Regulator for Vapor Burners	June 13, 1905
792,562	—Vapor Burner	June 13, 1905
795,422	—Means for Preventing Pounding in Internal Combustion Engines	July 25, 1905
796,684	—Electric Heater	Aug. 8, 1905
799,809	—Nozzle for Elastic Fluid Turbines	Sept. 19, 1905
801,419	—Electric Measuring Instrument	Oct. 10, 1905
805,248	—Electric Lamp	Nov. 21, 1905
808,263	—Power Transmitting Mechanism	Dec. 26, 1905
809,761	—Electrostatic Influence Machine	Jan. 9, 1906
*822,322	—Engine	June 5, 1906
822,323	—Thermostatic Control	June 5, 1906

No.	*Title*	*Date*
822,324	Governing Mechanism for Elastic Fluid Turbines	June 5, 1906
*824,048	Insulated Coil for Electrical Apparatus and making the same	June 19, 1906
832,708	Diaphragm Actuated Mechanism	Oct. 9, 1906
839,436	Curve Drawing Instrument	Dec. 25, 1906
841,356	Music Sheet Guiding Device	Jan. 15, 1907
848,607	Oil or Gas Engine	Mar. 26, 1907
854,777	Electric Heater 1	May 28, 1907
*854,778	Apparatus for Muffling the Exhaust of Gas Engines	May 28, 1907
857,122	Electric Heater	June 18, 1907
859,350	Unipolar Generator	July 9, 1907
877,473	Torque Regulating Mechanism	Jan. 21, 1908
881,502	Mechanical Movement	Mar. 10, 1908
884,539	Motive Power Engine	Apr. 14, 1908
884,540	Electric Heater	Apr. 14, 1908
890,819	Elastic Fluid Turbine	June 16, 1908
892,097	Vapor Generating Apparatus	June 30, 1908
892,196	Steam Generating Apparatus	June 30, 1908
901,498	Condenser	Oct. 20, 1908
902,024	Electric Heater	Oct. 27, 1908
910,743	Variable Resistance	Jan. 26, 1909
917,187	Electric Measuring Instrument	Apr. 6, 1909
920,789	Elastic Fluid Turbine	May 4, 1909
920,790	Elastic Fluid Turbine	May 4, 1909
924,856	Oil or Gas Engine	June 15, 1909
925,055	Measuring Instrument	June 15, 1909
*925,731	Flexible Coupling	June 22, 1909
927,191	Electric Measuring Instrument	July 6, 1909
945,993	Resistance Unit	Jan. 11, 1910
953,241	Elastic Fluid Turbine	Mar. 29, 1910
957,915	Elastic Fluid Turbine	May 17, 1910
960,440	Compensator	June 7, 1910
960,441	Production of Fine Metal Tungsten	June 7, 1910
969,734	Balancing Means for Turbines	Sept. 6, 1910
973,586	Electrical Welding of Sheet Metal	Oct. 25, 1910
980,703	Inc. Lamp	Jan. 3, 1911
984,719	Electric Welding	Feb. 21, 1911
993,910	Speed Indicator	May 30, 1911
996,377	Electric Measuring Instrument	June 27, 1911
996,378	Changeable Compression Engine	June 27, 1911
997,940	Generating High Temperature Vapor	July 11, 1911
1,001,709	Vapor Electric Apparatus	Aug. 29, 1911
1,001,710	System of Electrical Distribution	Aug. 29, 1911
1,003,547	Transformer Secondary	Sept. 19, 1911
1,006,805	Mercury Vapor Device	Oct. 24, 1911
1,008,622	Electric Heater	Nov. 14, 1911
1,010,987	Make & Break Sparker for Internal Combustion Engines	Dec. 5, 1911
1,011,526	Vibrating Rectifier	Dec. 12, 1911
1,012,934	Electric Metal Working Apparatus	Dec. 26, 1911
1,015,982	Regulating & Controlling the Production of Steam	Jan. 30, 1912
1,015,983	Regulation and Control of Steam Production	Jan. 30, 1912
1,021,219	Igniting Apparatus for Gas Engines	Mar. 26, 1912
1,021,220	Vaporizer for Internal-Combustion Engines	Mar. 26, 1912

No.	*Title*	*Date*
1,022,517	Electrical Measuring Instrument	Apr. 9, 1912
1,022,712	Uniting Metals	Apr. 9, 1912
1,031,489	System of Heating	July 2, 1912
1,031,490	Reduction of Ores	July 2, 1912
1,039,463	Electrical Resistance	Sept. 24, 1912
1,041,197	Arc Lamp	Oct. 15, 1912
1,045,641	Vapor Electric Device	Nov. 26, 1912
1,045,911	Electric Metal Working Machine	Dec. 3, 1912
1,047,593	Turbo-electric Ship Propulsion	Dec. 17, 1912
1,047,858	Turbo-electric Propulsion of Vessels	Dec. 17, 1912
1,048,915	Clamp for Electric Metal Working Apparatus	Dec. 31, 1912
1,063,303	Electrical Resistance	June 3, 1913
1,063,619	Steam Power System	June 3, 1913
1,072,530	Electric Heater	Sept. 9, 1913
1,075,738	Repairing Railway Rails	Oct. 14, 1913
1,076,467	Welding	Oct. 21, 1913
1,078,225	Electric Welding of Sheet Metal	Nov. 11, 1913
1,080,733	Valve Mechanism for Engines	Dec. 9, 1913
1,080,734	Condensing Apparatus	Dec. 9, 1913
1,083,956	Electric Seam Welding	Jan. 13, 1914
1,084,673	Spot Welding Machine	Jan. 20, 1914
1,085,769	Spot Welding Thin Sheets	Feb. 3, 1914
1,093,159	Turbo Ship Steadying Device	Apr. 14, 1914
1,095,131	Speed Indicator	Apr. 28, 1914
1,095,132	Power Transmitting Mechanism	Apr. 28, 1914
1,096,405	Internal Combustion Engine and Operating Same	May 12, 1914
1,097,895	Spot Welding	May 26, 1914
1,105,047	Oil Engine	July 28, 1914
1,105,716	System of Distribution	Aug. 4, 1914
1,112,238	Centrifugal Pump	Sept. 29, 1914
1,118,382	Propelling Ships by Polyphase Electric Current	Nov. 24, 1914
1,118,383	Centrifugal Pump	Nov. 24, 1914
1,118,384	Hydraulic Clutch Mechanism	Nov. 24, 1914
1,121,953	Telephone Metering System	Dec. 22, 1914
1,122,665	Spot Welding Machine	Dec. 29, 1914
1,123,624	Electric Seam Welding	Jan. 5, 1915
1,134,776	Induction Motor	Apr. 6, 1915
1,157,344	Means for Preventing Corona Loss	Oct. 19, 1915
1,168,346	Apparatus for Electric Welding	Jan. 18, 1916
1,173,688	Making a Vitreous Body of Variable Composition	Feb. 29, 1916
1,190,044	Measurement of Small Pressures	July 4, 1916
1,192,706	X-Ray Tube	July 25, 1916
1,220,997	Combined Spot and Butt Welder	Mar. 27, 1917
1,252,201	Electric Meter	Jan. 1, 1918
1,255,667	High Potential Insulator	Feb. 5, 1918
1,256,951	Cooling Spot Welding Electrode	Feb. 19, 1918
1,266,347	Electric Meter	May 14, 1918
1,273,203	Electric Welding	July 23, 1918
1,334,571	Electric Metal-Working Apparatus	Mar. 23, 1920
1,337,106	Process of Making Nitric Acid	Apr. 13, 1920
1,365,567	Leakage-Prevention Arrangement for Fuel Tanks	Jan. 11, 1921
1,375,982	Condenser	Apr. 26, 1921

No.	*Title*	*Date*
1,375,983	Electric Switching Device	Apr. 26, 1921
1,396,541	Electric-Battery System and Method of Operating Same	Nov. 8, 1921
1,450,464	Crystal Formation	Apr. 3, 1923
1,460,083	Recording Signal	June 26, 1923
1,472,504	Electric Heater	Oct. 30, 1923
1,491,440	Switching Apparatus	Apr. 22, 1924
1,491,441	High Speed Alternating Current Dynamo Electric Machine	Apr. 22, 1924
1,504,002	Electrostatic Condenser	Aug. 5, 1924
1,530,441	Mirror	Mar. 17, 1925
*1,532,002	Composite Quartz Body	Mar. 31, 1925
1,536,948	Electric Condenser	May 5, 1925
1,546,266	Process of Shaping Fused Silica	July 14, 1925
1,548,691	Line Welding	Aug. 4, 1925
1,555,775	Arc-Lamp-Feeding Mechanism	Sept. 29, 1925
1,559,203	Process of and Apparatus for Purifying Fusions	Oct. 27, 1925
1,563,051	Regulator for Inclosed Electrical Apparatus	Nov. 24, 1925
1,568,102	Refrigerating Apparatus	Jan. 5, 1926
1,587,445	Electric Welding or Riveting	June 1, 1926
1,588,210	Arc Interrupter	June 8, 1926
1,603,221	Method and Apparatus for Making Glass	Oct. 12, 1926
1,610,182	Fused Quartz Product and Process of Producing Same	Dec. 7, 1926
1,637,063	Electric Welding	July 26, 1927
1,665,331	Producing and Reproducing Sound Records	Apr. 10, 1928
1,680,705	Method of Making Insulators	Aug. 14, 1928
1,683,146	High Frequency Induction Apparatus	Sept. 4, 1928
1,701,346	Electrolytic Apparatus and Method of Operation	Feb. 5, 1929
1,717,281	Insulator	June 11, 1929
1,717,530	Electric Arc Welding	June 18, 1929
1,723,959	Safety Device for Gas Tanks	Aug. 6, 1929
1,746,202	Electric Welding	Feb. 4, 1930
1,746,203	Method and Apparatus for Electric Arc Welding	Feb. 4, 1930
1,746,204	Electric Welding	Feb. 4, 1930
1,746,205	Electric Arc Welding	Feb. 4, 1930
1,759,767	Liquid Level Gauge for Boilers	May 20, 1930
Re.17,826	Cooling Container	Oct. 14, 1930
1,843,792	Composite Silica Article	Feb. 2, 1932