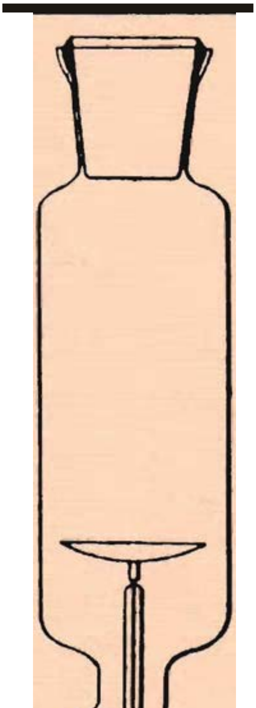
NIKOLA TESLA:

LECTURE BEFORE THE NEW YORK ACADEMY OF SCIENCES - April 6, 1897

Leland I. Anderson, Editor



TWENTY FIRST CENTURY BOOKS BRECKENRIDGE, COLORADO

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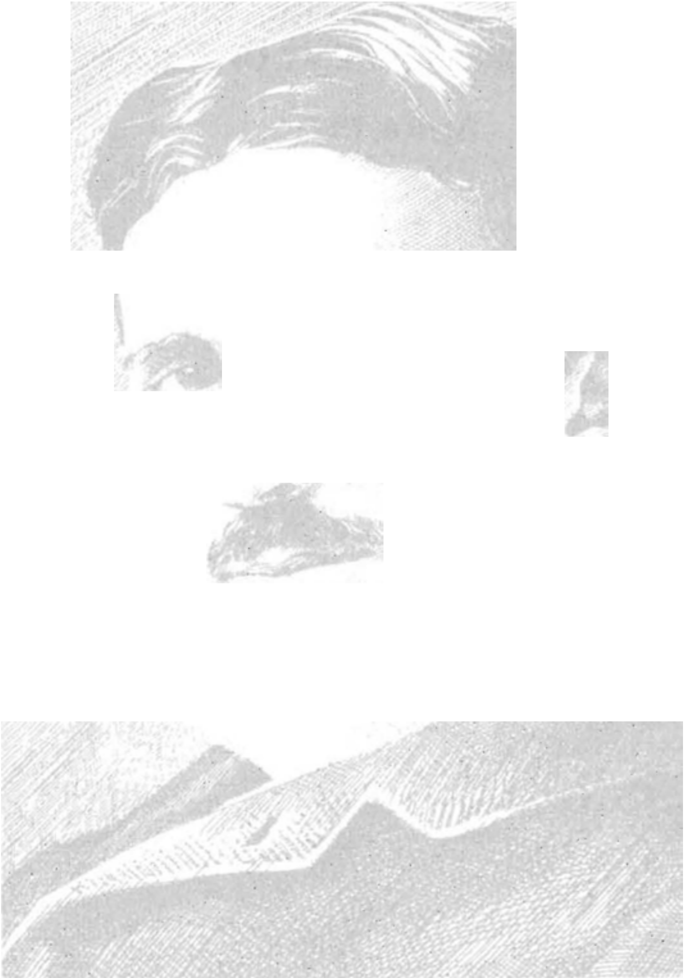

Nikola Tesla

International Telecommwlications Un.ion

NIKOLA TESLA: BEFORE THE NEW YORK ACAD™Y OF SCIENCES

The Streams of Lenard and Roentgen and l\!ovel Apparatus !Or Their Prcxiuction

April 1897

Reconstructed

Leland I.Anderson, Editor

1994

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Fonn oflisting: Sec. #.-Fig. #

Editorial Remarks

Section I of this lecture is presented with few changes from the original text by Tesla, an illustration of which is reproduced on page 30. The text would have benefited an editor's hand if presented to a publisher at that but no such editorial "smoothing" has been attempted in presentation now. Only minor changes have been introduced, such as in words that were separated before the turn of the century but now appear solid. They are: electromagnetic, electro-motive, in as much, foil, wave length. few articles and prepositions were missing, and their have set in brackets [ ]. As an additional to the reader, certain items have been marked brackets with an explanation provided in a note. Line-drawing figures 13 ab, 14, and 16, together with the series of six photographs of drawings of 120 bulbs appearing on pages 76-81, have been enhanced.

Section I appeared among a group of papers passed on to children by George Scherff, who was Tesla's personal secretary, business manager, and confidant from 1895 through A also in the archives of Tesla Museum copies, were m1ssmg some illustration drawings and photographs. These were drawn from the archives of Knight Brothers and Boyle Anderson.

Preface

Nikola Tesla was born of parents at Smiljan, the A ustro-Hungarian border province of Lika, now part of Croatia, at midnight July 9-10, 1856. His father, Milutin, was a Serbian Orthodox priest, and mother, nee Djouka Mandie, was a family line whose sons were the clergy and whose daughters were wives of the clergy. Serbian Orthodox church then used the Julian calendar, and it continues to use this today for days observance. The American colonies converted to the Gregorian calendar years before arrived at York in 1884. When crossed 'date ' 11 days dropped his personal calendar. Most institutions observe Tesla's birth date as 10, which date held for himself, but if the tolling church Lika could have heard in America when Tesla was born, the calendar date would have been July 21,

Establishing himself in United States, Tesla became a citizen in 1891. brought to the world great · gifts for which he induction motor and the multi-phase alternating current power distribution system driving it (1888); the fundamental system wireless telegraphy embodying "Tesla coil" (telemechanics (1898); the Tesla turbine (1913-20), which attracting great revival interest; and, among many leading inventive achievements, VTOL (1928).

* The Tesla family moved to nearby when Nikola reached the age of six to enter school. Adding to the uncertainty of the date accorded Tesla's birth is an official certificate of birth entered for him by the city Gospic his birth date as June 1856. certificate is reproduced in *Nikola Tesla: with Relatives* (Belgrade: Nikola Tesla Museum, 1993; in Serbian and English), illus. sec. I thank Milan Radovic, of Wisconsin-Madison Li- document.

braries, for translating this o, . . -···

50 following the presentation of the principles wi reless telegraphy now called at his in Tesla asserted inventive claim. It wasn 't until five months following death in 1943 that the United Supreme court declared the basic radio patent Marconi in- valid, the prior art of Tesla for system con- cept and apparatus, Stone the method of selectivity, and Lodge variable tuning.

In his lifetime, Tesla was granted over 30 honorary degrees and foundation medals from the world over. The unit magnetic fl ux density in the MKS system was named "tesla" on the occasion of the centennial year of his birth. The only other to share such recognition is Joseph

The 1897 lecture before the New York Academy of Sciences was the sixth historic lectures delivered in rapid succes- sion in America and i n The previous five lectures were:

A New System of Alternate-Current Motors," May 16, 1888, before a meeting of the American Institute Elec- trical Engineers (AIEE) in New York followed by the *trio series* of demonstration lectures on high frequency and high potential alternating currents, the first,"Ex periments with Alternate Current of Very High Frequency and Their Application to Methods of Illumi nation," May 20, 1891, before a meeting of the New York City; the second, "Experiments with Alternate Currents of High Potential and High Frequency," February 3, 1892, before the Institution of Electrical Engineers, London, followed a day (with some condensation) by special request at the Royal Institution, and by invitation, February 19, be- fore the Societe Internationale des Electriciens and the So- ciete Francaise Physique; and the third, "On and Other Phenomena," February 24, 1 before Institute Philadelphia and (with some variation) March 1, before a meeting of the Nation- al Electric Light Association in St. Louis (it was in the latter that the principles of radio commum- cation were first presented); and and Electri- cal Oscillators," August 25, 1893, a meeting of the

International Congress at the Columbian Exposition in Chicago, and (with some variation) November before a meeting the New York Electrical [illegible]".

delivered four additional"""·"11""' lectures or papers *in absentia*, the last in 1911.

Introduction

There are more things in heaven and earth, Horatio,
than are dreamt of in your philosophy.

Hamlet, Act 1, Scene 5

In 1895, the fluorescent coating of a cardboard screen offered just enough illumination for Professor Wilhelm Conrad Roentgen to find his way to the discovery of the X ray. The implications of his discovery for the medical profession were, of course, no less than staggering. Yet history has shown that its implications for the world of physics were more far-reaching than anyone could have imagined.

At the time of Roentgen's discovery, many scientists were quite comfortable with the Newtonian explanation of the way the universe worked and even discouraged students from pursuing careers in physics because, as they thought, physics offered little career potential: almost everything already had been explained! A few notable exceptions, among them black-body radiation and the Michelson-Morley experiment, challenged the neat and simple explanations of Newtonian physics, but the world of science was confident that these phenomena soon would be understood. The nature of light and electricity (ether waves vs. radiant matter) and the structure of the atom were still in the question-forming stage. Roentgen's discovery of the X ray signaled the end of two centuries' confidence in Newtonian physics. With little reservation, the discovery of the X ray can be considered the birth of modern physics.

Where, boundless nature, can I hold you fast?

Faust, 455

The trail leading to the discovery of Roentgen's invisible light began in the seventeenth century with two chance observations of visible light: Von Guericke noting that a faint glow occurred between his hand a spinni ng sulfur ball Piccard finding that light is from mercury sl oshing around the top a barometer. By the early eighteenth Hawksbee, knowing that a vacuum had been present i n upper part of Piccard's barometer, constructed glass vessels removing some the air. He excited them wi th frictional electricity and observed beautiful glowing streams of colored light Al most a century and a half passed before the real significance of this accelerated electron — would begin to be appreciated

The 1790 introduction of Volta's electric battery allowed Oersted, A mpere, Faraday, and Henry to deduce the relationship between electricity and magnetism. Page Rhumkorff induction the high voltage transformers, which could increase the few volts from a battery to many thousands volts. I n the Geissler veloped an efficient vacuum pump, similar to Piccard 's barometer, which employed the weight of to pull the air out of a glass a glass blower, fabricated many types of tubes, evacuated them using his own new pump, and watched them glow wi th beautiful col- ors when high voltage from ind uction coils was applied. Variations in the composition, the ki nd of gas, and the level of vacuum were used to expand the multicolor effects of Geissler tubes.

equi pment improved, higher vacuums were attained; Plticker, Hittorff , and Crookes observed streams of light emanating from the negative electrode of some of their discharge tubes. Furthermore, a magnet was seen to bend and deflect this stream, called the cathode ray. Crookes, Goldstein, and Perrin designed many variations of vacuum charge most of which demonstrated new of cathode ray. Magnetic-effect, paddle-wheel, and canal-ray tubes were only a few of such types.

In the nineteenth century, true nature of cathode was a subject of m uch controversy. I n 1803, Thomas Young showed that light had a wave nature and many scientists assumed that cathodic light (one name given to cathode rays) was just another light wave traveling in the ether. However, Crookes, among others, saw cathode ray as a stream of matter particles which he termed "radiant matter." In 1890, constructed an experiment in which cathode were found to exit a glass discharge tube through a thin aluminum window opposite the cathode. His untimely death m left his student, Lenard, with task of continuing their experiments. Lenard asked Roentgen to repeat some of the experiments that Hertz and he had conducted and presented Roentgen with some apparatus with which to accomplish them.

many scientists of his day, Roentgen focused on the cathode ray. On the evening of November 1895, he carefully covered a discharge tube with a black cardboard to prevent the light in tube from with his investigation. Immediately upon energizing the Roentgen noticed a greenish glow emanating from a nearby cardboard screen that been with a chemical compound known to in the of cathode rays. Cathode rays had never been known to journey more than a cen- ,.,.,,,..,,,1"'<' from discharge tube, and since the cardboard screen was more than a distance from tube, Roentgen concluded that the glow he was the effeet of a new kind of During the course of further investi.... ·.· ··· Roentgen to his to the ray as he held small lead fishing in front the discharge tube: shadow the bones in his were cast on the fluorescent cardboard.

The discovery was made. Givencertainty that X rays were being produced in quantities by of the discharge tubes in use at the time, X rays might have been discovered by any number of scientists during the previous several decades. Rather than diminishing Roentgen's achievement, however, this it considerably, demonstrating not only genius in recog1ruzi1ng what was happening but his in stopping tinvesti- On December 28, 1895, Roentgen published about 50 copies of preliminary paper and distributed them to his local colleagues in Bavaria. Early in he made announcement to rest of the world.

The of living bones tissues their bodies was disconcerting to most people, to say the

A New Jersey proposed a bill to outlaw the making of opera glasses, while a manufacturer offered X-ray-proof undergarments. In Roentgen's own culture, the sight of bones presaged imminent death, and Roentgen's wife was horrified by the in hand.

Obviously, the most immediate application of the new covery was in medical world, and medical practitioners, scientists, and instrument companies any information they could get. Crookes-type vacuum discharge tubes and induction coils were not easy to find outside of university physics laboratories. A Boston dentist, William J. Morton, actually made use of a simple light bulb connected to a borrowed induction coil to produce some the first X-ray ages in the United On 11, 1896, the New York *Electrical Review* answered the for information about X rays by launching a of eight by Nikola in which he presented many new ideas, inventions, and dealing with the ray, its production, use, and scientific explanation.

The Röntgen Rays, The Röntgen Rays,
What is *the craze,*
The town's ablaze
With the new phase
of ways.

Wilhelmina
Electrical Review (London)
17, 1896

Anderson's reconstruction of Tesla's lecture before the New York Academy of on April 6, is a most portant contribution. In this Tesla went beyond his titled "The Streams of and Roentgen Novel for Their Production," and expanded on his X-ray articles published in the York *Electrical Re- view.* large of his vacuum tubes were displayed on the walls of the hall. the tubes rec>re;enrea were not only Crookes and types but va- rieties of single-electrode tubes of Tesla's own invention, some of which were used for his Roentgen-ray demonstra- tions accompanying lecture.

During lecture, discussed the uses of some of tubes in his experiments with wireless telegraphy. Among his tubes, said, were "a great number of devices." Compare this statement with 1916 reported by Anderson in first book of this series, *Nikola Tesla On His Work With Alternating Currents:* "Well, in some of these bulbs I have shown, for instance, that a heat- conductor a stream or as I said at that charged particles, a few of bulbs have been exactly in the same manner the audion is used today."

is prompted to ask, "What was Tesla really looking for in his research and experimentation with vacuum discharge tubes?" His statements about using the tubes in the receiving and detection of wireless offers clues. his ture before the Academy, often referred to Lenard-Roentgen-streams and tubes; obviously considered Lenard and Roentgen to hold equal in the discovery of X The Lenard tube, as well as Lenard's experimentation, were of particular interest to Tesla that rays (streams electrons) actually emanated from the aluminum window opposite the cathode of tube and proceeded a centimeters into air. research by Corum and Kenneth Corum indicates that Tesla was looking for methods of moving electrons with such devices as open-air diodes or even relativistic electron-beam (REB) diodes, which, if as they are built today, including power supply, resemble closely a Tesla coil and a Lenard tube. speculation about Tesla's moving electrons is, perhaps, only the of the story. Other evidence, particularly his on particle beam weaponry, points to interest in moving larger particles.

Another great value Anderson's contribution in reconstructing this lecture is that it shows us historically the extent of Tesla's work with vacuum tubes up to 1897. Roentgen's announcing the discovery the ray Tesla with yet another area in which to contribute discoveries and inventions. This lecture on the rays Lenard and Roent- and Tesla's series articles in New York *Electri- Review* contain material far more advanced than any other contemporary work. 1897 lecture discussion of "reflected" Roentgen offered with data tables,

compares al most exactly to Arthur H. Compton's 1922 monograph on the topic of secondary radiation. Tesla alsc offered a design apparatus to generate "reflected" rays. Tesla's lecture is a fount of information beyond the knowl- edge of most of his contemJX>raries, a wide array of tables, charts, diagrams, photographs, designs, and suggestions of one process after another for the produc- tion of X rays, the use of vacuum tubes, and special
dures for refining the operation of all kinds of apparatus. Tesla, here and in other works, discussed scientific princi- ples not "discovered" until years later.

The most significant contribution of this text .rerhaps, that it shows in his true light one of v1s10nanes that ever man far ahead of his peers yet gentle and willing to give what he had to the world. With regard to the relationship between Tesla's work and the world of '""'"u"" it is curious to note that it has taken a better part of the last 100 years since his invention of the resonant for researchers to truly in duplicating the coil sign, this in spite of the great pains went to in making his recommendations clear. Let us hope that, as more informa- tion on Tesla's work becomes available, much greater atten- tion will be to it, to the betterment of our world.

Jim Hardesty
Judith Hardesty
Ithaca, New York
June 1994

cannot help looking at that little bulb of Crookes with a feeling akin to awe, when he considers all that it has done for scientific progress-first, the magnificent wonderful achievements of Roentgen. Possibly it may still contain a grateful Asmodeus, who will be let out of his narrow prison cell by a lucky student. At times it has seemed to me as though I myself heard a whispering voice, and I have searched eagerly among my dusty bulbs and I fear my imagination has deceived me, but there they are still, my dusty bulbs, and I am still listening hopefully.

N. Tesla

March 7, 1896

these efforts include (a) crystallization of his research work in wireless telegraphy, telephony, and transmission of power in the form of patent coverage; (b) the on wireless-controlled *telautomata;* (c) the development high intensity phosphor-coated vacuum-tube the fluorescent lamps today; (d) time-consuming task fending his patent courts.

The second reason relates to the growing, highly competitive atmosphere in wireless telegraphy development now recognized as radio. at that applications for the fundamental patents in telegraphy,[4] undoubtedly realized that detailed information contained in this of the portion (presented as I) was of proprietary and it would given away without first obtaining protection through patent applications. Whereas Tesla had giving freely to the world many technological ideas, m his *trio series* delivered in 1891, and [5] he now grew more cautious, and rightfully so, in protecting his own economic interests in the field of wireless communication.

Skirmishes on non-publication of lecture

that In United weekly r-nrnm.Prl'lal electrical journals were published: *Electrical Engineer*, *Electrical Review* , *Electrical World, Electrician, Electricity,* and *Western Electrician.* In addition to these were weekly *American,* which reported on a mix of scientific and engineering topics, as well as monthly engineering periodicals *Electrical* and *Engineering*

[4] U.S. Patent No. of March 20, 1900, of Transmission of Electrical " and U.S. Patent No. of May 15, 1900, "Apparatus for Transmission of Electrical Energy," both applications filed 2, 1897.

[5] Martin, T.C., *The Inventions, Researches and Writings of Nikola* (New York: The Electrical 1893), chs. 26-28 (pp. 145-373).

Magazine. early publication activity was primarily a result of the vast electrical industrialization and new business opportunities that sprung from inventions of Edison in the direct-current realm and, subsequently, the inventions of Tesla in alternating-current realm. The marketplace was unquestionably electrical news coverage, and commercial electrical journals fought to alive.

Thomas Martin, serving as president of the American Institute of Electrical for the undertook editorship of *Electrical World* in December 1888 but was discharged in March 1890 over a dispute with the owner the publication on compensation. The feud was aired on seven tabloid-size pages in the September 30, 1893 issue.[6] Martin subsequently found a as editor of *Electrical Engineer*.

In the Company published the book, *The Inventions, Researches and Writings of Nikola Tesla*, compiled by Martin, chief editor. This remains a classic a century later having been republished several times.[7]

years before death Martin remarked in a letter to Thomson, some money out my book, which was promptly borrowed from me by the titular component, so that two of work went for nothing."[8] The Company was undoubtedly in carious financial condition as the letter suggests stock was offered to Martin in lieu of cash receipts from sales of the book.

[6] I am indebted to Marc his forthcoming work, *The Tesla Trilogy*, for this revealing insight concerning Martin's business relationship with Tesla.

[7] The firs! reprint was undertaken in 1952 by the Lee Engineering Co. of Madison, Wisc., as a contribulion to the engineering industry.

[8] Jan. 16, 1917, in *Selections from the Scientific Correspondence of Elihu Thomson*, Abrahams, H.J., and M.B., eds. bridge, Mass.: MIT 1971).

During the year prior to the 1897 Academy Sciences lecture, the *Electrical Review* published a remarkable series of communications from Tesla in the journal on the subject of material stream emanations.[9] Not to be outdone, Martin presumably persuaded Tesla to have the Academy lecture published in the *Electrical* But obviously had second thoughts for reasons expressed earlier Martin, perhaps not fully appreciating the role an independent inventor depending for his upon successf ul marketing of patented inventions, could not accept Tesla's decision to not complete the lecture for publication.

Martin had a ravenous appetite for to make the *Electrical Engineer* financially successful. The following year, Martin allowed to published in November 17, 1898 without permission, Tesla's paper, "High Frequency Oscillators for Electro-therapeutic Other Purposes," presented the eighth annual meeting American Electro-Therapeutic Association in Buffalo, New York, September 14, 1898. An editorial salvo entitled "Mr. Tesla and the also appeared in the same issue- a sort of 'tit for tat' rejoinder on the non-publication the Academy of Sciences lecture-together with a specific patronizing editorial, "Tesla's Electrical Control of Moving Vessels or Vehicles from a Distance," dwelling on the im- practicality of his recent invention.[10]

Marti n certainly went beyond professional ethics in publishing the lecture. Undoubtedl y, the stress of financial problems of the *Electrical Engineer* was too trying. He needed 'leading-edge' and Tesla was not produci ng it.

[9] "Tesla's Startling Results in Radiography at Great Distances through Considerable Thickness of Substances," Mar. 11, pp. 48, 49; "Tesla's Latest Results," Mar. 18, pp. 146, 147; "Tesla on Reflected Roentgen Rays," Apr. l, pp. 171-174; "Roentgen Radiations," Apr. 8, pp. 183-186; "Tesla's Latest Investigations," Apr. pp. 206-211; 'Tesla Describes an Feature of the X-Ray Radiation," July 8, p. 43; "Roentgen Rays or Streams," Aug. 12, pp. 78, 79, 83; and "Roentgen Streams," Dec. 2, pp. 277, X.

[10] U.S. Patent No. 623,809 of Nov. 8, 1898, "Method and Apparatus for Controlling Mechanism of Vessel or Vehicles," application filed July 1, 1898.

Tesla was furious unauthorized publication prior to the opportunity given the American Electro-Therapeutic AssociatJ.on to publish in its *Transactions,*[11] and sent copies of his severe to all electrical journals in America and *Electrical Engineer* also carried the letter with accompanying defensive commentary running four columns in the November 24 issue.

To understand the crisis facing the *Electrical Engineer,* one must ahead another three months to March 11, 1899, when *Engineer* was taken over the *Electrical* merged publication becoming .or-r...,'''''' *World* Martin was retained, but as co-editor. temperament, he perhaps did not perceive as did others. Years later, in the fiftieth of *Engineering,* the official journal Martin's misadventure with the *Electrical Engineer* was not mentioned.

It should not that Martin held a permanent grudge toward even though later promoting ,Marconi in articles. Martin was too much of a gentleman to such professional competition interfere with true friendship. the wound the failed *Electrical Engineer* required some years to heal.

It was the endearing prose that he reserved for Tesla in his earlier articles appearing in the *Century Magazine,*[12] and these were not forgotten in 1911 when introducing him for an address on his new inventions before a meeting of the New York Section of the National Electric Light Association May 15, 1911. Martin reflected on Tesla's important lecture 18 years earlier before the Association, "On Light and Other High Frequency Phenomena," in which he presented the fundamental concepts of radio communication. And in the book which Martin co-authored with Stephen L. Coles, *The Story of Electricity* (1919), he remarked, "Tesla's influence may truly be said to have marked an epoch in the progress of electrical science."

[11] Tesla, "High Frequency Oscillators for and Other Purposes," American Electro-Therapeutic Association *Transactions,* 1899, pp. 9-29. This paper has been reproduced by First Century Books, Breckenridge, Colo. (1994).

[12] "Nikola " Feb. 1894, pp. and "Tesla's Oscillator and Other Inventions," Apr. 1895, pp. 916-933.

Lecture Commentary

High frequency apparatus

On March 1895, Tesla's laboratory at South Fifth Avenue (now West Broadway) in New York City was completely destroyed fire-all lecture apparatus, photographs, documentation. Charles Dana editorialized,[13]

> *The destruction of Nikola Tesla's workshop, with its wondeiful contents, is something more than a calamity. It is a misfortune to the whole world. It is not in any exaggeration to say that the men at this time who are more to the human race than this young gentleman can be counted on the of one perhaps on the thumb hand.*

On December of this same Wilhelm Roentgen (1845- 1923) presented his communication, "On a Kind New of " to Wtirzburg Physico-Medical Society, the news newspapers 11 days later. It was a significance, ability to "see" images through otherwise bodies, for which he was awarded the first Nobel in physics in ...,.......,u..,,11 lof that follows, Tesla describes detail his researches along the same lines undoubtedly would have him to the same discovery were it not for the circumstances of destruction his laboratory by fire.

Edward Hewitt, grandson of Peter Cooper—inventor-philanthropist who founded Cooper Union in 1859—has given an interesting account of Tesla's lost opportunity.[14] During his experimental researches m photography, Hewitt

[13] *The s1111* (New York), Mar. 1895, p. 6. c. 5.

[14] N.F., "Trout Fishennan-Sportsman of the old school, R. Hewitt calls himself 'last of the gentlemen mechanics,"' *Life,* July 15, pp. 86-100. See also reference to Hewitt's working with Tesla on photography in Thompson, *Roentgen Rays* (N.Y.: D. Van Nostrand, 1896) p. 157. Hewitt is mentioned by Tesla in his April 22, 1896 communication to the *Electrical Review.*

describes a morning in Tesla's laboratory the fire when attempting to photograph Mark Twain under a Geissler tube.[15] The resulting print was instead of the camera lens adjusting screw! Hewitt notes that neither he nor Tesla realized, until when Roentgen made his announcement, this was an X-ray photographic image.

As the title of the lecture suggests, Tesla presented and described many pieces of apparatus for generating high frequency, high voltage alternating currents to excite Lenard and Roentgen tubes. Beginning with a discussion of the evolution the resonant-coil system named after him,[16] diagrarnmatically shown in figure 1, Tesla uses a fluid-mechanics analogue to illustrate the operation of charging and spark-gap components of the primary coil circuit associated with the condenser illustrated in figure 2. Tesla often employed analogic models to describe operating principles of the systems and apparatus of his invention. Whereas there are certain limits of applicability of such models for electromagnetic phenomena, views on this topic are not in general agreement.[17]

Beginning with figure 3 and extending through figure 8 of Section I, Tesla shows his innate understanding of the practicaJ operation of these resonant-coil systems to produce powerful, high frequency and high potential alternating

[15] For a of Mark Twain with Tesla in his laboratory, see "Tesla's Oscillator and Other Inventions," *Century* pp, 916-933 (photo appears on p. 930).

[16] U.S. Patent No. of Nov. 3, 1891, "Method and Apparatus for Electric Conversion and Distribution," application filed Feb. 4, 1891.

[17] See "Jedno uopstenje zakona o centralnim silama o odnosu Nikole Tesla i Dordem Stanojevita" (A Generalization on the Law of Central Forces About the Relation Between Nikola Tesla and in "Nikola Tesla," Za gre1r>-;:,mu1an/uvo•11"'· July 7-10, 1976, pp. I In this paper, Trifunović discusses certain analogy problems in science and refers to the correspondence between Tesla and physicist Stanojevich during the time he was engaged in the discovery of analogies between the disparate phenomena of gravitational, magnetic, electrical, electro-[illegible] botanic- and biologic-cell, and planetary fields,

currents. design of physically small-size coils operating from existing municipal circuits is discussed, especially those for use in physicians' offices then supplied with 110 vol ts current or 60/125 cycles second[18] alternating current. Such were widely by physicians in the 1900s for electrotherapeutic purposes.[19]

Proceeding to the diagram shown in figure 7, Tesla has introduced a mechanical controller in the primary circuit allowing the alternate charging and discharging independent condensers in the primary circuit from the power source. He also to a modification of this circuit having "one continuous contact common to two circuits, and independent interrupters for these," allowing not only an alternate charging discharge of condensers but their simultaneous charging and discharge in parallel. These circuits are em vv"""""" in Tesla's United States patent No. of February 23, 1897 (application filed Sept. 3, 1896). The importance this technique was obviously not recognized by those attending the was the heart of Tesla's later work on what to as the "art of individualization" and embodied in invention known today as the AND logic gate.

Coming to the diagram 8, the layout of circuit elements is given for the desk-top coil unit shown in figure 9, which offered use in operating X-ray and various laboratory appliances. unit stood 18 inches high at discharge terminals and comprised several novel tures giving an energy conversion efficiency of 80 percent. months later, when Lord Kelvin attended a meeting of the British Association the Advancement of Science in

[18] Although the unit "Hz" for frequency is now universally adopted for measurement, at the time of publication of this 1897 lecture, and for some eight decades later, "cycles per second" was the unit of measurement. To avoid reading inconvenience Hz in editorial discussion and per second in the lecture text, cycles per second (cps) will be throughout this work.

[19] for example, Monell, *High Electric Currents in Medicine and* (N.Y.: William R. Co., 1910) and Eberhart, N.M., *A Working Manual of High Frequency Currents* New Medicine Publishing Co., appearing in editions from 1911 to 1923).

Science in Toronto, Tesla units to him on the occasion of his Street labora- tory in York City. several of these units, and later proceeded to enter a business venture with a Mr. Hopkinson for the manufacture of a sizes of and X-ray units, but information about the establish- ment this business enterprise not been located.[20]

next briefly describes work phosphor-coated bulbs to the incandescent-filament bulbs developed by Edison. became interested developing a lamp that would equal the intensity of sunlight, and in January, 1894, the first photograph taken in Tesla's laboratory by light only from his phosphorescent lamp appeared in the April, 1895 of the *Century Magazine* . It was an eight-minute ex- posure, but a little more than two years Tesla had achieved such brilliance in lamps the May 20, 1896 issue of *Electrical Review* (N.Y.) carried an illustration of a two-second photograph Tesla taken with a lamp of candlepower-again by the light of the bulb itself. Such a result with the combination of the existing emulsions and indoor lighting had not before been achieved.

This single-electrode lamp, first shown by Tesla in 1891 lecture—the first of *trio series* lectures in America and Europe during the years 1891-93-was patent- ed by him that [21] Following this demonstra- tion, Elihu Thomson filed a of Lighting" patent application that was determined to in interference with Tesla's patent. laboratory that he did actually produce operating lamps with a con- ductor and lead-in However, Thomson was unable to prove such a demonstration, although asserting earlier work on the subject, and his claim was therefore nied—the Patent Office declaring Tesla's priority in this vention.[22] In an unpublished statement entitled "Tesla's Artificial Daylight," written by Tesla and designed to secure

[20] Tesla letter to Scherff, Oct. 13, 1905 (Columbia University Libraries).

[21] U.S. Patent No. 454,622 of June 1891, of Electric L115,uuu!f>," application filed Apr. 1891.

[22] U.S. Patent Office Interference No. 17334, *Thomson vs.* notice filed July 12, 1895, decision of priority to Tesla June 10, 1897.

investment in a company to advance the application manufacture of these lamps, the merits of this form of mination were described:

> 'The present systems [interior lamps and street arc lamps] are not only they are also separable from disadvantages as, the large cost installation, which is chiefly due to the quanti ty of copper required; the frequent of the lamps, owing to their unavoidable deterioration; the disagreeable ron<•,...,l'"T<"r of the which, a small sur- is naturally too intense to the the necessity employing more or less opaque screens, which involve a considerable Joss in illuminat- power, and many other drawbacks of this nature. It is true, that recently Nernst and have secured some gain in efficiency of incandescent lamps or burners by use coatings of rare which mit higher degrees incandescence. this departure not done away the objectionable features above mentioned -on the contrary, it has added to them.
>
> In new lighting system, all disadvantages are successfully removed. The light is produced with a smaller of energy, more one eighth of is presently the same quantity of it is soft and to the closely offers tures of an ideal of any de- candlepower may be adapted to any kind of current of supply, and they last indefinitely."

We find that Tesla, one of the early energy conservationists in engineering, was describing a number of lighting parata found in use today, prominently fluorescent-lamp systems.

All lectures from 1891 dwelt at length on the ne- cessity completely air bubbles in the condenser and coil units of high frequency, high voltage disruptive- discharge oscillators. Not only amateur experim...... and researchers, but professional engineers and physicists have overlooked the harmful destructive effects of allowing air bubbles in such components.

This editor has witnessed the destruction of a costly high-power, high-voltage transformer used in a particle accelerator laboratory because the power was initially applied too quickly, than raising the primary voltage gradually, over days, allowing the coils to "cook" air bubbles out of the oil bath. well, most amateur experimenters and researchers have not taken the diligent, perfection care in insulating the components of their systems to the degree that Tesla advocated. It is often expressed, Tesla achieve brilliant resul ts?- I seem not to be able to reproduce them with the same effectiveness as he claimed."

In the of Sciences lecture, found it appropriate to present in some detail the which afforded him such success by describing a of insulating and inductor a manufacturing sense. method was then two months the lecture excluding air or from the dielectric separating of high potential in proxi mi ty, or remote portions of the same conductors, in as perfect a manner as and in a convenient practicable way.[23] In all rolled-foil condensers having waxed-paper were manufactured by a modification of the method describes and pioneered by the Cornell Dubilier Company.

With figure 11, Tesla diagrammatically shows a pair of secondary coils wound with turns their mid-point brought out as a unit designed to withstand the encapsulation exerted by the manufacturing process previously Tesla """'.'''''''' a significant statement the length of secondary coil windings, that each to or somewhat less than a quarter wavelength electromagnetic propagation in the winding, thus allowing a maximum potential difference at the terminals. As such, these coils represent a half-wave pair.

Tesla goes on to describe the functioning of the spark gap in a primary circuit, critically examining the early investigations of Johann Poggendorff (1786-1877) on the action of a

[13] U.S. Patent No. of Feb. 23, 1897, "Manufacture of Electrical Condensers, Coils, &c.," application filed Nov. 5, 1896.

in a vacuum,[24] and suggests various improvements in the design of the in the primary circuit. He describes the necessary attention to the construction of the to produce currents of high voltage and frequency "causing showers or continuous streams of thick, thundering sparks to dart out into space to a distance of 8 or 9 ... sometimes veritable lightning bol ts." Many readers today, in looking at the photographs of the discharges that Tesla produced in his lalx>ratories, usually do not consider din as- .,,.......,.au..A.1 with such displays. Tesla has made in other writings to wearing ear plugs, and it has been reported that the noise from his experimental station at Colorado Springs could 10 miles away.

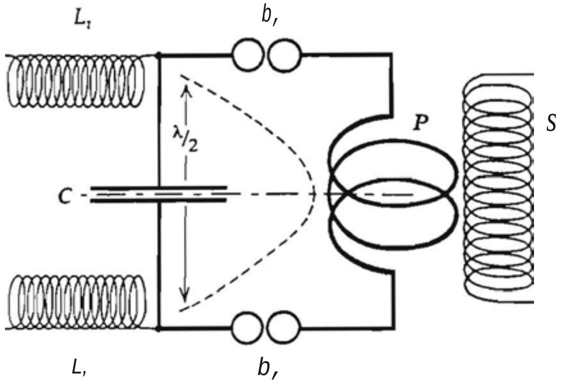
An element of "the discoverer's searching is found in observing an "exaggerated Thomson '[25] noticed the pnmary circuit of copper riblx>n, the inactive portion of which should be no more than five percent, is perceptibly cooler heat parently carried away from the to the coatings of the condenser. Of Tesla coils constructed then, no reports in open literature on this subtle, difficult-to-measure effect.

Another aspect of primary circuit, as was found for the secondary circuit, is critical attention to length. Tesla scribes that as as a quarter of an inch change in length of the primary circuit will have a pronounced effect on the performance of a coil! advocates that best is .... """ when a stationary wave is formed with a single

[24] Poggendorff, J., "Effects of Interrupting a Current Within Discharge " *Philosophical* 4th sec., Vol. 10, l pp. 203-307.

[25] *Encyclopaedia Britannica* (1 defines the Thomson effect as "the evolution or absorption of heat when electric current passes through a circuit of a material that has a temperature difference between two points its This transfer of heat is superimposed on the common production heat by currents flowing through conductors because of their electrical resistance. If a copper wire carrying a steady electric current [i.e., direct current] is subjected to external heating at a short section while the rest remains cooler, heat is absorbed from the copper as the conventional current approaches the hot point, and heat is transferred to the copper just beyond the hot point."

node located at a point of the discharge circuit or conductor equidistant from the opposite condenser coatings, as illustrated below.



With this design, a half-wave primary circuit length results. This may be difficult to achieve in practice for the construction of Tesla coil systems as revealed by the table shown below. For the desk-size unit illustrated in figures 9 and 12, for example, the operating frequency would be in excess of 50 Mc.

Operating frequency of secondary	Length of primary to achieve half-wavelength
10 kc	9.3 mi
50 "	1.9 "
100 "	4,900 ft
500 "	984 "
1 Mc	490 "
5 "	98 "
10 "	49 "
50 "	10 "

It is obvious that for a secondary coil constructed as above, and the primary constructed according to the same design criterion as described earlier, both coils will have nearly the same length and, essentially, the same number of turns-a 1:1turns ratio. It at first "How do we obtain any voltage gain?" Voltage gain in Tesla coil systems is not from the secondary/primary turns ratio: the Q of the coils and a standing-wave condition that results in coils appropriate length also contribute substantially to the gain Al though significant resonant can be achieved in a transformer having a 1:1 turns ratio from high Q values and properly adjusted length primary and secondary coils, such design is rarely undertaken.

The desk-size units illustrated in figures 9 and reqie careful design of the primary operating mumc1- supply circuits of 110 volts, to obtain high current exci- tation of the primary coil. half-wave circuit loop from the condenser coatings is a unique way to accomplish But, when a high-voltage, high-current supply is available, then the advantage of higher numerical values for secondary/primary turns ratio (approximately the square root of respective inductance values ratio) prevails.

Tesla advocated that the length of a grounded coil should be a quarter wavelength of the oscillation frequency, yielding the maximum potential at its terminal by virtue of a standing wave condition. The first of design nique was a photograph appearing in May 20, issue of the New York *Electrical Review* showing Tesla seated an 8-foot diameter flat-spiral coil his laboratory on Houston Street but without accompanying explanation. During this Tesla provided two diagrams showing these flat-spiral in experimental wireless transmitting and receiving antenna circuits, again without explanation.[26] following this lecture, applied for his first on wireless telegraphy such coils and describing the technique, now universally employed, for quarter-wavelength radio transmitter antenna circuits.[27]

Oliver Shallenberger, known for his development the induction ampere-hour meter in 1888 for the Westinghouse Electric and Manufacturing Company, which had committed itself to alternating current power equipment production by

[26] See Sec. I-Addendum, [27] See note 4.

15 and 16, pp. 72, 73.

acquisition of the "famous 30" patents on motors and systems, contri buted infonnation that has not appeared where the high frequency, voltage apparatus used by in obtaining the presented in first of 1896 X-ray communications to the *Electrical Review.'JJJ*

> to the apparatus and operation, which are especially important, it may be that the current was taken from an alternator, of a frequency of periods per second, passed through a primary coil of a transfonner for increasing the e.m.f. from 100 to from 16 to thousand. The secondary current was then passed through Leyden jars and a double cascade of slightly separated brass cylinders, whereby it was changed an oscillatory current of an extremely high frequency, which was then connected through the primary of a second induction coil having very few turns of wire, no iron core and having a ratio of 7 to L By this means the was to between 160,000 volts to was used to energize the discharge the generation of X rays."

we find that for driving experimental evacuated tubes, employed resonant-coil apparatus preservi ng a fractional wavelength for the secondary, than the primary.

The detennination of exact operati ng frequency oscillators was a vexing problem for all early investigators, a difficul ty those today working with having linear time-base may not fully appreciate. Wave meters, essentially a closed oscillatory circuit, with calibrat- substitution inductances and variable were used in the near of WWI.[29] But before the tu m of the century, experimenters and devised their own ad-hoc methods of frequency detennination.

In this lecture, a carefully cali brated ,,,,..,,.,, he did not push to patent but for which the diagrams

[28] Thompson, E.P., *Roentgen Rays--and the Phenomena of* the Anode *and Cathode* (D. Van Nostrand, 1896), pp. 136-138.

[29] for Mauborgne, *Practical Uses of the Wave* Meter *in Wireless Telegraphy* (Mc-Graw Hill, 1913).

presented in lecture clearly indicate that a patent was considered The patentable of device was the "visual synchronism" capability in reading divisions or markings a uniformly rotating disk illuminated with flashes from neon or spark sources associated with the system to measured. device is tcx.iay as the electronic- stroboscope pioneered by Harold Edgerton (I 1990).

The mechanical fork, a tuning fork with slit shutter, been used others unaware of Tesla's tion until about 1910 for uniform motion measurements. When this editor showed Dr. a copy of a portion this lecture revealing much earlier with stroboscopes using neon and arc flash illumination, Edgerton replied no claim invention of the concept.[30]

disk shown Fig. has 10 radial segments on the outer ring, with radial segments 9, 8, 6 the succeeding inner rings. Note that in Fig. 14, the outer ring is further subdivided into 10/20 divisions per segment with a adjacent to that ring.

Let r be the number of revolulions per second, s the number of radial in the ring, and a and b integral {1, 2, etc.). If the frequency of the flashes differs from r(s-a/b) by lib cycles second, then a.s radial segments will appear to revolve at a rate of 1 radius per second. Thus, a disk of s radial illuminated b-s flashes each revolution appears a disk having b·s if flashes occur sfb times for revolution, the disk appears to have s radial segments.

this methcxi to used as a detection scheme, it is dear that presence of continuous-wave would not of sufficient strength to excite a small neon flash lamp, typically requiring 90 volts for ignition. Tesla describes asing the circuit containing the lamp to near ignition with a battery pack. A number these detection circuits are to found in Tesla's patent and in a pair of

[30] Personal communication, Feb. 1988.

means and methods detection patents issued during the sue-ceedi ng four [31]

The method of synchronous rotating disks or spindles was employed by in continuous-wave detection devices and presented from 190lto 1905.[32] It was the receiving methods in the lecture together with visual synchronization measurement and de-tection schemes, publication of which would preem pt patent disclosures, that u ndoubtedly caused not to commit this portion of lecture to publication.

Lenard and Roentgen rays

The discovery of X rays was directly associated with ad-vances achieving high degrees of vacuum, following the discovery of the beautiful visual effects produced by William Crookes with partially evacuated tubes containing various residual gas compositions and phosphor coatings. pressures of a few centimeters of mercury, a shimmering pink streamer is observed along the length of the tube which fills the entire cross section as the pressure is further re-duccd. At about 2.5 millimeters, this glow begins to sepa-rate into identifiable regions until reaching 0.1 millimeters, proceeding from the cathode at one end of the tube to an anode at the other end, the familiar patterns now known as

U.S. Patent Nos. 61 of Nov. 8, 1898, "Method and Apparatus for Controlling Mechanism of Moving Vessels of Vehicles," application filed July 1, 1898; 685,954 of Nov. 5, 1901; "Method of Utilizing Effects Transmitted Through Natural Media," application filed Aug. 1, 1899; and "Apparatus for Utilizing Effects Transmitted Through Natural "application filed Nov. 2, 1899.

[32] U.S. Patent Nos. 685,953 of Nov. 5, 1901, "Method of Inten-sifying and Utilizing Effects Transmitted Natural Media," application filed June 1 of Nov. 5, 1901, "Apparatus for Utilizing Effects Transmitted From a Distance to a Receiving Device Through Natural Media," filed Sep!. 9, 1899; and 787,412 of April 18, 1905, "Art Electrical Energy Through the Nat ural Mediums," applicat ion filed May 16, 1900.

the Crookes dark space (in German literature, Hittorff dark space), negative glow region, Faraday dark space, and lastly the positive column with striations are observed. It is the positive column that is seen in neon signs operating at several millimeters of pressure.

Lowering the pressure from 0.1 millimeters of mercury, the Crookes dark space lengthens with the striations in the positive column becoming farther apart. At roughly 0.08 millimeters, the cathode dark space reduces in length to about l centimeter. The Crookes dark space, negative glow, and Faraday dark space regions will remain fixed in length along the tube with the positive column taking up the remaining length of the tube regardless of the tube's length. At pressures substantially below 0.01 millimeter, a green lluorescence appears on the inner walls of the tube, and below 0.001 millimeter, the tube becomes dark.

As an aid in evaluating the degree of vacuum obtained for the Lenard and Roentgen tubes that Tesla investigated and demonstrated , when a vacuum is on the order of 0.001 millimeter of mercury the X rays are easily absorbed, minimally passing through the human hand. These rays are referred to as *soft* X rays, roughly a few angstroms in wavelength. At 0.0003 millimeters of mercury, exceedingly high voltages are needed to produce a discharge and the X rays are quite penetrating, able to pass through the bones of a hand with little absorption. These rays are referred to as *hard* X rays, about 0.1 angstrom in wavelength.

It is significant that Tesla considered both Lenard and Roentgen rays in his communications and lecture regarding "penetrating rays" through substances. Some astonishment was expressed by radiologists of the results Tesla achieved in his experiments not only at the time they were presented in the lecture and in his 1896-97 communications appearing in the *Electrical Review* but as well by those reviewing these reports many years later. This is primarily because Tesla's researches involved *both* Lenard and Roentgen apparatus, as the titles of his reports so state, but his communications on the subject ha\'e generally been interpreted in terms of only X-ray apparatus and effects.

In briefly reviewing "rays" it is noted Philipp Lenard (1862-1947), in 1893, announced discovery of invisible rays produced a Crookes and capable of passing through a thin aluminum window. Now known as "Lenard rays", these are beams capable of passing window The thin aluminum window become known as a "Lenard window," in his experiments penetrating were produced at the point of first impact-the window.

Neither Lenard, Roentgen, or other researchers knew what they were dealing with in terms of "rays" up to that time. as well as other were at the fore-front investigation, undertaking researches to answer fundamental of the nature of rays particles. In the Academy of Sciences lecture, Tesla demonstrated a source of powerful rays which he as more nr.""r- ful than any before available.[33] The source of the was an arc closely-spaced electrodes in vacuum, now recognized as extreme ultraviolet radiation (approx. 500 angstroms). The ability to distinguish *soft* X and ex- treme ultraviolet was then difficult.

But 1897 marked a new era in physics with the identification of the sub-atomic particles. That year, Joseph Thomson identified electrons by measuring the ratio of their charge to mass, e/m, and knowing the charge the mass could calcu-lated.

Kelvin was in opposition to the evolving theories of atomic structure advanced Thomson, Rutherford, and others. was greatly influenced, for most of his lifetime, by the of Rudjer Boscovic (1711-1787), an extraordinarily remarkable scientist who in engineering, architecture, and archeology.[34] Of Boscovic remarked an unpublished 1936 interview article,

[33] Refer to Appendix for a review of the lecture in the *Electrical Engineer*, April 1897.

[34] A week-long celebration examining the life and work of Bosco-vić was held in Rome, May 1988, in observance sary of his death.

of the 200th anniver-

> relativity theory by is m uch older than i ts nr""""""r proponents. It was advanced over 200 ago by my ill ustrious countryman Boscovic, great philosopher who, not wi thstandi ng other and mul tifold obligations, wrote a volumes of excellent literature on a vast of subjects. Bosković with relativity, so-called time-space conti nuum ...."

Kelvin, in his 1884 Baltimore [35] referred to Bosco-vić's great book,[36] and in 1890s adopted Bosković's interpretation forces, the "force curve." When Joseph Thompson pu blished the discovery of the electron particle in 1897, Kelvin extended the concepts Boscovic to systems of electrons accounti ng for all phenomena and radioactivity- a model explaining ejecting at velocity. not Tesla's contemporary wri tings on but acknowledged years later, the theo- ries of Boscovic and Kelvin had influence on his pretation of experimental obtai ned.

Let us some of the resul ts described Tesla in his researches during period. Tesla correctly that the source of rays is "the place of *first* of the stream of particles within the bulb."[37] familiar of today, the rays emanate from a massive anode inside a tube bombarded by an stream of electrons a heated cathode under high potential difference. anode target is, this case, place of first impact of particle streams produced inside tube.

In his communication "On Reflected Roentgen Rays," appearing in the April 1, 1896 *Electrical Review*, Tesla gives a

[35] *Baltimore Lectures on Molecular and the Wave Theory of Light* \LA!uuvu. Cambridge 1904).

[36] Theoria *Philosophire Naturalis redacta ad unicam legem virium in natura existentium* (Venetia: Editio Venetia prima ipso auctore prresente, et corrigente, 1763).

[37] See Section III.

qualitative description of the intensity of rays which he interpreted to be reflected from a dozen metal and nonmetallic surfaces. He also reported that the relative strength of the reradiations from the various metals agreed with the se- quence of these metals in the activity series developed by Volta. At that time, the phenomenon of secondary radiation of X rays had not been hypothesized. It was not until 1922 that Arthur Compton presented in monogra h form a defini- tive analysis of secondary X-ray radiation.[8] It showed that Tesla's series of the relative strength of what he interpreted to be "reflected rays" from various metals agreed with the mass absorption coefficients for these metals when excited by soft X rays; i.e. in the region of 1 angstrom. The follow- ing year, the first successful reflection of X rays with a very small incident glancing-angle of the radiation was reported by Compton, thus revealing the experimental difficulty.

Tesla found no evidence of X-ray diffraction, but a dozen years later research apparatus became available providing W.H. Bragg, Max von Laue, Ernst Pohl, and Bernhard Walter the opportunity to show diffraction. As well, Tesla found no evidence of refraction. In 1925 the first successful experiments showing refraction were reported by Larsson, Siegrahn, and Waller.[39]

A review of the Academy of Sciences lecture finds Tesla stating he had succeeded in deflecting Roentgen rays by a magnet- the rays also charging a condenser at some distance.[40] But in his communications appearing in the April 22 and August 12, 18% issues of the *Electrical Review*, he modifies his remarks saying Lenard rays could be deflected by a magnetic field whereas Roentgen rays could not as observed by exposure of fluorescent-emulsion films. Thus, he identified a distinction between them in their producing penetrating rays. When the energy of Lenard rays is abruptly

[38] Compton, A.H., "Secondary Radiations Produced by X-Rays," *Bulletin of the National Research Council*, October 1922, (Vol. 4, Pt. 2, No. 20), the third and last of a series which formed the report of the Committee on X-Ray Spectra.

[39] Larsson, A., Siegrahn, M., and Waller, T., "The refraction of x rays," *Physical Review*, Feb. 1925, p. 235.

[40] Refer to Appendix for a review of the lecture appearing in the *Electrical Engineer*, Apr. 14, 1897.

decelerated by a magnetic from a bulk ,,.....r..Jr:•:S:..l source or an individual atom, as in passing through a Lenard window or in the bombardment of a massive target, the phenomenon bremsstrahlung radiation results.

Bremsstrahlung is observed for light particles such as electrons moving with through matter. particles "spit radiation a that direction of motion."1 From descriptions with Lenard apparatus, X by bremsstrahlung is an explainable result.

The tubes that Tesla employed in his researches had only one a cathode. He earlier remarked,

"Clearly, if we put two in a bulb ..., we limit the potential, for """""""""""" not only of the anode but of any conducting the practicable JX)tential on the cathode."[42]

for such a tube, place of first impact of an em1ssion stream emanating cathode would be the glass envelope at the other tube.

In his communication appearing in the March 18, 1896 *Electrical Review*, Tesla describes obtaining shadow graphs at a distance of 40 if it assumed that X rays were produced at the envelope at the end of the tube, that would not fully account the ability to obtain X-ray graphs at such a distance as 40 feet.

Tesla's researches were, in the main, wi Lenard rays —electron rays passing through a thin aluminum window, and with beams of particles that could not distinguished at that time as electrons or molecular He gives a most interesting description of the process working a tube to the in ously produced: point where are

f we attach a fairly exhausted an electrode to the terminal of a disruptive coil, we observe

[41] Feynman, R.P.. *Lectllres on Physics* (Reading, Mass.: 1963, Addison-Wesley), Vol. 1 of 3, p. 34--6.

[42] *E1ectrical* March 11, 1896.

small streamers breaking through the of the Usuall y such a streamer will through the and crack the bul b, whereupon the vacuum is impaired; but, if the seal is placed above the terminal, or if some other provision is made to prevent the streamer from passing through the glass at that point, it often occurs that the stream breaks out through the side of the bul b, producing a fine hole. Now, the extraordinary thi ng is that, in spite of the connection to the outer atmosphere, air cannot rush into the bulb as long as the hole is very small. The glass at place where the rupture occurred may grow very hot-to such a degree as to soften; but it will not collapse, bulge out, showing that a pressure from the i nside than that of the atmosphere On I have observed that bulges out and the hole, through which the streamer out, becomes so large as to be perfectly discernible to the As the matter is expelled from the bul b rarefaction increases and the streamer becomes less and less whereupon the glass closes again, hermetically sealing opening. process of rarefaction, nevertheless, continues, streamers being still visi ble on the heated place until the highest degree of exhaustion is reached, whereupon they may disappear. Here, then, we have a positive evidence that matter is bei ng expelled through the walls of the "[43]

This curious process, in its examination a near century later, -n,,---- that the internal was the result an internal force. operated his single-electrode bulbs at extremely high voltage, high frequency currents. An electron beam develops at the cathode as a result of hi gh-field emission duri ng the negative half of the current cycle.[44] It concentrates on a poi nt at the end of the tube arisi ng either localized ionic stress, trace impuri ties, or a high of dopant additi ves. The

[43] *Electrical Review*, March 18, 1896.

[44] For a discussion of the internal process of bulbs excited by frequency, high voltage alternating currents, see Corum, J.F., and Corum, K.L., "Critical Speculations Concerning Tesla 's Invention and of Electrode X-Ray Vu A-1 Discharges for Power Processing, Resonances and Particle Beam Weapons," *of the 1986 Interoational Tesla Symposium,* Colorado pp. 7-21 - 7-44.

spot then becomes a virtual because of temperature increase, between anneali ng and melting points (variable withlass composition, approx. 450-500°C and 1
1 ,500 C, respectively), resulting in significant conducti vity to the outer surface in contact with dispersed-medi um return of the high voltage source i mpressed on the cath- ode. When a point color, i ts specific re- """"au„.., can drop from 100 trillion ohm-centimeters at room temperature to 10,000 ohm-centimeters at anneali ng tem- peratu re and u ni ty at the poi nt. usi ng such ex- tremel y high voltages on and single-electrode tubes, Tesla advises i n his communication appearing in March 18, issue of not to overheat them m conti nued use.

This editor has viewed a video an experiment performed 1985 by Dollard showi ng the same process a single-electrode bul b developing a hot spot, the glass bulg- i ng out, rarefaction increasi ng, and bul b subsequentl y resealing. This process yet to critically investigated.

Tesla's December 1896 communication to *Electrical Review* refers to a "material projecting from single-electrode bulb and he later remarks,

> "Roentgen gave us a gun to wonderf ul gun, i n- deed, projecting of a thousandfold greater pene- trative power than that of a cannon ball, and carrying probably to d istances of many miles, with veloci- not produci ble i n any way we know of."

This germinal idea of projected particle in air, the succeeding experimental work u ndertaken i n Colorado Springs 1899 extremely high potentials and the production of electron beams, undoubtedly crys- tallized Tesla's approach a particle-beam weapon which he to the allied powers as WWII storm- clouds were gatheri ng.[45]

[45] This design appears in *of the Tesla Centennial Symposium*, Colorado Springs, 1984, pp. 144-150, using an abbreviated fonn for unit expressions: e.g., acceleration pressed simply as "meters" rather than "meters/second²." A of this design apµ1umvu is as well held by the Tesla Museum in Belgrade.

Harmful actions from Lenard and Roentgen tubes

The portions of lecture that Tesla did to publish were form of two comm unications appearing in the May 1 and August 9, 1897 issues of the *Electrical Review* (Secs. II and III of this reconstructed lecture) on the subject of actions from Lenard and tubes . He felt an necessi ty to present medical community and those undertaking in penetrating rays of the possible dangers in the operation of apparatus for their production.

Tesla describes radiation experiments that today would be unthinkable to subject the body-exposing a hand to radiation from a Lenard tube and the hand bec.:on1ing warm and later much reddened and swollen. Believing this may have been the result of a mechanical injury, he thrust his hand dose to window of the tube and instantly pai n. The pain lasted a days afterward and later he observed that all the hair was destroyed and that the nails on hand had grown anew. describes the tightening of or stiffening of when a hand is held close to window of the In a sever case, the skin gets deeply ored and places, and ugly, ill-foreboding blisters form thick come off, exposing raw flesh which discharges pain, feverishness followed.

When unknown realms involving the human who either inadvertently or with known experiments having uncertain outcome to taught the valuable lessons from which we benefit a result of the harmful effects Tesla experienced, continues in these communications the advocacy for the proper construction and shielding of the apparatus with particular concern for medical professionals and patients.

Tesla was the constant of Elihu Thomson, an trical i nventor and of the period. Neither Thomson nor Electric Company (later acquired by Company) were successful in challenging Westinghouse Electric and

Manufacturing Company on the Tesla for alternating current distribution systems motors. The scene courts was all too walking in, in formal attire his attorneys, and as a witness astonishing court and """"""""""""".." with a dis- of recall and caustic wit.

A tawdry impress on an overzealous biographer shows attempting to elevate by misstatements of fact concerning subject's competitor or adversary. Thomson's biographer, David Woodbury,[46] saw Columbian Exposition demonstrating Tesla's of alternating current power distribution a nonevent-Thomson presumably had also accomplished the various demonstrations!

In an i Thomson X rays, Harold Abrahams and Marion in their compilation of Thomson's correspondence,[47] engage in unbecoming historiographic distortion by entering a surprisingly impertinent reference note for a letter from Dr. William Greene to Thomson dated December 20, 18%, mentioning an X-ray bum suffered by Thomson on his finger during experiments. The editors mention Thomson's "lively controversy with Nikola Tesla who thought that X rays were ." No record exists of such an exchange on the of harmful effects of X-ray radiation, but a lively exchange did occur between them six years prior to the of lecture on the nature effects of high frequency currents. Although beneficial the readership in providing an airing of the it appeared at the expense of Thomson.[48]

reconstructed of lecture follows. It is now seen as a contribution to the history of the emerging scientific and e101orrtents of that period not previously ,,.presented.

LI.A

[46] Woodbury, D.n, *Beloved Scientist* (McGraw-Hill, 1944).

[47] *Selections from the Scientific of Elihu Thomson* (see note 8).

[48] The exchange occurred in a succession of communications to the *Electrical World* following the in its Feb. 1891, issue of the first of Tesla's *trio-series* on high frequency alternating currents: Thomson, Mar. pp. 204-5; Mar. 21, pp. Thomson, 4, p. Tesla, Apr.11, pp. 272-3.

I haunted thee where the Ibis
From the Bracken's crag to the Tree.

N. Tesla
November 4, 1934

Section I

IMPROVED APPARATUS FOR THE PRODUCTION OF POWERFUL VIBRATIONS; HIGH FREQUENCY MEASUREMENT METHODS.

Ladies & Gentlemen:

You will still vividly, no the excitement which a year ago was by the announcement of the discoveries of Professor Roentgen. Suddenly, without any preparation, Roentgen surprised world with two wonderful results. showed us how to a photographic impression of an object invisible to the and, what seemed more extraordinary, enabled us, the help of his luminous screen-now known as the fluoroscope-to see, with our own outlines the object. We are living in an of exceptional intellectual activity, and important of the advances are often recorded, but were almost the order of the telescope and and such discoveries come no more than once or in a century.

Scarcely can any one of us hope to again witness in his lifetime an event of so widespread a scientific and popular interest. desire to see things which seem hidden from sight is more or strongly developed in every human being,through all degrees of this sentiment, from the curiosity the unenlightened to the absorbing desire for knowledge of highly refined, and this in itself was sufficient to engage universal apart from this, these discoveries brought promise of to numberless sufferers and all over the world the fibers humanity. It is hardly necessary for me to tell you that the hold of me also, mine was a singular, grave case, I had not recovered from its effects to this day. I hope you will pardon a slight digression which I have a strong reason to

and not so m.-ch those of in: and scer. t v:ieuc.1111 t:.bes, althoueh s e p!iotoi'>r"i'hs lier HA:11wis.i ta k.:n w i;!i these. As bo h the arti ss and m, aeU' were bus · on other 111at ers the plates in t!ieir ordlnar:; holders 11·ere f requ.i,,tl:1 ·p1.1t in so:ne corner of th l abora o r;· ;;ntil 11 suiti.bh O,?portunit.; for carr;;int; on the ex;> Qrimcn ts was f ;iund. Dt;.ring these inveati ,;i.ions ma ll}· plates gave a result, vMh m«n:i othe n failed, a!ld on s.me of these hoth :!r. Alle;:, wh.J then aa- dshd me, and myself noted unaccountable marks ar.d defees. *Ur.* Alle:; partlcularl:; round it traordlnar; that, in spite of his e"re, !Can;,· pla es prov,;d defective and unsucoeutul. The Ul.):1ng of these photographk i01pressions b:; means of Crook s bulbs br lui;ht rruhli to m:; mind th;; expertmn a or Lena.rd, sor.1a reat;;.res or 'llbich, paruc-...l11rl.1 the action on 11. sensitive plate, had tas.:: lnated me *tra:i* the start, and I resolved to go over the ground eo•1ered bi him with assiatance and improved ;..pplian.::es. Just. 11.111 *m;:* at.ent.ion na arrested *b;i* this teat;,ire *fD;j* 111.bor11tory with al.most ever;, t:;J.ng 1t contained was destroyed; end the few months tolloliin£: passed in inh1ue ac:iv1t;r w'hic!! made me temporarily forget *:fi:1* proJects. lied hardl;,· finished the work of nconat.ruetion and resu:ied th course of m;; idea when the news of Roentgen's achievement reae d me. lnstantl;r the truth flashed upon my mind. hurried to repeat his ineilmpletel;; reported experLO!en . and. there l behel the won- der m;, self . ':hen -too late- l realized that *:ey* g.lld ing lilpi ri had ag&in pro"'pteQ. me 1md hat l had flliled to c::pr.,hend his ."l;;seri· ous signs.

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the close of 1894, the necessity of recovery a straining task, on which I have been laboring for a number of years and which commands my energies, it occurred to me to actinic action of phosphorescent bodies. The did not appear to have been studied, and I began the work at once, securing later, at the suggestion of some connected with the *Century Magazine,* the assistance of Messrs. Tonnele & Company, artists' photographers, of city, then doing work this n"'1"'-L'·'"'·. In these experiments, I employed an improved apparatus for the production of powerful electrical vibrations as well as one of my alternators of old design. A variety of Crookes tubes, single-electrode globes, and vacuum bulbs without external electrodes were experimented upon. A surprising fact was soon brought to light; namely, that the power the Crookes bulbs varied and that some, which emitted a comparatively strong luminosity, hardly showed an effect, while of much light-giving power, produced strong impres-

I wish to state here, in to be clear, that my efforts were directed toward investigating such actions true PhC)SPltlorescent light, as bulbs without preciable emission of heat, and not so much those of a;ce11l vacuum tubes, although some photographs were likewise taken with these. As both the artists and myself were busy on other matters, the in their ordinary holders were frequently put in some comer of the laboratory until a opportunity for carrying on the experiments was found. During these investigations many plates gave a result, many others failed, on some of these Mr. Alley, then assisted me, myself noted unaccountable and defects. Mr. particularly found it extraordinary, in spite of his care, many plates proved defective unsuccessful. The of these photographic by means of bu!bs brought freshly to my mind the experiments Lenard, some tures of which, particularly the on a sensitive plate, had me from the I resolved to over the covered by him with assistance and proved Just as my was by this

feature, my laboratory with almost everything it contained was destroyed; and the few months following passed in intense activity which made me temporarily forget my projects. I had hardly finished the work of reconstruction and resumed the course of my ideas when the news of Roentgen's achievement reached me. Instantly the truth flashed upon my mind. I hurried to repeat his incompletely reported experiments, and there I beheld the wonder myself. Then—too late-I realized that my spirit had again prompted me and that I had failed to comprehend his mysterious signs.

The statement of these facts might have been misinterpreted at the time of Professor „...,,uc1ẽrı's announcement, and I have kept silent, although I was unable to overcome entirely my feeling in the introductory lines of my first of a series ofarticles I wrote on this subject in the columns of the *E1nr1>rrr·.n1 Review.* Presently, however, I have no fear of a misunderstanding of my works, and I am my painful but stimulating experience to some of those, who have lightly written of this new art, more appreciate this new I was quite well acquainted with the results of naturallv often thought of his beautiful and promising experiment;, and yet the possibility of the plates being marked and spoiled by some action of the bulbs never presented itself to my mind. some might see in this only an argument for my own shortsightedness, others, more kindly disposed towards me, will with myself, consider it a demonstration great words, which I will not in the which say that, what Nature not want to reveal to one's mind, one cannot force it from her with screws and levers.

But while I have failed to see what others in my place might have perceived, it was always since my conviction, which is now firmer than ever, that I have not been forsaken by the kind spirit who then communed with me, but that, on the contrary, he has further guided me and guided me in the comprehension of the nature of these marvelous manifestations. Perhaps, in bringing to your attention some new facts which I have discovered in addi tion to those al ready annou nced, I may i nduce, at least some of you, to interpret these as I do. For though, that I might my chief this I m ust your kind indulgence to dwell in a few works on the novel appliances which are exhibited for i nspection. When I trace their I find it clearly i n my recognition of the fact that an economical method of producing electrical vibrations of high frequency was the key for the solution of a num ber most important problems in science and industry. I nsignificant as machines may seem to you, they are nevertheless result of labors extending through a number of years, and I can truthfully say that many times the difficulties which I have encountered in m y to perfect them have appeared to me so great as to almost prive me of to continue the work. When the experimenter has to spend years of patient effort only to that a mere microscopical cavity or air bubble in the essential of this apparatus is fatal to the attainment of result sought for by him; when he has to find that his machine does not perform well because a wire he uses is a quarter of an inch too long or too short; when he notes that now a part his apparatus in action will colder i n an apparently inexplicable way, and next that the same part will overheated, though to all the conditions are unchanged; when observations at every step and ordinary instruments and methods of measurement are not available, then his progress is necessarily slow and his energies are severel yFinally, I am glad to say, I have trium phed over at least the chief obstacles, and any stands now in the way of obtaini ng electrical oscillations of frequencies up to a few millions a second from ordinary supply circuits with sim ple and fairly economical appliances. What this means I not discuss. It will be judged by those who have kept in touch wi th the development in this and allied fields. These machines you see are a of the types I have developed, and as they stand here they are chiefly intended to replace the ordinary i nduction coil i n its numerous uses.

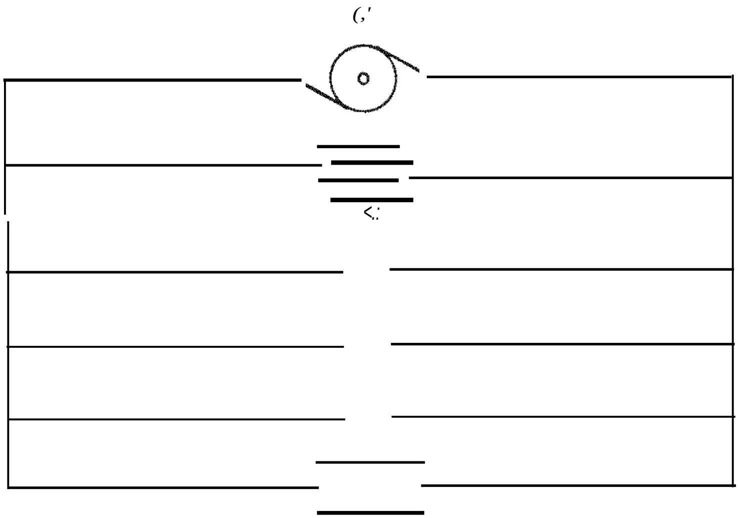


Fig. 1.-Method of transformation of electrical energy by oscillatory condenser discharges.

to broad these transformers or electrical oscillators, as they might most properly called, it is pie enough has been advanced by me some five or years ago. A condenser is charged from a suitable source and is then in convenient way discharged through a circuit containing, as it the primary of the transformer. first diagram, Fig. 1, illustrates a generator a condenser *C*, for charging and discharging the any kind *b* adapted to an intermittent break in the dielectric. The circuit containing the high or low tension *d* through which the discharges being properly extremely rapid electrical vibrations which, so far we know are unattainable by any other means, result; and these set up, by inductive action in any neighboring circuits, vibrations which give to many curious phenomena. Having familiarized myself with at the time when some laws governing were not quite well understood, I have retained certain conceptions which I have then formed and which, though primitive, might stand even now in light of our advanced knowledge.

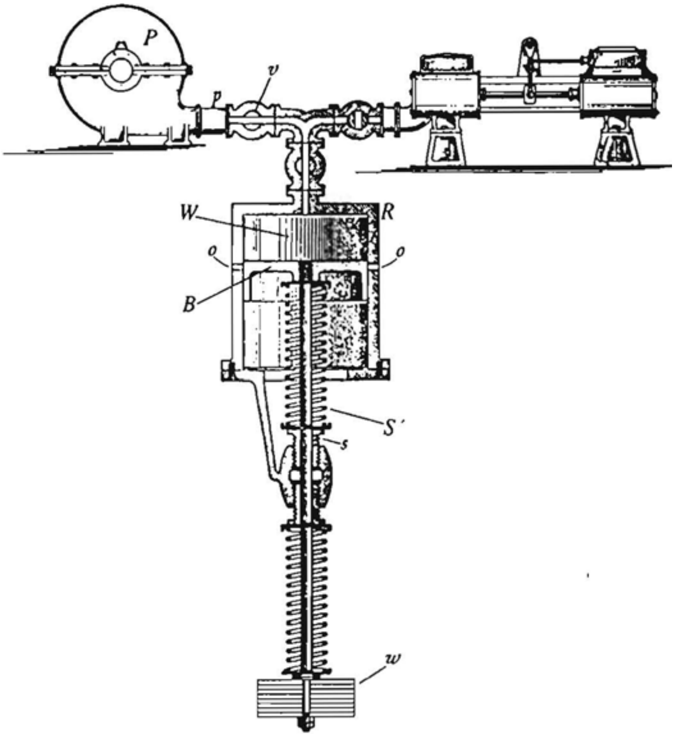


Fig. 2.-Mechanical analogy of electrical oscillator.

I have likened a condenser to a reservoir *R* into which by means of a pump *P* an incompressible fluid as water *W* is supplied through a feed pipe *p*, as illustrated in the second diagram, Fig 2, the fluid representing electricity, the pump the generator and the feed pipe the connecting wire. The reservoir has a movable bottom, held up by a spring *S*, and opens the ports *oo* when the Ouid in the vessel has reached a certain height and the pressure has become sufficient to overcome the elastic force of the spring. To complete the model, adjustable weights *w*, a screw *s* for allowing the tension of the spring, and a valve *v* for regulating the flow of the fluid are provided. With the giving away of the bottom, the Ouid in the reservoir acquires velocity and consequently momentum, which results in an increased pressure against the bottom causing the latter to open wider, and more of the fluid rushes out than the pipe can supply, whereupon spring reasserts itself, the ports, the same process is repeated in more or rapid succession. This opening and closing of bottom may be likened to the making and breaking of the conducting path, frictional resistance in mechanical system to the ohmic resistance and, obviously, the of the masses to the self-induction of the electric circuit. Now it evident that, in order to in action the mechanism without the em- ployment of auxiliary means, the rate of supply through the must to the rate of dis- charge through oottom; for, if it be otherwise, the ports will simply remain open and no vibration will place. more rate of supply equals the average rate of the quicker will the oottom open and close; and it is furthermore from a consideration of simple mechanical principles if the supplied so fast through the feed pipe that bottom vibrates as it would of its own accord, then the amplitude of the vibration will be largest, the bottom the strongest, and the amount fluid will be IJ""""""-' through the ports. All these considerations hold good the electric circuit, and in with high frequency machines, which were purposely magnified with the view of rendering their observation more easy, I have found that that condition is fulfilled when capacity, self-induction, frequency vibration bear a certain relation, which observation I have utilized in adjustment of inductive circuits. You will note that this condition the rate supply and most portant in practice, especially when no positively acting me- chanical means are employed for the rupture of the dielectric, is a distinct one and should not be confounded with the condition determining the oscillatory character of the discharge investigated long ago by Lord Kelvin.

next in evolution of principle and adaptation to practical uses was to with the system illustrated Fig. 1 a coil as shown in

Fig. which modified the action in many now well

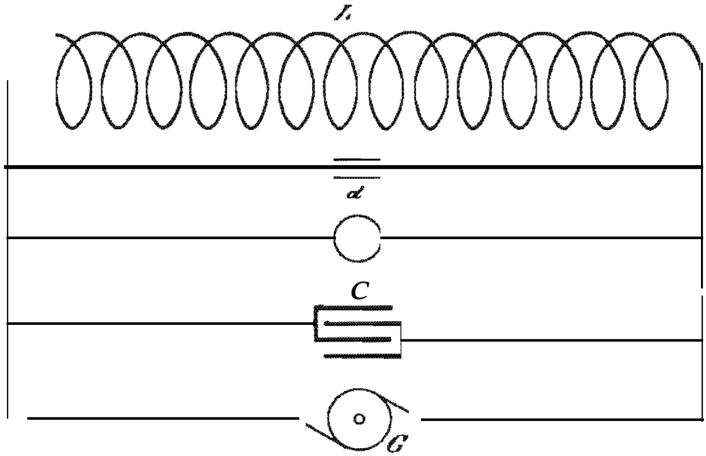


Fig. 3.-System ilJustrated in figure 1 with self-induction coil.

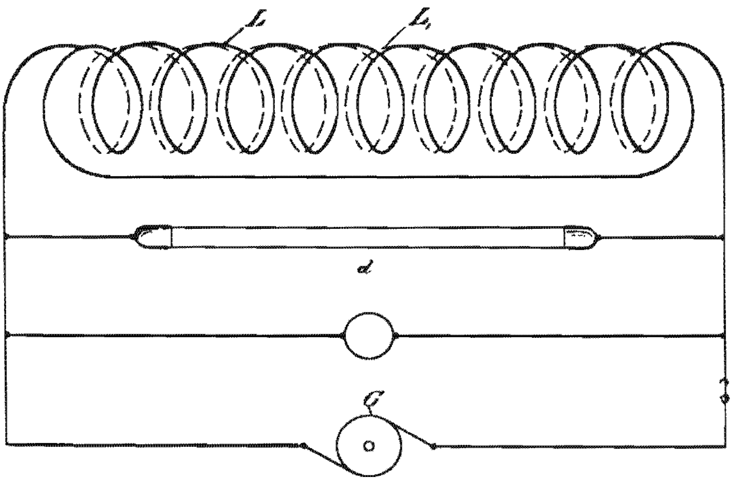
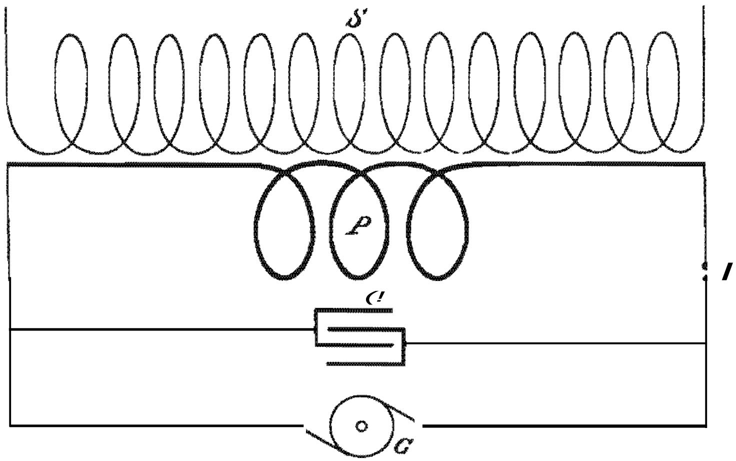


Fig. 4.-Coil wound to secure greatly increased capacity.



5.-Associating a secondary coil with a primary circuit coil.

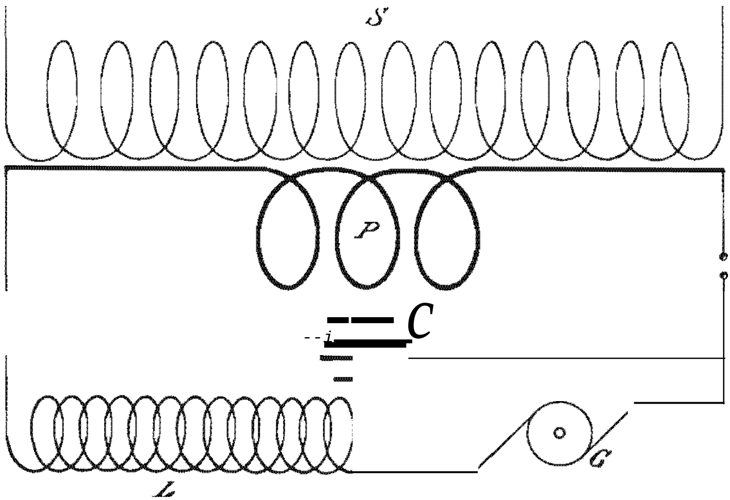


Fig. 6.—System adopted for existing municipal circuits.

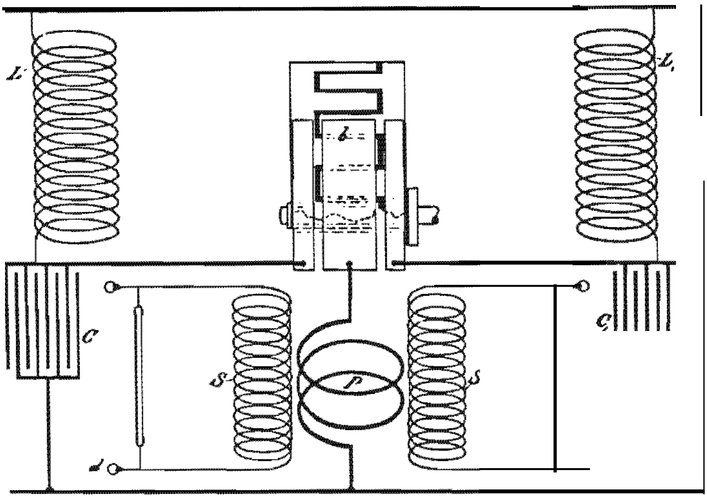


Fig. 7.—Circuit controller allowing condensers to discharge alternately and successively.

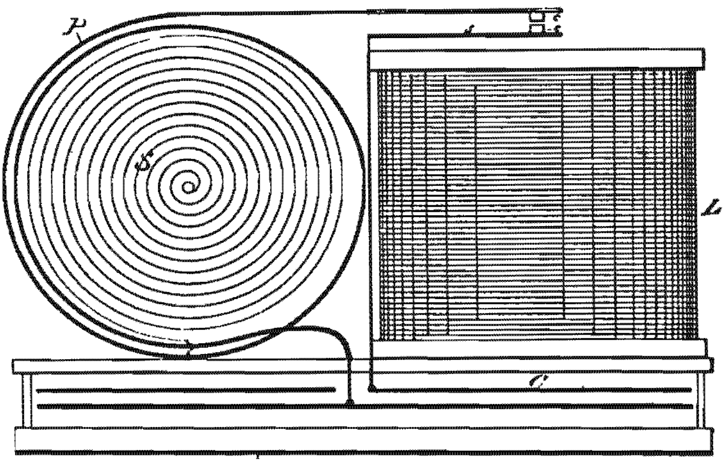


Fig. 8.-Arrangement of parts and circuits of a small oscillator.

understood ways. In a simplified form of this arrangement condenser, as a distinctive part of the system, was done away with, necessary capacity given to the coil itself, and for this purpose the turns of the latter were wound as illustrated in Fig. 4 so as to the storage of the and the largest possible amount ˆ energy. I associated a secondary coil S with the primary circuit *P*, as shown enabling obtaining of any tension required. in diagram Fig 6. was adopted as suitable municipal circuits. Again, the self-explanatory diagram typically illustrates a further improved disposition as in some of machines with two or more A modification plan with one continuous contact common to the two circuits, and independent interrupters for each these, allows adjustment of the phase of currents through the which is practical advantage some uses ˆ the apparatus. finally, in diagram Fig. 8 is shown the exact arrangement the parts and circuits of one of these small oscillators with a break similar to that usually employed with coils. Although the majority of preceding arrangements have described by me before, I thought it necessary to dwell on them here in to present clearly and comprehensively the subject.

A specific result of value the operation of Roentgen bulbs is obtainable by the use of two linked as shown 7, or otherwise, or entirely independent two separate primaries. Namely, in usual commercial bulbs the vacuum gets higher when current is passed through the in a direction and is lowered when the direction the current is This is a direct „..,':::'..t"'"''r·◦ of some conditions which, as a rule, are sent in the operation the usual apparatus; that is, asymmetry of the opposite current impulses, the unequal configuration or temperature of the two electrodes, or causes which tend to unequal the dissipation of the energy from both electrodes. It should be stated, though, that a certain point, the electrodes begin to act as entirely independent, the vacuum continues to increase no matter which way current is through primary. In the illustrated in 7, or in its

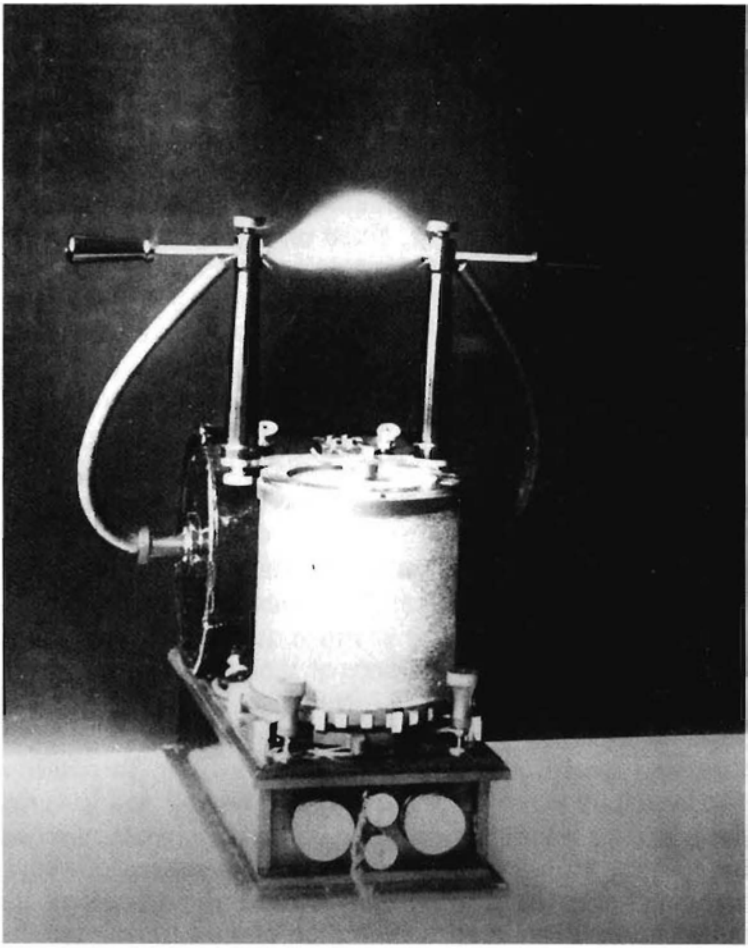


Fig. 9.-Photograph of small oscillator diagrammatically shown in figure 8.

modifications referred to, the trouble attendant upon the operation of ordinary apparatus is practically done away with as the current though the primary is automatically reversed, and in this manner a tube which is first brought to the proper degree of exhaustion by means of one circuit can be worked for a long time without appreciable increase of vacuum or diminution of effectiveness.

A photograph of one of these finished instruments, Fig. especially to be used in operation of Roentgen bulbs, or in general as a laboratory appliance in place of the ordinary induction coil, an idea of ac- arrangement of the parts. The condenser Fig. 8, is contained in a box *B* upon which is mounted in front the motor controlling the circuits, in this instance simply a coil *L* actuating a spring *s*, on of same. This coil, designated as the charging coil, serves at the same time to the pressure of the source to any desired for charging the condenser. This is an practical advantage, as it enables reduction the capacity of latter so that it need not be more a few of that otherwise needed for an equivalent conversion of energy. Besides, the smaller the capacity, the quicker is the vibration and the shorter be the high tension . The '-'1""'"arge circuit *P* surrounding the secondary coil is formed of a few turns copper ribbon and mounted on top the box behind the charging coil, all connections being as short as possible so as to reduce as much as it is practicable both self-induction and resistance of the discharge circuit. On the front side the box, 9, containing condenser, are mounted the binding posts for connection with the line, two fuses, a reversing switch. addition, two adjusting screws are provided raising and lowering iron core within the coil as a means for within current of supply and regulating the discharge of the secondary circuit. The instrument rubber columns carrying the dis- rods, which are visible on top, dismounted, can enclosed in a of x 9 x 6 inches inside measure.

The mode operation may as follows: At the start, the spring contacts *cc*, being closed and the condenser practically short a strong current passes through the charging attracting the armature fastened to spring and separating the contacts. Upon this, energy stored the coil, assuming form of a high tension discharge, rushes into the condenser charging the same to a high potential. current through the coil now subsiding, the armature ceases, and the spring reasserts itself and closes again the contacts. With the closing of the latter the condenser is discharged through the primary or discharge circuit, the constants of which are so chosen that an extremely rapid vibration of the electro-magnetic system including the crn1ae:nstr and primary coil results. The currents high frequency thus obtained induce corresponding currents of high tension in the secondary. Simultaneously, however, with the discharging of the current from supply again rushes through the charging coil is stored for next charge of the condenser, this process repeated as

as the spring and closes the contacts.

Although the an ordinary induction coil, it seen that action is en- different, and advantages of this new principle over the old are so as to hardly any lengthy comment Merely to convey a true and more complete information I may mention a few of the most important ones. for instance, the economy. The instrument referred to takes on a HO-volt direct-current circuit, according to load and from 5 to 30 watts. It a powerful stream of sparks 6 in but be desired this distance can easily doubled increasmg energy consumed; in fact, I have found it practicable to produce by the use this principle of 1 foot in length involving no expenditure of than 10 watts. But in an strument designed for a variety of uses, a departure must be made from a design insuring the greatest length. Of the total energy consumed the apparatus, 80 percent can be obtained circuit. Owing to the small total energy consumed and of parts instrument remain cool by long continued working with the of contacts which, course, are slightly heated. latter are subject to much less deterioration than is commonly case, as the condenser is small and, moreover, the current from the same does not, like an ordinary coil, pass simply through contacts and a few short connections, but has to traverse primary coil, this reducing the current and diminishing much the ..-....,,.., effects.

Consider next the advantages of the absence of fine in the secondary coil. Owing to the rapidity of vibration of the primary currents, comparatively turns of wire give the required pressure in the secondary circuit. illustrate this feature by a practical experiment I take a simple paper cylinder, wound with only one layer ordinary net wire, the secondary In spite of there being only a few long inches in length- are obtained when the is inserted within or brought near to the discharge circuit of instrument. A secondary of this form is simplest best suitable for the production of sparks, but it is somewhat inconvenient to handle.

most advantageous features these instruments however, in the quality of the effects produced, which are the result the rapidity or suddenness of the discharges tained. appreciate this we only need consider that a spark of, for instance, 6 inches in length, obtained with an instrument giving half a million vibrations a second, involves maximum pressures which, if produced with ordi- nary methods, would sparks many hundred

since the electrical force to vibrate a certain quanti- ty of electricity increases rapidly; that is, with square the of the frequency of Therefore, pressures such as obtainable cannot be in any way by static machines or ordinary induction coils.

Still another of a more practical bearing I may illustrate by lighting a vacuum tube from an instrument furnishing currents of a frequency of much over half a million a sec:ona. Although the tube has a volume of only 2112 [cubic] inches, it emits more light than a tube 6 or 7 feet long and 1 in diameter, such as I shown on other occasions, and that is a tube having 60 times the bulk and a proportionately larger amount of energy. So small a tube as this shown could not at all be brought to this luminosity by the use of the ordinary currents without soon getting overheated, and no better test of the increased ciency of the light production can had than producing as a luminosity in a small tube without undue heating.

Another convenient and advantageous feature of such an instrument will be found its capability of being operated from alternating as well as from direct-current municipal circuits. With the special object in view of enabling their being used to the best advantage on alternating circuits also, Ihave determined the physical constants in a few types to suit cuits of the frequ[illegible]''' usually adopted here; that 60 or 125 cycles per second.

In the development and practical application of the principle underlying this kind of apparatus, one of the greatest difficulties encountered was the insulation of the secondary coils and condensers, particularly of the latter. The stored energy of a condenser is of an explosive nature, and when released suddenly in a way as it is in these instruments, it partakes much of the character of explosions of such a body as dynamite and enormous maximum pressures result, which strain the dielectric layers in the condensers and coils to their utmost. No matter how good and thick an insulation is provided, it cannot withstand such strains if there be even a slight absorption loss caused in any strained portion of the apparatus. An ordinary condenser, insulated as usual by thick layers of mica, which easily stands a few thousand volts of steady or slowly varying pressure, breaks down invariably; and no wonder it does; for, with vibrations of several hundred thousand a second, such a condenser with air bubbles or cavities of any kind, unavoidable when the usual method of construction is followed, will convert into heat the larger portion of the energy supplied to it. To investigate the flow of an alternating current through a coil with an iron core which is not laminated is hardly less crude than to carry on a research of rapid electrical vibrations with a condenser in which there are cavities or air bubbles, or in which, in general, air has access to the highly charged conductors. No estimate of the vibration period of an electromagnetic sys–tem can in such a case be made with any accuracy, whereas, when a nrr.nor plan of construction is followed and the dissipation of Pruo.rau obviated, the experimental result closely agrees with the calculated period. By properly building up

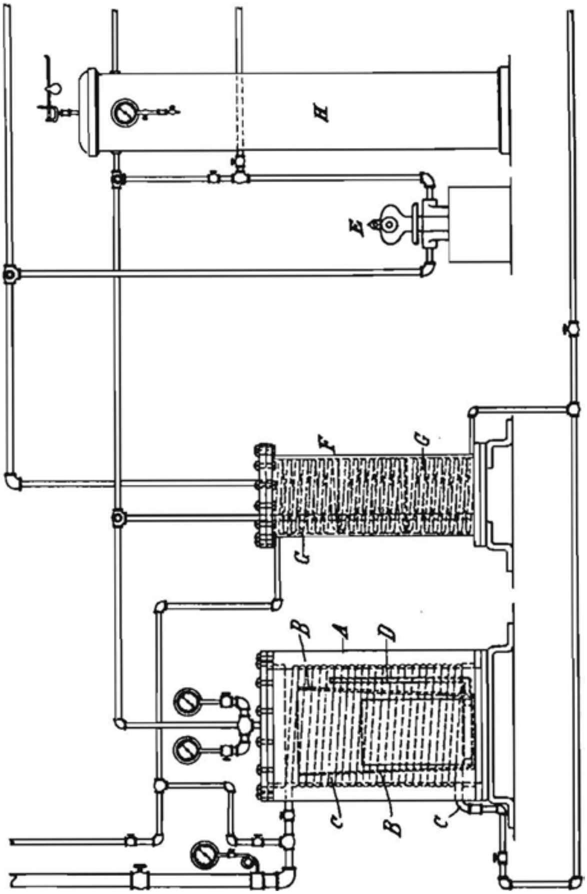


Fig. 10.—Apparatus [illegible] the manufacture [illegible]

the condensers and coils, I have produced electromagnetic systems in which a slow vibration, once started, continues a minute or more, this indicating the absence of any serious friction loss. It is important to consider the preceding facts when dealing with standards and instruments of measure. A standard condenser prepared in the ordinary way of mica sheets and tinfoil, while indicating the correct value of capacity when used with a steady or slowly varying potential, will have its measured capacity greatly increased when the variation of potential rapid. like manner, an electrostatic voltmeter with its vanes immersed in though a precious instrument ordinary currents, is practically useless in the measurement condenser charges of frequencies of a hundred thousand a second, its indication far too low.

In view of the importance of subject, a words on the process of insulating, which has been adopted by me after of experimentation, may of One form of apparatus as used by me is illustrated in diagram Fig. 10. *A* is a of withstanding great pressure, which is connected to a pump *E* and reservoir *H* through a condensing reservoir kept by means the coiled pipe *G*. The tank *A* is likewise provided with a coiled pipe *C*, through which steam or cold water may be passed at will. The condenser is build up of insulating and conducting sheets in any way, several layers of very thin paper being together so as to avoid defects which may arise from holes or punctures. the same reason, it is to mix the sheets when received from factory, as a great number of them may injured at the same place. The been by the application moderate electrical pressure as that of a supply circuit 220 volts, is placed a vessel *B*. A pipe *D*, reaching to bottom of this may provided, through which the insulation, when liquefied the may flow in, but this is of importance. vessel *B* containing the condenser next placed in the *A*, and the top of the latter bolted down, steam is then passed through the pipe *C* the insulating mass is kept at [proper] temperature which is a little above the melting point of the compound regulating the steam supply. The pump is now connected with the by opening the valves, and a vacuum about inches or slightly more is established. When the melted compound has thoroughly permeated the interstices of the condenser, steam is then shut off and cold water passed through the coil C. The process of slow cooling being far the connections of the pump are reversed and air is forced into the tank *A* with the result of compressing strongly the fluid insulation and forcing it into all interstices. The pressure is preferably maintained until the mass is solidified. The application of the pressure is not only of great advantage because the insulation is forced into the interstices and prevented from shrinking away when cooling, but, in addition, any small gas bubble, which might remain in the condenser and would otherwise at ordinary atmospheric or smaller pressure be fatal to the instrument, is strongly compressed and the danger considerably lessened. The mass in the tank *A* being solidified, steam is again turned on the pipe C for a few minutes in order to soften the insulation on the periphery and allow the

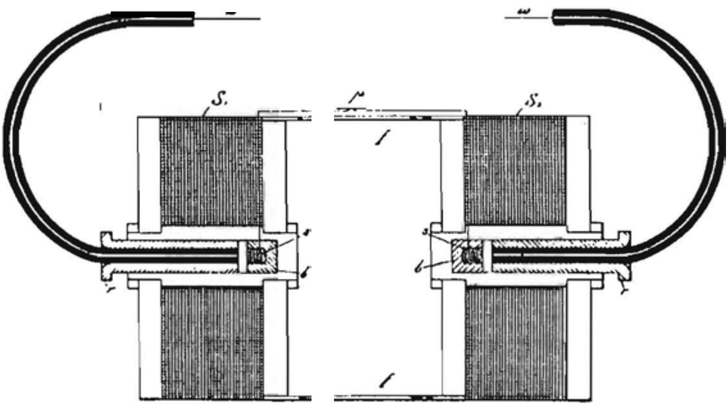


Fig. 11-High potential coil system having terminals at centers.

vessel *B* to be lifted out of the tank, whereupon the condenser is taken out of the vessel and the superfluous insulation cut off. In the same manner, primary and secondary coils are treated. As insulating material, I have found best to use a mixture of beeswax and paraffin of low melting point, about half of each being taken. This gives a tough mass which [but slightly] shrinks away from the metal upon cooling. Condensers and coils manufactured in this manner will withstand incredible pressures. Very often in adjusting the primary discharge circuit, it may happen that sparks of ^{3}/s or *1/z* inch dart across the condenser terminals, and yet it will not break down, although the """""""""""" is no more than a few thousandth of an inch in ....„... ␣. I have been unable to detect any increase of whatever in the condenser after long working.

To enable the secondary coils to withstand the effect of the enormous pressures producible with instruments, I have recognized it as necessary to build them on the general plan illustrated in Fig. 11. The diagram shows two flat spirally wound coils, S_1 S_2, which are connected with their outer ends to a contact plate *p* in the proper direction so as to form in reality one single secondary coil, the terminals of which are respectively at the centers of the two wooden spools upon which the two parts of the coil are wound. These spools are held together by a cylinder of thin fiber sheet *ff*, which is sufficiently strong to solidity and perforated in order to allow the melted wax to fill the hollow spaces when the coil is put through the insulating process before described. In the centers of spools are fastened threaded brass bushings to which the free ends of the secondary coils S_1 S_2 are connected and into which can be screwed brass pieces *ss*. are fastened to the end of the hollow plugs of hard rubber *rr*, through which pass flexible wires *w w*, heavily insulated with gutta-percha, which serve to connect secondary high potential ends to the on the top of the instrument (Fig. 9). It not to insulate the wires *w w* with soft rubber, kind of insulation is soon destroyed by the ozone generated at their surface in consequence of the streamers which will form even if the rubber be very thick. The thickness of the insulation between the superimposed layers of secondaries is practically determined from an proximate estimate of the difference of potential between jacent layers. Originally I have used heavily insulated wires with from two to four braids, but presently I am using ordinary magnet wire which, in manufacturing the coil, is wound together with a string of a thickness equal to that of the wire. This is a convenient mode of insulating, not requiring specially prepared wire and secures re- sults. The middle of the secondary circuit, or common of the two coils, is connected to ground, or so the mains, and this generally through primary discharge The small contact plate, or spring serves to establish connection upon the secondary being the primary coil. The length of the secondary coils is so determined that it is somewhat less or equal to a quarter of the of the disturbance produced in the course, on the es- timate of the speed propagation of the disturbance through this circuit. It is obviously that the length of the secondary circuit is made to approximate more or less a quarter of the wavelength, according to how much mal allowance is made for the capacity of the circuit under nor- ment working conditions. the ordinary uses of the instru- of qualitative as [a] laboratory chiefly for production lowance effects tension discharges, little al- is generally capacity the terminals but if the apparatus is for instance generating a large quantity of streamers between plates of surface, or for charging from the or [other] such uses, then of the is made much smaller, and advantageously an even fraction of a quarter of that which is without any allowance for capacity than that by the coil. Finally, if secondary currents of low tension are desired, the coil is constructed one spool and of only layers, all in proximity to primary so as to the mutual induction coefficient reduce the resonant rise of potential as much as possible. The closure of the magnetic circuit oxygen at ordinary or high while of little with low quency currents, is a remarkable with currents of these unusually when conditions are the occurrence resonant phenomena, and I am anticipating practical uses of oxygen in connection.

A secondary coil constructed in manner illustrated 11 has many important advantages, the chief ones being safety in handling and the facility it affords for obtaining ootentials far those producible if the ordinary of construction are followed. In to convey an of the pressures obtainable even with so small an instrument as one described, a photograph the same action with two loops of cotton-covered wire attached to the discharge rods, is added (Fig. outer wire loop was in the experiment only in diameter to enable it being properly shown in the print, but it could have been much larger since two parallel wires feet long may be stretched the secondary terminals of instrument practically the whole space between them, 4 inches wide, is seen in dark covered with fine luminous streamers. is a surface of 5 square feet, and yet the energy taken from the supply circuit during the performance is 35 watts. To produce with an ordinary transformer such a quantity of these streamers, which may be for manufacture of ozone or similar purposes, would require a considerably amount of and a more costly apparatus.

These extreme of potential obtainable by the use the principle here involved are the result of the enormous suddenness or rate of change the primary current impulses. In the ordinary method of the strength of the primary current, either by alternating same or break- the conducting path, we are limited to the comparatively insignificant rate of producible by means of a high frequency or rapid but by use of the condenser discharges is practically no limit to the sud- denness the impulses, and any potentials and spark lengths desired can be readily obtained. instance, I have been able to produce, by applying the principle in a peculiar manner, immense the theoreti- cal maximum value of which can measured only in many millions volts, causing showers of continuous streams thundering to dart out into to a distance of 8 or 9 feet from an insulated wire, which behave sometimes like veritable lightening bolts and have afforded to the few who witnessed them during last two or three years in my laboratory a not easily forgotten. Nor is it at all difficult to increase, a hall or open space,

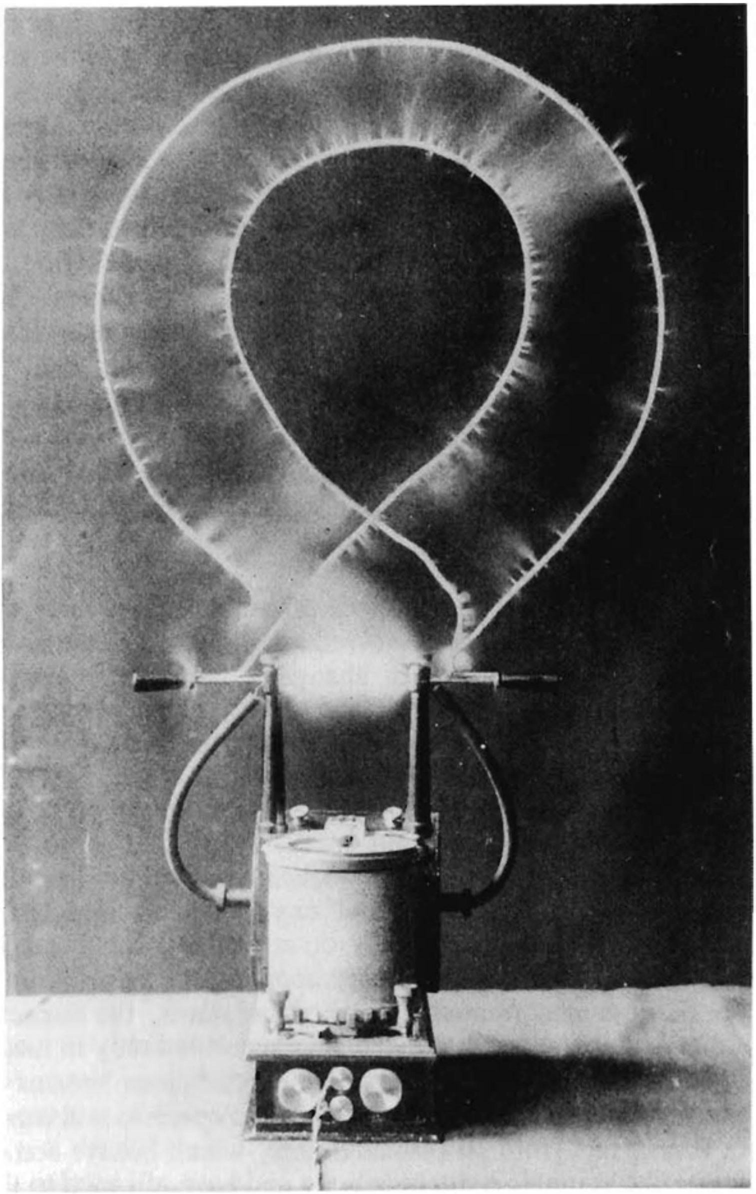


Fig. 12.-Photograph of coil system illustrated in figure 11 in action. Luminous streams cover an area of 5 square feel

many times the potential and sparking distance by the employment of such means and methods.

Although in oscillators great suddenness of change the strength of currents depends chiefly on the electrical constants of the some advantages of minor but practical importance may secured by a proper con- struction of the devices used as convenient, though not in- dispensable, accessories of system for the purpose of ar- bitrarily making and breaking circuits. Accordingly, I have devoted considerable time to their study and perfec- tion, and in connection with the typical arrangements of the circuits illustrated in 1, 4, and 5, I have dwelt in my earlier on this subject on a variety of such circuit tem1pters in vacuum, air, other fluids at low or great pressures.

It been known long ago, the investigations Poggendorff, that, when the vibrator or break of an induction was enclosed in an exhausted vessel, interruption of the currents was suddenness, the vacuous space acting in a certain measure like a condenser, connected, as usual, around the break. My experiments with several kinds of such circuit breakers have led me to that vacuous space is not exactly equivalent a but of an the "r''''''''''r1 suddenness being simply due to the rapid carrying away of the volatilized material forming the arc and, therefore, dependent on the velocity with which disintegrated matter is away and also on amount of latter. Thus, with very hard platinum-iridium contacts small currents, there is little difference; but, with soft platinum points and heavy currents, influence of the vacuum is well noticeable, while, with mercury or in easily volatilizable conductors, the difference is very great. The of the exhausted is also of some consequence, break gaining suddenness when the is larger.

Looking at Poggendorff's observations in this light, it appeared dear to me that only a small velocity of the particles composing arc can be obtained the effective pres- depending on at least with low frequency impulses

mechanical means, and with currents of limited strength which can be passed through the contacts without quickly destroying them, is necessarily only a minute fraction of the atmosphere being besides, very materially reduced by the oppositely acting attraction of the parallel-current elements of the arc. Pursuing further this train of reasoning, it seemed likewise evident that, if an insulating fluid be forced mechanically between the contact points with such velocity that the particles composing the arc were carried away quicker than it was possible with a small pressure producible in the gaseous matter in vacuum, the suddenness of disruption would be increased. This conclusion was borne out by my experiments in which I found that a fluid insulator, such as oil or alcohol, forced through the gap with even moderate velocity, increased very greatly the maximum rate of change of the primary current, and the length of secondary wire necessary for a certain spark length was in some instances reduced to 25 percent of that usually required. The length of the secondary was still further reduced by the use of insulating fluids under great pressure. As regards the suddenness of the current impulse following the closing of the contacts, the introduction of an insulating space or film of greater dielectric strength than that of the air at ordinary pressure, though producing a distinct effect, is of small consequence when the interrupter in its operation actually breaks the arc, since the electromotive force of a battery or municipal supply circuit is generally insufficient to break down an insulating film of even so small a thickness as 0.001 inch.

The continued effort to perfect the various automatic contrivances for controlling the supply current has clearly brought out their mechanical limitations, and the idea of utilizing the discharges of the condenser as a means for producing, independently of such mechanical devices, the sudden variations of the current which are needed for many purposes in the arts, appears evermore a happy and timely solution. In this novel process, a function of only minor importance is assigned to the mechanical means; namely, that of merely starting periodically the vibration of the electromagnetic system, and they have no other requirements to fulfill beyond those of reliability in operation and durability, features which are left to the skill of the mechanic and which, in a fair measure, it was not difficult to attain in a number of types.

Considering, then, that the rate of change of the discharge or primary current in these instruments is made to depend chiefly on the physical constants of the circuit through which the condenser discharges, it is evidently of utmost importance to construct properly the latter circuit, and in the investi 12:a1l0r1s which were carried on with this object in view, several noteworthy observations have been made.

First of all, one draws the obvious conclusion that, inasmuch as the primary coil in a transformer of this kind con- usually very few turns of copper of inappreciable resistances, the insulation between the turns should not require much care. practical soon convinces him of his error, for, very often it happens that, owing to an exceptional resonant difference of tential between adjacent turns becomes so great as to rupture even a good ordinary insulation. this reason, it was found necessary to treat the primary coils likewise in the manner described, thus securing the additional advantage of stiffness, which from the expansion of the metal sheets and thickening of the insulating layers during the heating in vacuum and subsequent contraction of the metal in cooling to the normal temperature after the insulation has solidified.

the experimenter is surprised when realizing the importance the proper adjustment of the length of the primary coil He is naturally prepared to find that, the discharge circuit is of small length, the introduction in this circuit of a small inductance or tional would produce an appreciable difference in result obtained as, for instance, in the spark length of the secondary coil. But he certainly does not expect to observe that sometimes as little as 1/4 inch conductor more or less would be of a telling effect. To illustrate: It is quite easy to produce with this kind of apparatus a spark of feet in length, and by merely taking off or adding to the primary

1 inch of thick copper wire so the spark length to one half. Observations of this kind impress the experimenter with the importance the adjustment circuits accurate determination of constants. His attention is forcibly to the of reducing as much as it is practicable self-induction and resistance discharge circuit, former with object of the quickest possible vibration. the chiefly for reasons of economy also recognizes the necessity bringing down to the minimum resistance all connecting wires. A discharge a small instrument, as the one should have no more five percent of inactive conductor; its should negligible, the self-induction should be not more than a few centimetersJ*l I found it 1mperato use thin the primary coils, with these an is the most curious of been made. It occurs, namely, that, under certain conditions, the primary coil gets cooler by continued working. For a long time this appeared doubtful, but finally it was positively ascertained and ascribed to an effect, to which heat is to the tinfoil of the corldenscr.

It might not appear quite at first why the primary discharge is so to variations of length, for a circuit of length connected to condenser and, that between capacity and is as to satisfy laid down by Kelvm, oscillatory discharge will take But it must remembered that the velocity of propagation of the disturbance in the circuit depends on quant1t1es, and that best result is when the velocity is that a wave is with a single node which is located but not always, at a point of discharge circuit or conductor equidistant from the opposite """"""""""""" ıser coatings. Under such the maximum effective pressure at the terminals is obtained. But

* In contemporary units. a few tenths microhenrys.

this state of things is only possible when the speed of the propagation through the discharge circuit is such that this circuit is traversed by the disturbance exactly in the time interval needed to complete half of one vibration. Now, since the speed is extreme and the length of the circuit very small, entirely insignificant variations of the length may often produce astonishing changes in the performance of the apparatus. These statements, of course, should not be construed as generally applicable; for they refer only to such cases in which the vibration in the discharge circuit, started by one operation of the circuit controller, does not die out before the succeeding operation of the controller. This may be made clear by a mechanical analogue. Suppose a weighted spring is clamped in a vise and a sudden blow is struck which sets the spring vibrating. Let the vibrations die out and let another blow be delivered. The spring will vibrate again as before, and it matters little what weight is attached to the spring, what the elasticity of the latter or, in general, what its period of vibration, and at what intervals the blows are delivered, process of conversion of the energy of the blows into the [illegible] of the vibrations will be effected with equal economy, except for secondary causes, immaterial for the present consideration. Exactly so is it with the electromagnetic system, and in the early stages of development and practical adaptation of the principle underlying the instruments described, I have employed condensers, either ordinary or electrolytic, of very large capacity and have caused them to discharge at comparatively long intervals through a primary circuit of negligible self-induction and resistance, thus producing current impulses which would sometimes reach, at least theoretically, maximum values of as much as 100,000 amperes. A high maximum rate of change in the primary current was thus producible, but, nevertheless, the average rate of change was still small. Considering again the mechanical analogue before mentioned, a valuable lesson is at once derived. Looking upon the weighted spring as an appliance for converting energy, both and output mand that the vibration of the spring should [illegible] as long as possible and that the blows should be struck as often as it is practicable. To satisfy this twofold requirement, the blows must of be delivered the spring is still vibrating, and now it becomes most important to properly time the blows. Similarly again, the electromagnetic system, the controller must operate at definite intervals of time in to secure most vibration with the least supply of energy. In the construction of ora:;t1cal instruments, number of the fundamental current impulses is arbitrarily adopted; the condenser, prepared by a spe- cial process, cannot be adjusted great inconvenience. and and to a extent also the turns of the primary coil are likewise determined beforehand from pra:;tical considerations. Furthermore, it is desirable, reasons of economy, not to resort to an otherwise convenient method of adjustment, which would be to a variable self-induction in with primary These conditions more difficult the exact adjustment of the various quantities, and I have sometimes found it of advantage to adopt one or other plan such as will readily suggest themselves. For example, I have used an additional coil wound upon the primary and connected in parallel to the same, or Ihave completed the adjustments by determining properly the self-induction and capacity of the secondary coil.

In order to facilitate the observation and to enable the exact determination of the oscillations of electromagnetic systems as well as of vibrations or revolutions of mechanical such as circuit controllers used con- """""""" it was recognized as indispensable, in the course of investigations, to construct a proper apparatus for such purposes. I determined from outset to myself what is known as visual synchronism. In this scheme, usually a or cylinder with marks or divisions, which is rotated with uniform is illuminated by a periodically varying or intermittent source of light, divisions appear- stationary space when revolutions of the disk are synchronous with the in intensity or intermittence of the light-giving source. The virtue of such a method evidently resides in uniformity the velocity of rotation or eventually in the of period of the vibration produced. Having been confronted with problem of rotating a body with rigorousl y uniform velocity, which is requi red many instances, or wi th the problem producing a vi bration of constant period, I have devoted some to the study of this subject, in the course of time several solutions, more or practical satisfac- tory, have presented themselves.

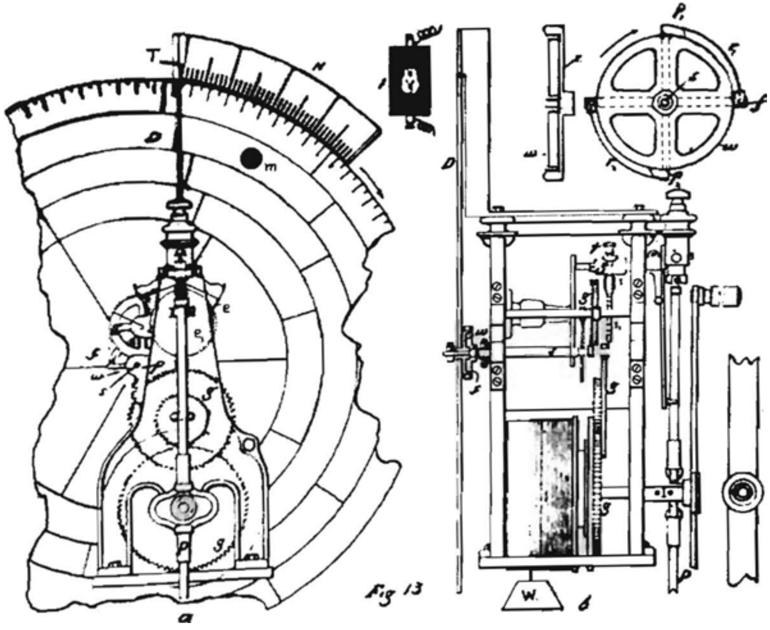
One of these for instance, was to by means of comnr"""""11ˆ air or steam, the vi bration of a freely movable pl unger to which was rigidly connected a coil or core of an electric generator. the motion of the plunger, alternating currents were generated which were passed through a or through primary of a transformer, in which case the secondary coil of latter was joined to the terminals of the condenser. Care being taken that the air or steam pressure was applied onl y duri ng a short interval of when pl unger was passi ng t hrough the center of and the oscillations of the electromagnetic system, composed of and generati ng coil, bei ng properl y determined so that funda- mental resonance took place, it was found that, under such conditions, the governed the vibrations of plunger; the applied fluid pressure, while capable of produci ng in the ampli- tude, were very wide wi thout any appreciable on period of vibration of mechanical system, the currents generated therefore of rigorousl y constant period. currents thus obtained were then utilized in a num ber of ways to produce uniform rotation.

Another way to the same resul t and in a more prac- tical manner was to currents of differi ng phase by a steam engine of special design, which the reciprocati ng motion of the work performi ng plungers and attached mag- netic cores or coils was controlled by a freely oscillating val ve, the period of which was maintained constant by mechanical means or by the use an electromagnetic tern, similarly as before. A synchronous alternating motor operated by the two or three phase currents thus generated rotated with so uniform a velocity as to drive the wheel work of a with fair accuracy

Still other solutions of the problems to I may mention which, though satisfactory, have proved sometimes convenient and sufficient for many purposes. example: a direct-current motor laminated or without any iron, was connected in series with a condenser through a commutator or interrupter fastened on the shaft a light [weight] armature. This device was so constructed that it alternately closed and opened the terminals of con- as usual in the instruments before described. The condenser terminals being closed, a strong current impulse passed through the motor, and upon the terminals being opened the discharge current hi gh tension rushed into the condenser. But the duration of both of suc- ceeding current impulses, and consequently all which passed through the motor, were made chiefly dependent on the self-induction of motor coils on the capacity of the condenser and were, therefore, with certain limits of variation the applied little dependent on latter, and consequently a motor with a negligible tion operated in this manner, turned with nearly uniform velocity. The was the more constant greater the controlling influence of electromagnetic system which, of course, was most complete when the number current impulses, the capacity, and self-ind uction were so adjusted fundamental resonance was ....,•...,..... As before in most these novel instruments described, such adjustments are observed and, whether provided with rotating interrupters or circuit-controlling springs, they partake more or less of virtue preceding principle. For this reason, the contact springs in these instruments not fall into harmonics, as they do ordinary induction coils from supply circuits where physical constants are generally such that similar adjustments are impracticable.

It should that, a long time, it was known a motor, driven with currents terrupted at regular intervals, a marked tendency to maintaining a constant speed; but by introduction a condenser in the circuit and the careful adjustment quantities, this is very much and for many purposes a uniform velocity obtained in this manner. Instead of using interrupted currents for operating the motor, it is practicable to rotate a separate coil, wound on same or on a second arma- and to pass alternating currents generated in this coil through the condenser. It is important for the attainment a satisfactory result in such cases to determine the constants so that the amount of stored in the co1na<:ns1er should as large as possible.

While a number of such arrangements were readily available, it was found, nevertheless, that they were inadequate to the many different requirements of the laboratory, and accordingly an instrument was devised which is illustrated in 13 ab. It proved itself to so necessary and valuable an implement in experimental investigations that scription here may afford information. cut is in- •..,.,..,,,..., to show a substantial and carefully constructed clock mechanism with the usual escapement *e*, gearwheels *ggg*, and a 1-second pendulum A small shaft s, carrying a disk of diameter, was geared to the clockwork through a pinion *p* of a proper number of teeth, as to give to the shaft a velocity best suitable for observations. Now, in to rotate the with a uniform velocity, some difficulties, well known to clockmakers, had to be overcome. The chief of these is due to the fact that rotation of shaft s, being controlled by the escapement *e*, which, at ular intervals, retards train of wheels *ggg*, is not effected with uniform but periodically varying velocity, which may all values from zero to a maximum, dependent on the driving weight *W*. Owing to this circumstance, when such a disk *D* of large diameter is rigidly geared to any kind clockwork, it exerts, by reason of the momentum which it necessarily acquires, a strong reaction upon the pendulum, altering the of the same more or less, according to the momentum it This difficulty is known to even in cases in which the step by step movement is practically done away with, as, for in clockworks with centrifugal governors, or circular pendulums, in which slow oscillations are produced the reaction of the moving mass upon the regulating ....,...



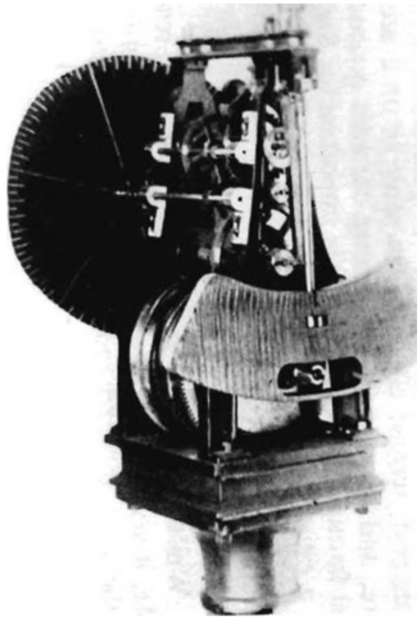


Fig. 13.-Special instrument to exactly determine wavelength and phase.

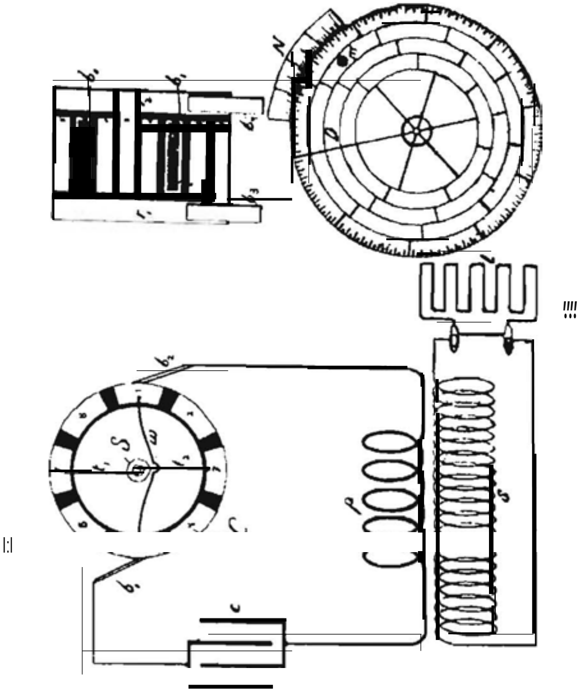
Some clockmakers have proposed an elastic connection between the body driven and the escapement, but this does not [do] away radically with the difficulty. On the other hand when, in an attempt to overcome this disadvantage of the step-by-step movement, a quick-acting escapement is used, whereby the periods of rest are reduced, and consequently the inf1uence of the momentum of the body upon the period of the pendulum, the result aimed at is but imperfectly a"""""""""" and, besides, such an apparatus is suitable for observation. Namely, it will be recognized as desirable for a number of reasons the disk D should be rotated normally either once or twice a to whether a 1- or 1h.-second pendulum is used. This being the case, the experimenter can render himself easily an account of the constancy of the speed by observing a mark m on the and noting that it occupies a fixed position in , rel- to that of the pendulum, in a phase of vibration. the computation the vibrations is rendered more convenient under such conditions.

problem, clearly put, was then to rotate a as the disk or other with any desired but uniform velocity in a way such the of vibration of pen- dulum was not affected, even though the rotated possessed considerable momentum. entirely satisfactory solution of this problem was arrived at in the following manner. On end of the shaft s, Fig. b, was fastened a light metal piece f in the shape a cross, carrying on two its opposite sides pivoted pawls p_1 and on the other two light springs r_1 which the pawls gently against the periphery of a washer w, which was provided with many very fine teeth or serrations cut s1m1-larly to of escapement wheels. The washer w was arranged to tum very freely on the shaft s, and to it was fastened the disk D. The pawls p_1 p_2 were made with sharp edges to fit in the w, and by these means disk could rotate freely on the shaft s in the direction indicated the arrows, but rotation the opposite direction was prevented by the

The operation of the apparatus now be at once understood. On the start, the escapement wheel e was released by unscrewing the thumb screw t and shifting the sleeve S on rocking support. The pendulum was next started when the escapement wheel had attained the normal velocity, the sleeve S was slipped back quickly fastened -control escapement being thus to pendulum. work and the shaft s now [illegible] with periodically varying but the disk D continued to move uniformly, the pawls $p_1 p_2$ slipping on the periphery of the washer w during periods when revolution of the the pendulum. When, however, after some time, owing to the very but unavoidable in and bearings, the speed of the disk would slowly diminish and fall below maximum velocity which the shaft s was capable of imparting to then the pawls would give it a impulse, in this manner the disk was kept constantly at the maximum velocity. By each of the pendulum, the disk would thus one its on the amount of energy to it by the succeeding impulses. This amount of energy of course, on the velocity of the shaft s during the period when the [illegible]-ment was free, since this velocity was determined by the driving weight, the speed of the of the disk could within limits by the weight. It will observed would rotate considerably faster than the shaft s, but it was easy to adjust the driving weight so that the disk rotated just once by one swing of the pendulum. In producing the rotation by these means, the influence of the momentum of the disk upon the period the pendulum is found negligible. This result, of course, could not be [illegible] by connecting the disk rigidly with s, even if a quick acting escapement would be used, as suggested. uniformity of rotation secured in this way leaves, for all practical purposes at least, nothing to desired. The apparatus might been improved by supporting the on an independent bearing and, perhaps, by it horizontally in a jeweled support. But the friction was very small, since, by arresting shaft *s* suddenly, disk would generally rotate something like 100 times or more before stopping, and such improvements were thought unnecessary. The vertical position was, however, chosen it was much more for purposes of observation. In to reduce weight of disk as much as possible, a consisting of a circular rim with narrow spokes, was cut out of thin aluminum sheet, and black paper glued on the frame-all marks and divisions of former being, of course, white. I found it convenient to draw concentric circles a number of marks such that all vibrations within the of apparatus could read In addition, a segmental piece hard rubber *N,* supported on a *T* and properly marked, was used to read fractions or, respectively, take corrections for any irregularity the rotation during a prolonged period of the disk was placed a vacuum tube or, in place, an adjustable spark gap *l,* which was to the secondary of a small transformer, the primary which was positively controlled by the mechanical or electromagnetic system the vibrations of which were to determined. In preparing a spring the desired period vibration for one of the instruments scribed, for the spring was provisorily mounted on the instrument and the latter put in operation. The disk, intermittently illuminated by the discharges of the secondary was released from the pendulum and rotated until synchronism was attained, the revolutions being computed by observing the white mark *m.* The constants of the spring were modified a simple calculation from the first result, and in the trial, as a the vibration was so as to enable use of the escapement, the adjustment being completed, generally by altering the weight of the hammer on the spring until marks on disk, by the normal speed rotation, appeared stationary in space.

The apparatus described in will be found very convenient and saving in a many lines of experimentation. By means of the same, it is practicable to rotate a body of weight \Vi th uniform and adjustable velocity, and it itself to the operation of circuit con- trollers, curve and all kinds of such devices. It will be found most in tracing current or electromotive-force curves of will afford material help in a number of physical quantities. But its most valuable use in the investigation of electrical vibrations is, perhaps, the purpose determining exactly the angular velocities of dynamos, particularly of alternators. Among the various quantities which, in alternate-current experimentation and practice, one to determine frequently, there are some, which even a laboratory or shop in the midst of disturbances a or can ascertained with sufficient precision, while there are others which can be only approximated, particularly if, as is very often the case, practical methods of measure must resorted to. So, for example, the close measurement of resistances no nor does that currents and electromotive forces, although the exactitude is necessarily smaller; but in determining one is liable to make a considerable error, still a one in measuring inductances, and probably the estimating frequencies In many such crude as speed counters or tachometers are still resorted the experimenter is disappointed to that of long and painstaking tests is impaired to determine exactly frequency. To make matters worse, very often too, latter is the and most important quanti- ty. In view of these facts, a descri ption of the methoo adopt- ed by me determination angular may be some

The commonly are illustrated diagrammatically in *a* and *b*. On shaft *S*, a, of the generator fastened a commutator or controller C, provided with any suitable number of eight being



shown in this instance. Four of these, *1, 3, 5,* and 7 serve to establish the connections of the circuits, while the intermediate ones, 2, *4, 6,* and *8* are entirely insulated, idle segments. Assuming the generator to be an alternate-current machine, the terminals t_1 t_2 of the armature winding, or of any desired coil or part of the same, are led through the hollow shaft, as may be the case, and connected to the diametrically opposite segments *3* and 7, while the segments situated at right angles, that is *1* and *5,* are connected together through a wire w of inappreciable resistance. Two brushes b_1 b_2, supported in an ordinary holder allowing their being shifted in any position, are arranged to bear upon the periphery of the controller C. These brushes are connected to a circuit comprising a condenser c of proper capacity and a primary coil p, which has but a few turns of very small self-induction and resistance and is joined in series with the condenser.

The operation of the devices is as in the instruments before referred to. When, with the rotation of the shaft S, the brushes b_1 b_2 are brought in contact with the segments *1* and *3*, the condenser is charged to a potential which can be adjusted at will by shifting the brush holder. The condenser retains a certain charge until the brushes b_1 b_2 come to bear upon the connected segments *1* and *5*, whereupon an oscillatory discharge through the primary p takes place with the result of inducing strong current impulses in the secondary s, which momentarily light up the vacuum tube or spark gap l placed in proximity of the disk D, which is rotated with uniform velocity, as before described. With the rotation of the circuit controller, the brushes are again brought in contact with the *1* and *3*, and the operations are repeated, at complete revolution of the armature shaft a definite number of impulses being passed through the vacuum tube or spark gap. In the device illustrated, there will be only two impulses for each revolution of the armature, but any greater number be arranged for by augmenting the number of the segments and connecting them in the same manner. It should be stated that current impulses, which pass into the condenser whenever the brushes b_1 b_2 are on those segments which are connected to the armature coil, ordinarily produce no appreciable effect in the secondary s. This might be the case if the number of segments would be very large and would then be at once noted. The proper adjustment of the circuit through which the condenser discharges is, of course, preferable but not absolutely necessary.

When it is inconvenient to use armature current, as illustrated in Fig. 14 a, then the controller C is provided with two sliding rings r_1 r_2. Fig. 14 b, which are made to bear two additional brushes b_3 b_4. The latter are then connected to a direct-current source as the ordinary supply cir- preferably through a self-induction coil, which serves to to a higher potential. The r_1 r_2 mere!y to the segments *1* and *3* current charg- i ng the condenser, otherwise nothi ng be changed on the s.

The marks or divisions on peri phery the disk *D* are suitabl y so that by normal speed of the genera- tor they appear stationary in space. bei ng the case, the speed may be at once and easily computed from the number of segments on the controller and that of divisions on the disk and from the speed of the latte1: The frequency of dynamo currents is then by taki ng i nto consideration the of

availing himself of this method, the experimenter can get the accurate value for angular velocity, no matter how much the speed of the dynamo may vary, if he only takes the precau tion to his readings for electromotive force, current, etc., at instant the on the disk are stationary. Should the consume more time, 1t 1s easy to take the for any variation by simply observing, wi th to a fixed line on rubber piece *N,* the number of divisions which are to added or u1;;\ U\..1Nu from, the of disk.

Section I Addendum

WIRELESS TELEGRl\PHY METHODS; ADVANCES IN ELECTRICAL OSCILLATORS; EXPERIMENTAL VACUUM BULBS.

This portion of the lecture was not completed for publication by Tesla. The and drawings pr..... in the lecture on subject of telegraphy receiving methods, an extension his presentation on novel high measurement methods, were considered too revealing in terms of patent applications in progress. The following Addendum section is derived from Section IX, "Arrangements for receiving," *Nikola Tesla On His Work With Alternating Currents* and is believed to summarize his remarks on this subject

"The [of the instrument shown in Section I, Fig. 13 cut] was intended to produce an absolutely constant rotation so that certain intervals of could be definitely fixed, and in to these of time I could analyze the waves... The bottom of [Fig. shows vacuum designed for currents. They were secondary transformer and illuminated the I used, for · two vibrations of different then there was a and I would notice, as this rotated, the marked travel one way or the other. When synchronism was obtained, lines appeared stationary.

"I am now showing [Fig. 15, top] a [drawing of a] for telephonic and telegraphic I used in my laboratory on [left] is a transmitter ..., [below] is an inductance which is bridged by a such as by speaking into it, or it by hand or otherwise, variations in the intensity of the waves are produced.

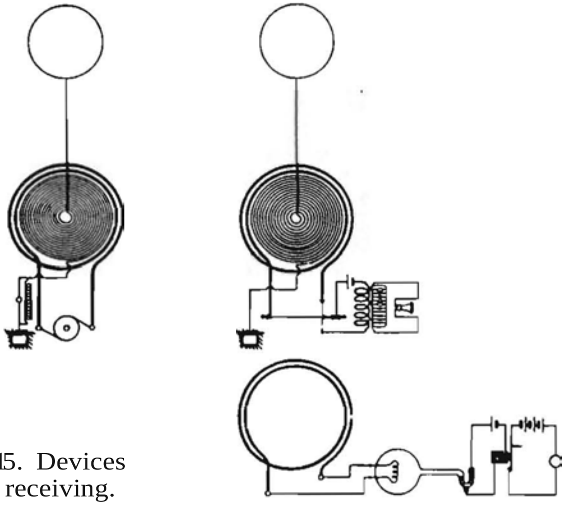


fig. 15. Devices for receiving.

"On the receiver side [right] I have my antenna and self-inductance coil connected to the ground, and in the secondary I have a wire which is under a tension. Another wire, likewise under tension, controls two microphonic contacts or carbons. The tension of this wire is adjustable, and as I will show in another drawing, I can regulate the pressure of the contacts so that a certain current from a battery, here, will flow through this primary coil.

"When the transmitted oscillations are controlled and produce corresponding variations in the intensity of the received effects, then the current generated in [the secondary of the receiver] heats that wire more or less and the alternate heating and cooling of the latter results in periodic expansions and contractions vary(ing] the microphonic pressure of the contacts in obedience to the changes produced in the transmitter. In the secondary [of the transformer], I have a telephone [receiver] specially wound to reproduce the speech..."

"My transmitter was on Houston Street and I would take the receiver with me. For instance, I would take a few toy balloons, go on the roof, and then put my box there with the instruments and listen to the signals.

"This [Fig. 15, bottom] is another [drawing of a] device which I also used with success, but not telephonic. It operated on the principle of the Reis air thermometer ... [I]n the bulb is a resistance wire which is heated and cooled, owing to the fluctuations of the received currents. The attendant expansions and contractions of the air operate a little mercury column, pushing it back and forth. Curiously enough, for receiving telegraphic signals, this crude instrument was certainly good, but of course it was not suited for telephonic reception.

"That [shown in Fig. 16] ... illustrates a way of producing audible notes by reaction of the received impulses upon a magnetic field. [At upper left] is a transmitter, diagrammatically represented, with an arrangement for varying the intensity of the waves emitted, and on the receiver side I have, as you see, a grounded antenna. [The] secondary [has a conductor under tension in] a very powerful magnetic field, and [the reaction of] this conductor, traversed by the received currents in the field, causes the conductor to emit audible notes.

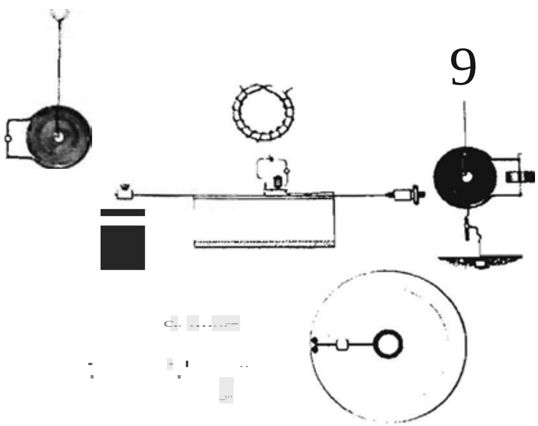


Fig. 16. Other Ways of receiving.

"I [have] several magnets of various forms, like this [Fig. 16, center], and employed a cord in the field, which, when the current traversed it, vibrated and established a contact. Or, I [use] a small coil ... through which the current was passed, and which by its vibrations prcxiuced the signal, an audible note, or anything else ... [I]n my writings ... I had already shown the reaction of the high frequency and low frequency currents on magnetic fields, and had specified the frequencies within which one has to keep in order to receive efficiently audible notes."

In addition to the electrical oscillator unit shown in Fig. 9, Section I, Tesla also exhibited two other units. The first is shown in Fig. 17 which was covered by a patent applied for nine months earlier.[49] A second is shown in Fig. 18 an advance look at a form of oscillator utilizing one of a series of eight hermetically-sealed, mercury circuit controllers for which patents were applied beginning the following two months. This unit was covered by a patent applied for eight months later.[50]

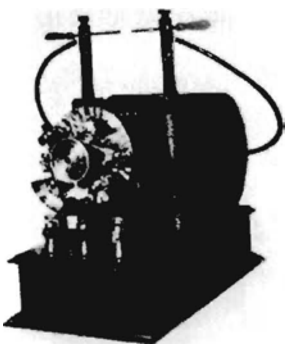


Fig. 17

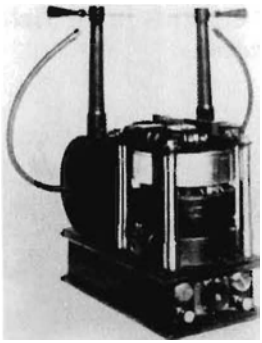


Fig. 18

These units were described by Tesla the following way years later as presented for the lecture.

[49] U.S. Patent No. 568,179 of Sept. 22, 1896, "Method and Apparatus for Producing Currents of High Frequency," application filed July 6, 1896.

[50] U.S. Patent No. 609,245 of Aug. 16, 1898, "Electrical-Circuit Controller," application filed Dec. 2, 1897

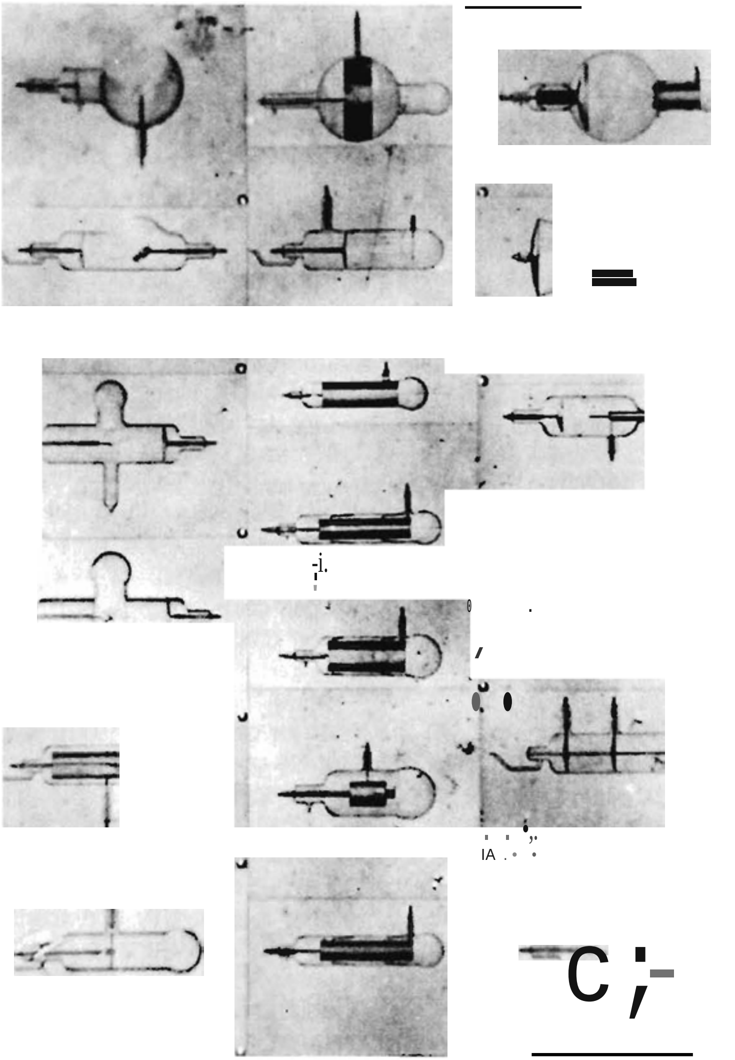
"[The unit in 17] a oscillator ... tended for production Roentgen rays, and scientific research in general. It comprises a box containing two condensers of the same capacity on which are supported the charging coil and transformer. automatic circuit controller, hand switch and connecting posts are mounted on the front plate of the inductance spool as is also one of the contact springs. The box is equipped with three terminals, the two external ones serving merely for connection while middle one carries a contact bar with a screw for regulating the interval during which the circuit is closed. The vibrating spring itself, the function of which is to cause periodic interruptions, can be adjusted in strength as well as distance from the core the center the charging coil by screws visible on the top plate so that any desired conditions of mechanical con- trol might be secured. The primary coil of the transformer is of copper sheet and taps are made at suitable points for the purpose of varying, at will, the number of turns. The induc- tance coil is wound two to adapt the instrument both to llO and volt circuiLco; and secondaries were provided to various wavelengths prima- ry. The output was approximately 500 watts with damped waves 50,000 cycles per second. short periods of time undamped oscillations were produced in screwing the vibrating spring tight against the iron core and separating the contacts by the adjustmg screw *which performed the function of a key*.

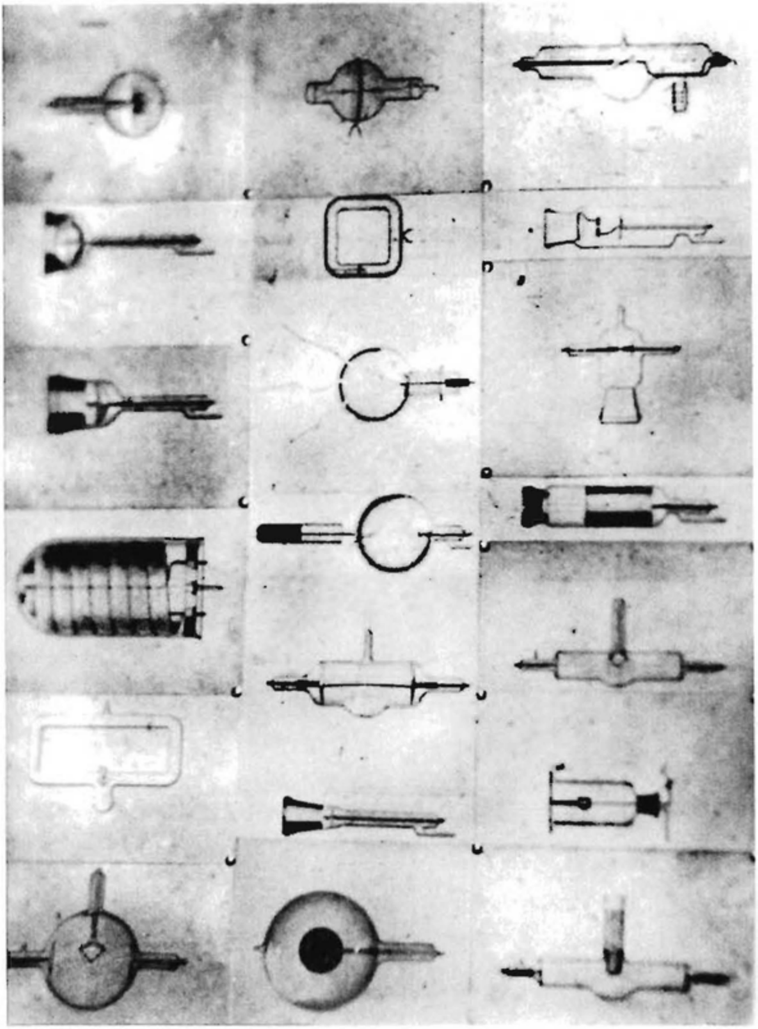
"[The unit in Fig. illustrates a transformer with a rotary break. are two condensers of the same capacity in the box which can connected in or multiple. The charging inductances are in the form of two long spools upon which are supported secondary A small direct-current motor, the speed of which can be with- wide limits, is employed to drive a specially constructed make and I n other the oscillator is like the one illustrated [at left] and operation will be readily understood from the This transformer was ' m my wireless experiments freuently for lighting laboratory by my vacuum "[1]

[51] Tesla, "Electrical " *Electrical Experimenter*, 1919 pp. 228-229

259-260, 276, 276.

"[I now show on the wall of this Academy drawings of] a great variety of bulbs I used. Every one that you see was built, not in one, but in several forms ... Among these bulbs I have a great number of receiving devices ...."





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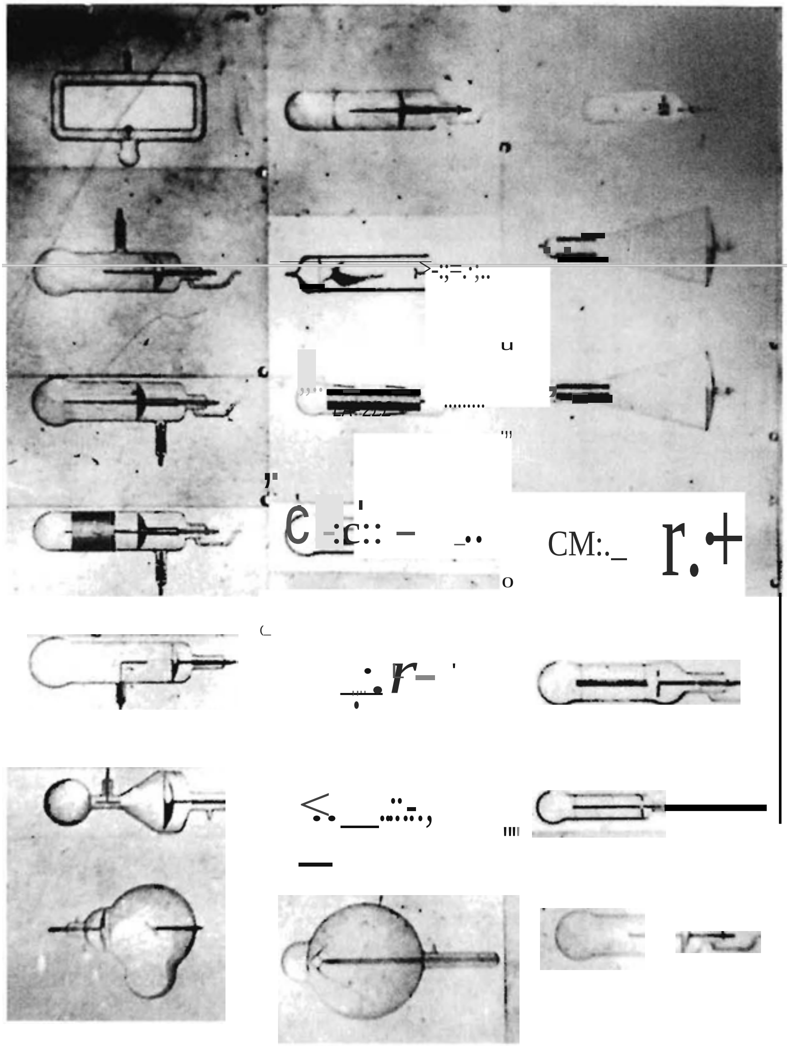

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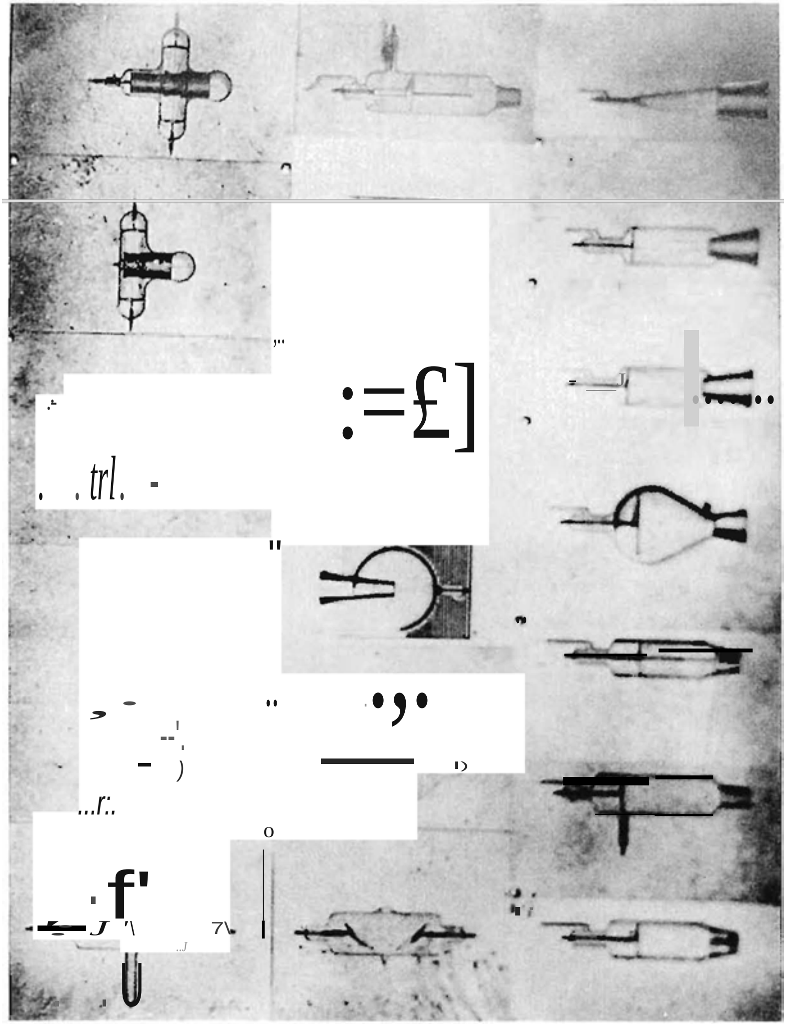
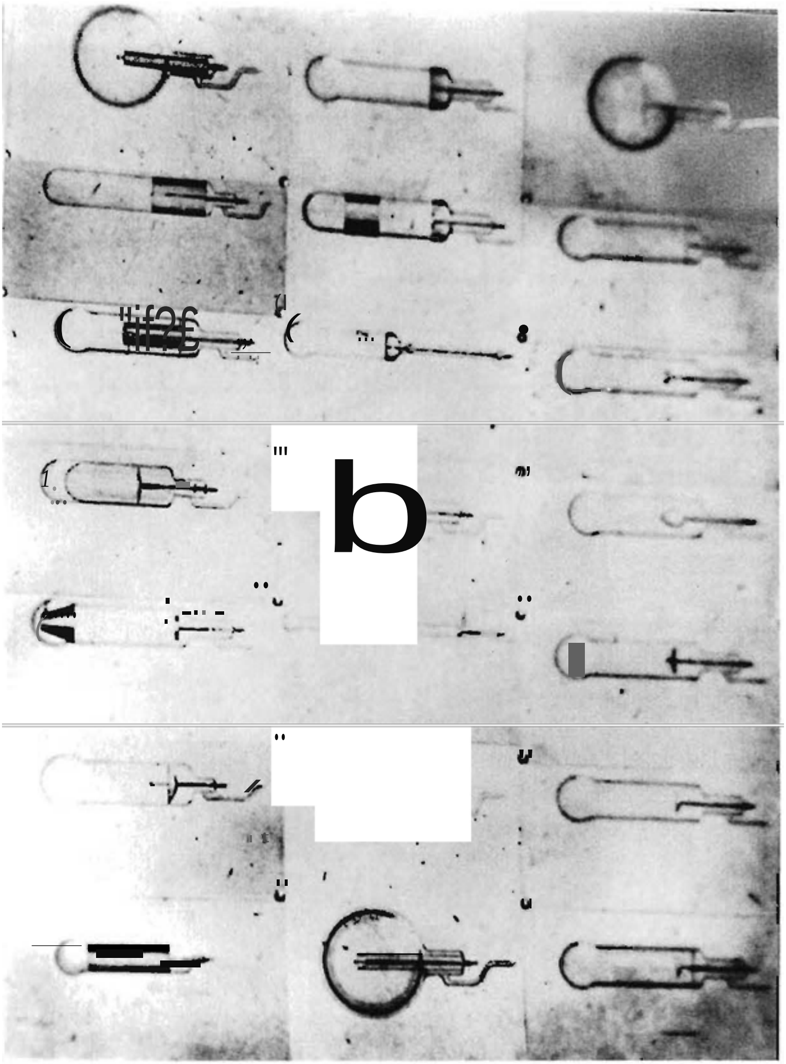
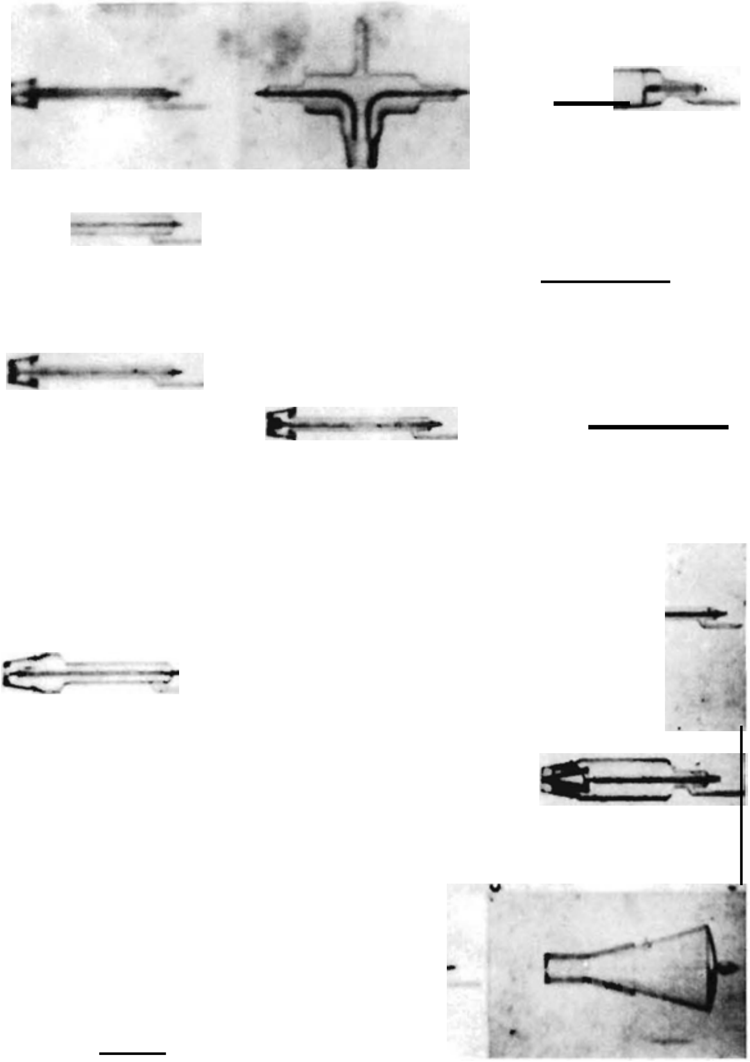




Group V



Group VI

Section II

THE HlJR1FUL ACTIONS OF LENARD AND [illegible] TUBES.

the Editor Electrical Review:

The extending use the Lenard Roentgen or bulbs as implements of physician, or as instruments of research in laboratories, makes it desir- particularly view possibility of certain hurtful actions on human to investigate the nature of influences, to ascertain the conditions under which they are to occur and --what is most important for practitioner- to render all injury impossible by the vance certain the employment unfailing remedies.

As I have in a previous communication to your esteemed joumal (see *Electrical Review* of December 2, 1896), no experimenter need be from using freely the Roentgen rays of a poisonous or deleterious action, and it is entirely wrong to give room to expressions of a such as tend to impede the and create a prejudice against an already highly and more promising discovery; but it cannot be denied that it is equally uncommendable to ignore dangers now when we know that, under certain circumstances, they actually exist. I consider it the more necessary to be aware these dangers, as I see coming into general use of novel apparatus, capable of developing rays of incomparable power. In scientific laboratories the instruments are usually in the hands of persons in their manipulation and capable of approximately estimating the magnitude effects, the omission of precautions in the present state of our knowledge, not so much to be apprehended; but the physicians, who are keenly appreciating the benefits derived from the proper application of the new principle, and numerous amateurs who are by the beauty of the novel manifestations, who are passionately bent upon experimentation in the ne\vly opened up fields, but many of whom are naturally not armed with the special knowledge of the electrician-all of these are much in need of reliable information from experts, and for these chiefly the following lines are written. However, in view of the still incomplete knowledge of these rays, I wish the statements which follow to be considered as devoid of authoritativeness, other than that which is based on the conscientiousness of my study and the faith in the precision of my senses and observations.

Ever since Professor Roentgen's discovery was made known I have carried on investigations in the direction indicated by him, and with perfected apparatus, producing rays of much greater intensity than it was possible to obtain with the usual appliances. Commonly, my bulbs were capable of showing the shadow of a hand on a phosphorescent screen at distances of 40 or 50 feet, or even more, and to the action of these bulbs myself and several of my assistants were exposed for hours at a time, and although the exposures took place every day, not the faintest hurtful action was noted -as long as certain precautions were taken. On the contrary, be it a coincidence, or an effect of the rays, or the result of some secondary cause present in the operation of the bulbs-as, for example, the generation of ozone-my own health, and that of two persons who were daily under the influence of the rays, more or less, has materially improved, and, whatever be the reason, it is a fact that a troublesome cough with which I was constantly afflicted has entirely disappeared, a similar improvement being observed on another person.

In getting the photographic impressions or studying the rays with a phosphorescent screen, I employed a plate of thin aluminum sheet or a gauze of aluminum wires, which was interposed between the bulb and the person, and connected to the ground directly or through a condenser. I adopted this precaution because it was known to me, a long time before, that a certain irritation of the skin is caused by very strong streamers, which, mostly at small distance, are formed on the body of a person through the electrostatic influence of a terminal of alternating high potential. I found that the occurrence of these streamers and their hurtful consequence was completely prevented by the employment of a conducting object, as a sheet of wire placed and connected as described. It was observed, however, that the injurious mentioned did not seem to minish gradually with distance from the terminal, but ceasea abruptly, and I could give no other explanation for the irritation of the skin which would be as plausible as that which I have expressed; namely, that the effect was due to ozone, which was abundantly produced. The latter peculiarity mentioned was also in agreement with this view, since the generation of ozone ceases abruptly at a definite distance from the terminal, making it evident that a certain intensity of action is absolutely required, as in a process of electrolytic decomposition.

In carrying further my investigations, I gradually modified the apparatus in several ways, and immediately I had opportunities to observe hurtful influences following exposures. Inquiring now what changes I had introduced, I found that I had made three departures from plan originally followed: the aluminum screen was not used; second, a bulb was employed which, instead of aluminum, contained platinum, either as electrode or impact plate; third, the distances at which the exposures took place were smaller than usual.

It did not to [illegible] that the interposed aluminum sheet was a very effective remedy against injury, for a hand could be [illegible] for a long time behind it without the skin which othetwise invariably and very quickly occurred. This fact impressed me with the conviction that, whatever the nature the hurtful influences, it was in a large measure dependent either on an elec-[illegible] action, or electrification, or secondary effects ing therefrom, such as are attendant to formation streamers. This view afforded an explanation why an observer could watch a bulb for any length of time, as long as he was holding the hand in front the body, as in examin- with a fluorescent screen, with perfect immunity to all parts his body, with the exception of the hand. It likewise explained why bums were produced some instances on the opfX>site side of the body, adjacent to the photographic plate, whereas portions on the directly exposed part of the body, which were much nearer to the bulb, and consequently subjected to by far stronger rays, remained unaffected. It also made it easy to understand why the patient experienced a prickling sensation on the exposed part of the body whenever an injurious action took place. Finally, this view agreed with the numerous observations that the hurtful actions occurred when air was present, clothing, however thick, affording no protection, while they practically ceased when a layer of a fluid, quite easily penetrated by the rays, but excluding all contact of the air with the skin, was used as a preventive.

Following, now, the second line of investigation, I compared bulbs containing aluminum only with those in which platinum was used besides, ordinarily as impact body, and soon there were enough evidences on hand to dispel all doubt as to the latter metal being by far the more injurious. In support of this statement, one of the experiences may be cited which, at the same time, may illustrate the necessity of taking proper precautions when operating bulbs of very high power. In order to carry out comparative tests, two tubes were constructed of an improved Lenard pattern, in size and most other respects alike. Both contained a concave cathode or reflector of nearly two inches in diameter, and both were provided with an aluminum cap or window. In one of the tubes the cathodic focus was made to coincide with the center of the cap, in the other the cathodic stream was concentrated upon a platinum wire supported on a glass stem axially with the tube a little in front of the window, and in each case the metal of the latter was thinned down in the central portion to such an extent as to be barely able to withstand the inward air pressure. In studying the action of the tubes, I exposed one hand to that containing aluminum only, and the other to the tube with the platinum wire. On turning on the former tube, I was surprised to observe that the aluminum window emitted a clear note, corresponding to the rhythmical impact of the cathodic stream. Placing the hand quite near the window, I felt distinctly that something wann was striking it. The sensation was unmistakable, and apart from the felt, differed much from that prickl...,_ feeling by streamers or minute sparks. Next I examined with the platinum wire. No sound was emitted by the aluminum window, all the energy of the impact being seemingly spent on the platinum wire, became incandescent, or else the matter composing the cathodic stream was so disintegrated that the thin metal sheet offered no material obstruction to passage. If big lumps are hurled against a wire with large meshes, there is considerable pressure exerted against the netting; if, on contrary-for illustration-the lumps are very small as compared with meshes, the might be not manifest. But, although the window did not vibrate felt, nevertheless, again, distinctly, something was impinging against the and the of warmth was stronger than in the previous case. action on the screen there was apparently no difference between the two tubes, both rendering it very bright, and definition of shadows was the same, as far as it was possible to judge. I had looked through screen at tube a few only when detracted it was not until about later, I observed that the hand exposed to it was much reddened and swollen. Thinking that it was to some accidental injury, I turned again to the examination of the platinum tube, thrusting the same hand close to the window, and now I felt instantly a sensation of pain, which became more when hand was placed near the window. peculiar was that appeared to be seated, not at but deep tissues of hand, or rather in Although aggregate exposure was certainly not more than half a minute, I had to suffer severe pain for a few afterward, some time I observed that all the hair was destroyed and that the nails on injured hand had anew.

The bulb containing no platinum was now experimented with, more care being taken, but soon its comparative harmlessness was manifest, for, while it reddened the skin, the injury was not nearly as severe as with the other tube. valuable experiences thus gained were: The of ::.vruv-āuiıı; hot striking the exposed member; the pain *stantly* the injury produced *immediately* after the sure, and the increased violence due, in all probability, to the presence of the platinum.

Some time afterward I observed other remarkable actions at very small distances from powerful Lenard tubes. For instance, the hand being held near the window only for a few seconds, the skin seems to """"""""""ne tight, or else the muscles are stiffened, for some resistance is experienced in closing the fist, but upon opening and closing it repeatedly the sensation disappears, apparently no iH effect remaining. I have, furthermore, observed a decided influence on the nasal discharge organs similar to the of a cold just contracted. But the most interesting observation in this respect is the following: When such a powerful bulb is "watched for some time, the head of the observer being brought very close, he soon after that experiences a sensation so peculiar that no one will fail to notice it when once his attention is called to it, it being almost as positive as touch. If one imagines himself looking at something like a cartridge, for instance, in close and dangerous proximity, and just about to explode, he will get a good idea of the sensation produced, only, in the case of the cartridge, one cannot render himself an account where the feeling exactly resides, for it seems to extend all over the body, this indicating that it comes from a general awareness of danger resulting previous and manifold experiences, and not the anticipation of an unpleasant impression directly upon one of the organs, as the eye or the ear; but, in case Lenard bulb, one can at once, with it is in the head. Now, this not of any value except, perhaps, in of and acuteness of the feeling, were it not that same sensation is produced when working for some with a noisy spark gap, or, in general, when exposing the ear to noises or explosions. Since it seems impossible to imagine how the could cause such a sensation in any other way except by directly impressing the organs of hearing, I conclude that a Roentgen or Lenard tube, working in perfect silence as it may, produces violent explosions or reports and concussions, which, though they are inaudible, take some material effect upon the bony structure of the head. Their inaudibility may be sufficiently explained by the well founded assum ption that not the but some finer medium, is concerned in their propagation.

But it was in following the third line of inquiry into nature of these hurtful namely, studying the influence of distance, that the most important fact was unearthed. To illustrate it popularly, I will say that Roentgen tube acts exactly like a source heat. one places the hand near to a red hot stove, he may instantly injured. he keeps hand at a certain small dis- he may be able to withstand the rays for a few minutes or and still be injured by prolonged exposure; but if recedes only a little farther, where the heat is slightly less, he withstand the heat in comfort and any length of time wi thoutany injury, the radiations at distance being too weak to seriously interfere with the life process of the This is absolutely the way a bul b acts. Beyond a certain distance, no hurtful effect whatever is pn:xiuced on the skin, no matter *how long* exposure. The of bums is also as might be expected from a source of high heat. I have maintained, in all deference to the opinions of others, that those who have likened the on the skin and tissues to sunburns have misinterpreted them. There is no similarity in this respect except insofar as the reddening and peeling of the is concerned, which may result from innumerable causes. The bums, when slight, rather those people often receive when working close to a strong fire. But when injury is severe, it is in all like received contact with fire or from a iron. There may be no period of incubation at as is evident from the foregoing remarks, the taking effect immediately, not to say instantly. In a severe case the skin deeply colored and blackened in places, and ugl y, ill-foreboding blisters form; thick layers come off, exposing the raw flesh, which, for a ti me, discharges freely. Burning pain, feverishness, and such sym ptoms are of course but natural accompaniments. One single injury of in the abdominal region, to a

and zealous assistant-the only accident that ever hap-
to any one but myself in all my laboratory experi-
ence-1 had the misfortuneto witness. It occurred before all these and other experiences were gained, following directly an exposure of five minutes at the fairly safe distance 11 inches to a very highly-charged tube, the protecting aluminum screen having unfortunately omi tted, it was such as to fill me with the gravest apprehensions. Fortunate!y, frequent warm baths, free application of Vaseline, cleani ng, and general bodily care soon repaired the ravages of the destructive agent, and I breathed again freely. Had I known more than I did of these injurious actions, such unfortunate exposure would not have been made; had I known less than I did, it might have been made at a smaller distance, and a serious, perhaps irremediable, injury might have resulted.

I am using the first opportunity to comply with the bitter duty of recording the accident. I hope that others will do li kewise, so that the most ""'"""1""r"' knowledge of these dangerous actions may soon be acquired. My apprehensions led me to consider, wi th keener interest than I would have felt otherwise, what the probabilities were in such a case of the internal tissues bei ng seriously injured. I came to the very comforting conclusion that, no matter what the rays are ultimately recognized to be, practically all their destructive energy must spend itself on the surface of the body, the internal tissues being, in all probability, safe, unless the bulb would placed in very close proximity to the or that rays of far greater intensi ty than now producible were generated. There are many reasons this should so, some of which will appear from my statements ring to the nature of the but I may able to cite new facts A significant feature of the case reported may be mentioned It was observed that on three places, which were covered by thick bone buttons, the skin was entirely unaffected, while it was entirely destroyed under each of the small holes in the bu ttons. Now, it was impossible for the rays, as investigation showed, to reach these points of the skin in straight lines drawn from the bulb, and this would seem to that not all injury was due to the or radiations under consideration, which unmistakably in straight lines, but that, at in part, concomitant causes were responsible. A experimental demonstration of fact be obtained in the following manner: The experimenter may a bu!b to a and small so as to illuminate the f1uorescent screen to a certain intensity at a distance of, say 7 inches. expose hand at that distance, and the skin will reddened after a certain duration of exposure. may now force bulb up to a higher power, until, at a of 14 the screen is illuminated even stronger than it was at half that dis- tance. rays are now evidently stronger at the distance, and yet he may expose hand a very long time, and it is to assert that he will not injured. course, it is possible to forth arguments which deprive above demonstration of So, it stated, that the actions on the screen or photographic plate do not give us an idea as to the density and other quantitative features of the rays, actions entirely a qualitative character. Suppose the are formed streams material particles as I it is thinkable that it might be of no partic- consequence, insofar as the impression on the screen or film is whether a trillion of particles per square millimeter the layer or only a million, for example; but with the actions on skin it is these must surely and materially depend on quantity of streams.

As soon as the before-mentioned was recognized, namely, beyond a distance even most powerful tubes are incapable of producing injurious action, no matter how long the exposure may last, it became important to ascertain safe distance. Going over all my previous experiences, I found very frequently, I have had which at a distance of for illustration, gave a strong impression the chest of a person with an of a few minutes, and times have subjected to from at a of from 18 to inches, time of exposure varying from 10 to 45 minutes, and never the faintest trace of an injurious action was served. With such I have even long exposures at di.'r''''''''''.of 14 always, of course, through a thin sheet or wire gauze of aluminum to the ground, and, case, observing the precaution that the metal would not give any spark when the person was touching it with the hand, as it might sometimes be the electrical vibration is of extremely high frequency, in which case a ground connection, through a condenser proper ....u•A<V•- ty, resorted to. In all these bul bs con- taining only aluminum were used, and I therefore still sufficient data to form an exact idea of what distance would have safe with a platinum tube. the case ously cited, we see that a grave injury at a distance of 11 but I that, had the protecting screen been would been very slight Taking my t her, I am convinced that no serious injury can result if e distance is greater than inches and the impression is taken in the manner I have scribed.

Having been success[ul in a number inquiry pertaining to this new of I am able at present to a broader of the actions of the bul bs, which, I hope, will soon assume a quite definite shape. the present, the following statement may sufficient. According to the evidences I am obtaining, the bulb, when in action, is emitting a stream of small material particles. There are some experiments which seem to that these start from outer wall of bulb; there are others which seem to prove that there is an penetration of the wall, in the case of a thin aluminum window, I have now not the least doubt that some of finely disin- tegrated cathodic matter is actually forced through. These streams may simply be projected to a great the ve- locity gradually diminishing the formation of any waves, or may give to concussions longitudi- nal waves. for the consideration, is entirely immaterial, assuming existence of such streams of particles, and disregarding such actions as might due to properties, chemical or physical, of the matter, we have to consider following specific actions:

First.. There is the thermal effect. The temtoeratu:re electrode or impact not in any way us an idea of the degree of particles, but, if we consider probable velocities they correspond to r"''''''''''''r≤L-tures which may be as as 100,000 degrees centigrade. It may be sufficient that particles are simply at a high temperature to pnx:l.uce an injurious action, and in many evidences point in direction. But against is the experimental fact that we cannot demonstrate a transference of heat, and no satisfactory explanation is found yet, although in carrying investigations in this direction, I have arrived at some results

Second, there is effect. We have absolute experimental that that particles or rays, to express myself generally, convey an immense amount of electricity, and I have even found a way of how to estimate and measure that amount. it is likewise possible that mere fact of these particles highly electrified is to cause the destruction of tissue. Certainly, on contact with the skin, the charges will be given off, and may rise to destructive local currents in minute paths of the results are in accord with this view, and, in pushing my inquiry in this direction, I have been still more successful than in the first. Yet, while as I have suggested before, view explains best the action on a sensitive layer, shows that, when the supposed particles traverse a grounded plate, they are not deprived entirely of their electrification, which is not factorily explained.

The *third* effect to be considered is electro-chemical. The charged particles give rise to an abundant generation ozone and other gases, and we know, by experiment, destroy even such a thing as rubber, and are, therefore, the most in the destruction the skin, and the dences are strongest in this direction, since a small layer of a fluid, preventing the contact of matter with the seems to stop all action.

The *last* to be considered is the purely mechanical. It is thinkable that material particles, moving with great speed, may, merely by a mechanical impact and unavoidable heating at such speeds, sufficient to deteriorate the tissues, such a case layers also be injured, whereas it is probable no such would occur if of the former explanations would be found to hold.

Summing up my experimental experiences and the con- ""'"""' derived from them, it would seem first, to abandon the use of bulbs containing platinum; second, to substitute for them a properly constructed Lenard tube, containing pure aluminum only, a tube of this kind having, the that it can constructed with great mechanical precision, and therefore is capable of producing much sharper impressions; third, to use a protecting screen of sheet, as suggested, or, instead of this, a wet cloth or of a fluid; fourth, to the exposures at distances at least, inches, and preferably expose longer at a distance.

New York, May 1,

Section III

THE SOURCE OF ROENTGEN RAYS AND THE PRACTICAL CONSIRUCTION AND SAFE OPERATION OF LENARD TUBES.

the Editor of Electrical Review

I have for some felt that a few indications in regard to the practical construction of Lenard tubes of improved de- a great number of which I have recently exhibited before the New York Academy of Sciences [April 6, 1897], would be useful and particularly as by their proper construction and use of the danger """"v"""""ıg the experimentation with avoided. The simple precautions which I in my previous communications to your are seemingly disregarded, and cases of are being almost daily reported, and m view were it for no other reason, the following lines, to subject, would have been written before had not and unavoidable duties prevented me from doing so. A short and, I may most unwelcome interruption of work which has been claim- my attention makes now possible. However, as opportunities are scarce, I will utilize the present to dwell in a few words on some other matters in connection with this subject, and particularly on a result of importance which I have reached some by the aid such a Lenard tube, and which, if I am correctly informed, I can only in part consider as my own, since it seems that practically it has been expressed in other words by Professor Roentgen in a recent communication to the Academy of Sciences of Berlin. The result to has reference to the much disputed question of the source of the Roentgen rays. As will be remembered, in the announcement of his discovery, Roentgen was of that the rays which affected the sensitive layer from the fluorescent spot on the glass wall of the bulb men next made the cathc""""" responsible still anode, while some thought that the rays were solely from fluorescent powders or and speculations, mostly unfounded, increased to an extent that, despairingly, one would exclaim with the poet:

"O gliicklich, wer noch hoffen kann,
Aus diesem Meer des Irrtums aufzutanchen!"l*I

My own experiments led me to that, regardless the location, the chief source of rays was the place of the *first* impact of the projected stream of particles within bulb. was merely a broad statement, which of was a case, as in his first experiments the fluorescent spot on the wall was, dentally, the place of the first impact cathodic stream. Investigations carried on up to the present day have only confirmed correctness of the above opinion, and the of the first collision of the stream of be it an anode or independent impact body, the glass wall or an minum window is still found to be the principal source of the rays. But as will be seen presently, it is not the only source.

Since recording the above fact my efforts were directed to finding answers to the fallowing questions: First, is it necessary that the impact body should be within the tube? Second, is it required that the obstacle in path of cathodic stream should be a solid or liquid? And, third, to what extent is velocity of the stream necessary the generation of and influence upon the character of the rays emitted?

In order to whether a body located of the and in path or the of the stream of particles was capable of producing same peculiar phenomena as an object located inside, it appeared necessary to show there is an actual penetration of particles through wall, or otherwise the actions of the posed streams, of whatever nature they be, were ficiently pronounced in the outer region to the wall of the bulb as to some the effects which are peculiar

* Oh, he who still hopes to
Out sea of errors and false views! *Faust,* 1064-5

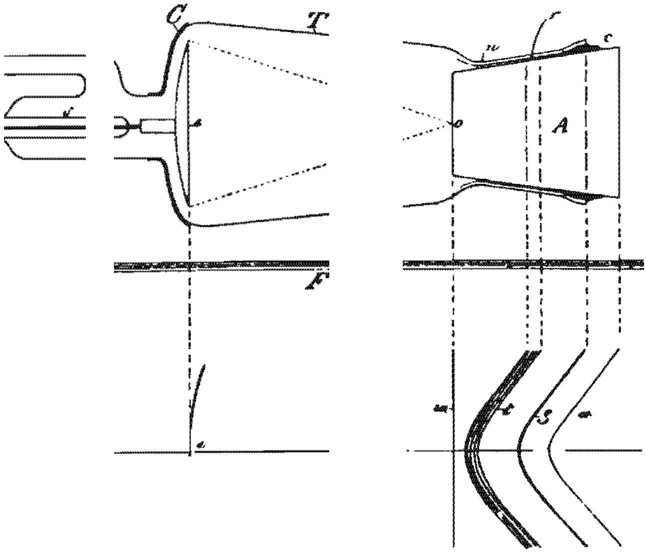


Fig. 1. an experiment revealing the real source of the Roentgen rays.

to a cathodic stream. It was not difficult to obtain with a properly prepared Lenard tube, having an exceedingly thin window, many and at first surprising ev 10enas of this character. Some of these have already been pointed out, and it is thought sufficient to cite here one more which I have since observed. In the hollow aluminum cap *A* of a tube as shown in diagram Fig. 1, which will be described in detail, I placed a half-dollar silver piece, supporting it at a small distance from and parallel to the window or bottom of the cap by strips of mica in such a manner that it was not touching the metal of the tube, an air space being left all around it. Upon exciting the bulb for about 30 to 45 seconds by the secondary discharge of a powerful coil of a novel type now well known, it was found that the silver piece was rendered so hot as to actually scorch the hand; yet the aluminum window, which offered a very insignificant obstacle to the cathodic stream, was only moderately warmed. Thus it was shown that the silver alloy, owing to its density and thickness, took up most of the energy of the impact, being acted upon by the particles almost identically as if it had been inside of the bulb, and what is more, indications were obtained, by observing the shadow, that it behaved like a second source of the rays, inasmuch as the outlines of the shadows, instead of being sharp and clear as when the half-dollar peace was removed, were dimmed. It was immaterial for the chief object of the inquiry to decide, by more exact methods whether the cathodic particles actually penetrated the window, or whether a new and separate stream was projected from the outer side of the window. In my mind there exists not the least doubt that the farmer was the case, as in this respect I ha\·e to obtain numerous additional proofs, upon which I near future.

I next endeavored to ascertain whether it was necessary that the obstacle outside was, as in this case, a solid body, or a liquid, or broadly, a body of measurable dimensions, and it was in investigating in this direction that I came upon the important result to which I referred in the introductory statements of this communication. I namely observed rather accidentally, although I was following up a systematic inquiry, what is illustrated in diagram Fig. 1. The diagram shows a Lenard tube of improved design, consisting of a tube T of thick glass tapering towards the open end, or neck n, into which an aluminum cap A, and a spherical cathode e, supported on a glass stem s, and platinum wire w sealed in the opposite end of the tube as usual. The aluminum cap A, as will be observed, is not in actual contact with the ground glass wall, being held at a small distance from the latter by a narrow and continuous ring of tinfoil r. The outer space between the glass and the cap A is filled with cement c, in a manner which I shall later describe. F is a Roentgen screen such as is ordinarily used in making the observations.

Now, in looking upon the screen in the direction from F to T, the dark lines indicated on the lower part of the diagram were seen on the illuminated background. The curved line *e* and the straight line *W* were, of course, at once recognized as the outlines of the cathode *e* and the bottom of the cap *A* respectively, although, in consequence of a confusing optical illusion, they appeared much closer together than they actually were. For instance, if the distance between *e* and *o* was 5 inches, these lines would appear on the screen aoout 2 inches apart, as nearly as I could judge by the eye. This illusion may be easily explained and is quite unimportant, except that it might be of some moment to physicians to keep this fact in mind when making examinations with the screen as, owing to the aoove effect, which is sometimes exaggerated to a degree hard to believe, a completely erroneous idea of the distance of the various parts of the object under examination might be gained, to the detriment of the surgical operation. But while the lines *e* and *W* were easily accounted for, the curved lines *t, g, a* were at first puzzling. Soon, however, it was ascertained that the faint line *a* was the shadow of the edge of the aluminum cap, the much darker line *g* that of the rim of the glass tube *T*, and *t* the shadow of the tinfoil ring *r*. These shadows on the screen *F* clearly showed that the agency which affected the fluorescent material was proceeding from the space outside of the bulb towards the aluminum cap, and chiefly from the region through which the primary disturbances or streams emitted from the tube through the window were passing, which observation could not be explained in a more plausible manner than by assuming that the air and dust particles outside, in the path of the projected streams, afforded an obstacle to their passage and gave rise to impacts and collisions spreading through the air in all directions, thus producing continuously new sources of the rays. It is this fact which, in his recent communication before mentioned, Roentgen has brought out. So, at least, I have interpreted his reported statement that the rays emanate from the irradiated air. It now remains to be shown whether the air, from which carefully all foreign particles are removed, is capable of behaving as an impact body and source of the rays, in order to decide whether the generation of the latter is dependent on the presence in the air of impact particles of measurable dimensions. I have reasons to think so.

With knowledge of fact we are now able to form a more general idea of the process of generation of the radia- tions which have been discovered by Lenard and Roentgen. It may comprised in statement that streams of min- ute material particles projected from an electrode with great velocity in encountering obstacles wherever they may within the bu!b, in the air or medium or in the sensitive layers themselves, give to rays or radiations possessing many of properties of those known as light. If this phys- process of of rays is undoubtedly demonstrated as true, it will have most important conse- quences, as it will induce physicists to again critically exam- ine many phenomena which are presently attributed to trans- verse ether waves, which may lead to a radical modification of existing views and theories in regard to phenomena, if not as to their essence so, at least, as to mode of their production.

My effort to arrive at an answer to the third of the above questions me to the establishment, by actual pho- tographs, the close relationship which exists between the Lenard and Roentgen rays. photographs bearing on this point were exhibited at a of the New York Academy of Sciences- referred to-April 6, 1897, but unfor- tunately, owing to the shortness of my address, and concen- tration of thought on other I omitted what was most important namely, to describe the manner in which these photographs were obtained, an oversight which I was able to only partially the day following. I did, however, on that occasion illustrate and describe experiments in which was shown the deflectibility of the Roentgen rays by a mag- net, which establishes a still relationship, if not identi- ty, of the named after two But description these experiments in detail, as well as of other investigations and results in harmony with and restricted to the subject I brought before that scientific body, will appear in a communication which I am slowly preparing.r* J

* The communication" referred to is undoubtedly the lec- ture, "High Frequency Oscillation for Electro-Therapeutics and Other Purposes," presented before The American Electro-Therapeutics

Association, Sept. 14, 1898.

To out clearly of the photographs in question, I would recall in some of my previous contributions to scientific I have endeavored to dispel a popular opinion before that the phenomena known as those of Crookes were dependent on and indicative of high vacua. With this in view, Ishowed that phosphorescence and most of phenomena in Crookes bulbs were at of the gases in the use of higher or more sudden electromotive impulses. Having this well demonstrated fact before me, I prepared a tube in the manner described by Lenard in his first communication on this subject. The tube was exhausted to a moderate either by chance or of necessity, it was found that, operated by an ordinary high-tension coil of a rate change the current, no rays of of the two be detected, even when the was so highly as to become very hot in a few moments. Now, I if the suddenness of the impulses through the were sufficiently increased, rays would be emitted. To test this I employed a coil a type which I repeatedly described, in which the primary is operated the discharges a condenser. With such an instrument desired suddenness the impulses secured, in this respect, as the energy the is the most violent-explosive we know, and any potential or electrical pressure 1s Indeed, I found that in increasing the suddenness of the electromotive through the tube-without, however, increasing, but rather diminishing the total energy conveyed to it-phosphorescence was ob- served and to appear, feebler Lenard rays and by pushing the far enough, Roentgen intensity, which me to obtain photographs the finest texture the bones. Still, the same tube, when again operated with the ordinary coil of a lmv rate of in the primary current, emitted practi- cally no rays, even when, as before much more ener-

, as judged the heating, was through it. experience, together with the fact succeeded in producing by use pressures,

obtainable wi th apparatus this express
pu rpose, some i n free led me to the

conclusion that in lightning discharges and Roentgen rays must be generated at ordinary atmospheric pressure.

At this juncture I realize, by a perusal of the preceding lines, that my scientific interest has dominated the practical, and that the following remarks must be devoted to the primary of this communication-that to giving some data for construction to those engaged in the manufacture of the tubes and, a few useful to practicing physicians who are on such information. The foregoing was, not lost object, much as it shown much the result obtained depends on the construction the instruments, for with ordinary most of the above observations could not have been made.

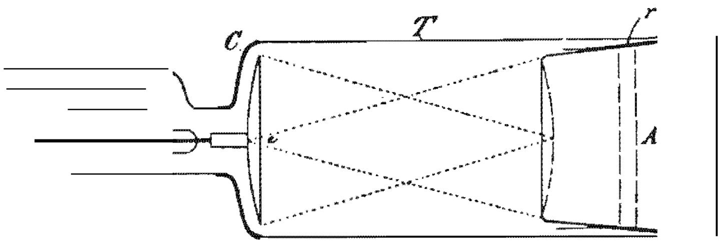


Fig. 2.—Improved Lenard tube.

I have described form of tube illustrated in Fig. 1, and in 2 another still further improved design is shown. case the cap having a straight as before, is shaped spherically, the center of the coinciding with that of the electrode *e*, which itself, as in Fig. 1, has its focus in the center of the window of cap *A*, as indicated by dotted lines. aluminum cap *A* has a tinfoil ring *r*, as in Fig. 1, or the metal of the cap is out on that so as to afford a bearing of small between and the glass. This is an important detail as, making the bearing surface small, the per unit area is increased and a more perfect joint The ring *r* should be first spun out and then ground to fit the neck of the bulb. If a tinfoil ring is

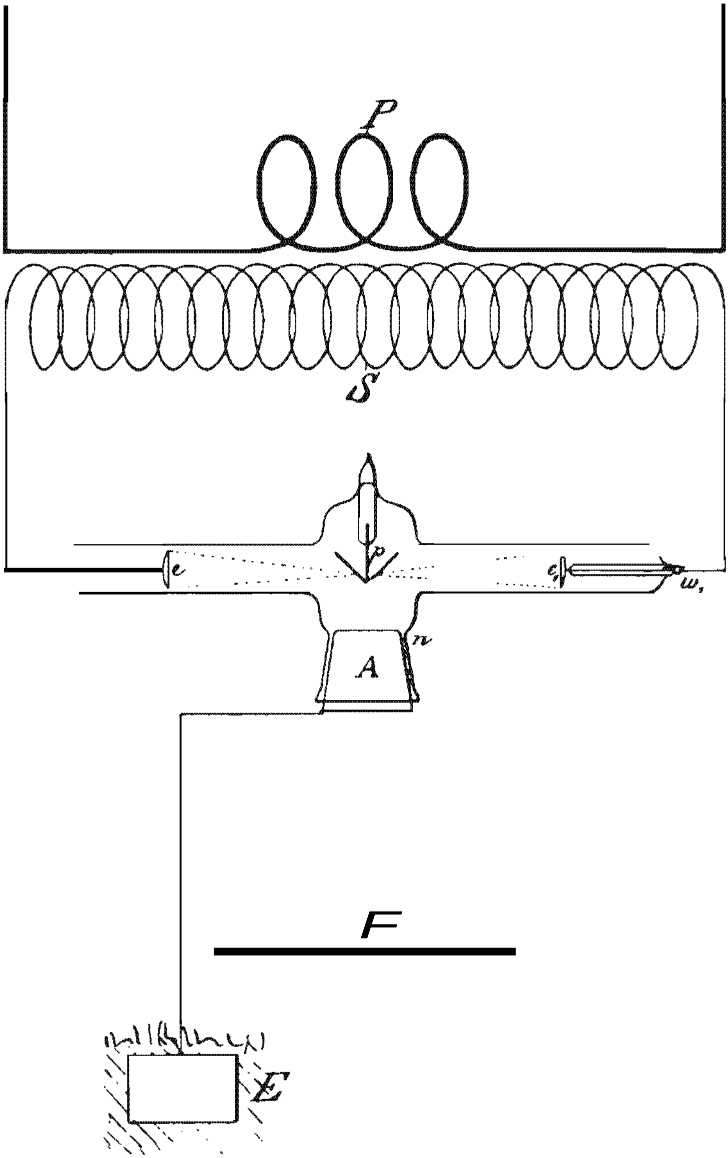


Fig. 3.-Illustrating arrangement with improved double-focus tube for reducing injurious actions.

used instead, it may be cut out of one the ordinary tinfoil caps obtainable in the market, care being taken that the ring is very smooth.

In 3 I have shown a modified design of tube which, as two types before was comprised in the lection I exhibited.as will observed, is a double-focus tube, with impact plates of iridium alloy an aluminum *A* opposite the same. The tube is not shown cause of any originality in design, but simply to illustrate a practical It will noted that the aluminum caps in the tubes described are fitted inside of the necks and not out- side, as is frequently Long as demonstrat- ed that it is practically impossible to maintain a high vacuum in a tube with an outside cap. The only way I have been able to do this in a fair measure is cooling the cap by a jet of for instance, and observing following precautions: The air jet is first turned on slightly and upon this the tube is excited. The current through the and also the air pres- sure, are then gradually increased and brought to the normal working condition. Upon completing the experiment pressure and current through the tube are both gradually re- duced and both so manipulated no differences in temperature result between the glass aluminum If these """"""""11h are not observed vacuum will mediately impaired in consequence of uneven expansion of the glass and metal.

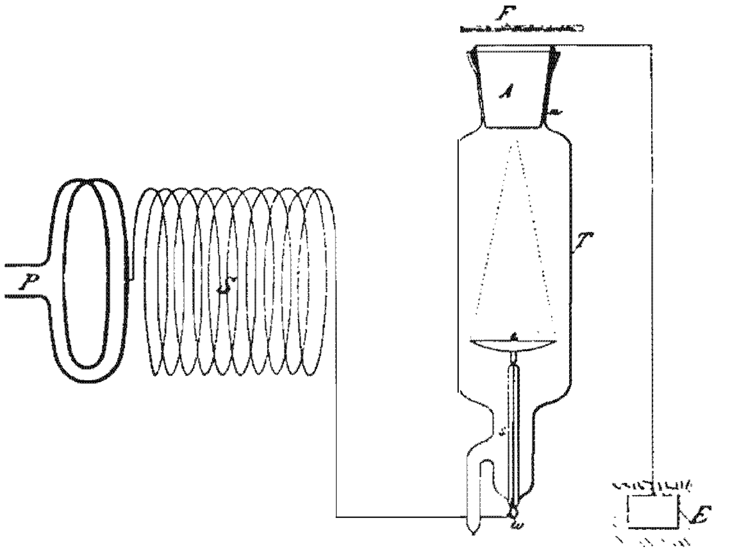
With as these presently described, it is quite unne<essar·v to observe this precaution if proper care is taken in their preparation. In inserting the cap the is cooled down as low as it is deemed advisable without endangering glass, and it is then gently pushed in neck of the tube, care that it sets straight.

The two most important operations in the manufacture of such a tube are, however, the thinning down aluminum window and the in of the cap. The metal of the latter may be one thirty-second or even of an inch thick, and in such case the central portion may thinned down by a countersink tool about one-fourth of an in diameter as far as it is possible without tearing the sheet. The further thinning down may then be done by hand with a and, finally, the metal should be gently beaten down so as to surely close the pores which might permit a Instead of proceeding in this way I have employed a with a hole in the center, which I have closed with a of pure aluminum a few thousandths of an inch thick, riveted to the cap by means of a washer of thick metal, but the results were not quite as satisfactory.

In sealing the cap I have adopted the following procedure: The tube is fa'''1.....11 on the pump in the proper position and exl''''' until a permanent condition is reached. The ae:!?re:e is a measure of perfection of the joint. considerable, but is not so serious a defect as might thought. Heat is now gradually applied to the by means of a gas stove until a temperature up to about boiling point of sealing wax is reached. The space the cap and the glass is then filled with sealing wax of quality; and, when the latter to boil, the is reduced to allow the cavity. The again increased, and this of heating and is repeated several times until the entire cavity, upon of the temperature; found to be filled uniformly wax, all bubbles having disappeared. A little more wax is then put on top the exhaustion on an hour or so, according to capacity of the pump, application of moderate heat much below the melting point of the wax.

A tube prepared in this manner will maintain the vacuum very well, and will indefinitely. If not used for a few months, it may gradually the high vacuum, but it can be quickly worked up. if after long use it '''''''''es necessary to clean this is easily done by gently warming it and cleaning may be done first with acid, then with alkali, next with distilled water, rectified alcohol.

These tubes, when properly prepared, give impressions much sharper and reveal much more detail than those of ordinary make. It is important for the clearness of the impres- that the electrode should properly shaped, and that focus should the cap or slight-ly inside. In fitting the cap, the from the electrode should •...,a.:,un.A• as exactly as possible. It should also be remarked that thinner the window, the sharper are the impressions, but it is not advisable to it too thin, as it is to melt at a point on turning on current.



4.-Hlustrating arrangement with a Lenard tube for safe working at dose range.

The above advantages are not the only ones which tubes offer They are adapted of ex-amination by surgeons, if the peculiar manner illustrated in and which are self-explanatory. It will seen that in each the cap is to the ground. This decidedly diminishes the injurious action and enables also to take impressions with very exposures a seconds only at range, inasmuch as, during the of the bulb, one can ly touch the cap without owing to the ground connection. shown 4 is par-ticularly advantageous with a form of single terminal, which coil I described on other occasions and which is diagrammatically ill ustrated, P the primary and S the secondary. I n this high-potential terminal is connected to the electrode, the cap is grounded. The tube may be placed the indicated in the drawi ng, under the operati ng or even in contact wi th the body of the impression requi res only a few seconds as, for i n examining parts of the mem bers. Ihave impressions wi th such tubes and have '"'"'''n1..... no i njurious action, but I would advise not to expose for longer than 2 or 3 minutes at very short distances. In this respect the experimenter should bear in mind what I have stated in previous communications. At all events it is certain that, in proceeding in the manner scribed, additional safety is obtained and the process of taking impressions much quickened. To cool the cap, a jet air may used, as before stated"'• or else a small quanti ty of water be poured in the cap time when an impression is The water only slightly impairs the action of the tube, while it maintains the window at a safe temperature. I may add that the tubes are improved by providing back of the electrode a metallic coating C, shown in Fig. 3 and 4J*l

New York, August 9, 1897.

* These figure references are incorrect in the original text of this vvu'u'"".au1Ju they should be to Fig. 1 and Fig. 2.

Appendix

Contemporary Reviews of Lecture by Nikola Before the York Academy of Sciences April 6, 1897

Electrical Engineer, 14, 1897

"Mr. on Roentgen Rays" (Editorial) and "Mr. Tesla the New York Academy Sciences" (Review) pp. 400-401.

Electrical Review (N.Y.), April 14, 1897

"The New Academy of An Interesting Electrical Exhibition-Address by Nikola Tesla announcing recent achievements" (Editorial) p. 175.

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(E11tered al ucot11k/tU1 rn<1U at the New Yol'k Post Office, .April 9, 1888.]

VOL. XXIII. NEW YORK, APUIL 14, 1897. No. 467.

Jn! . TESLA ON R.OENTGEN R.AYS.

LAST wee!;: l\r r. TP:>la ;;a ve some of the l'('Rlllts of h is experiments iu the lloma iu of Itii11tgen ra ys, hefore th e New Yori;: Ae:ulem y or Sden<:cs, n n<i SilOWCll some or his latest tyt)es of hl h f requency genern tors.)I r. Tesla st ill ntlhe1·es to h is 01·lgi11n l view that the n u ntgcn eff ects are <lne to the a<:tion or mo\een\cs lH'Ojectetl from the tu he at high veloci ties, lm t we m ust confess our inabili ty to reconcile th is view wit h the results of h is experiments in tlet1eding tllC Rontgen ru ys by menns of n rungru t, u nless we assu me the molecules chnrgctl and n t the sa me ti me. en!lowell wit h a vorticnl motion, n poi nt w h ich lHr. Tesla did not elal>ornte on. It is so rarely t hut Mr. Teslu. appears on the Iectme plntf orm that it is to be regrett d th nt the conditions smromHling ll is lnst nppearnnce were not more favorable. It was hnrtlly fair to Mr. Tesln, or to the nudience which had as8embled solely to greet him, to delny his appearance untll two other estimable hnd tnkeu up the time of the nu't11ence for nenl'ly of an hour. . The result was that it was close on to 10 o'clock hel'o1·e l\fr. 'l'esln began, n n!l he was forced to concl ude his address in lts Initial stages. It ls to be hoped, for the benefit of the science at large thnt Mr. Tesla will find time to write out his arl1Jress In t'nll for the Trnmm.ctlom1 of the Academ y. Brief as his u tterances were, they were e:s:tremely I nteresting and they e'\"lrlencerl a mellow-i ng nnrl a mnstery imllcntlve ot' higher perf ection tlrn n ever of bis powers ns n n Investigator· nnd elucldator of ohscure nat-u rnl phenomena.

MR.. TESLA BEFORE THE NEW YORK ACArmnv OF SCIF!NCES.

ON April 0, Mr. Nikola Tesla clcllvererl before t he New Yorlc Academ y Of 8cle11ces n n n clllrcss "On t he h'cn ms or Lennrcl nnd R1int i.;e11, wit h Novel A ppn rntus for 'rhel r Pro1h1c-l lo11." 'rlw Jpc·l11r1•r hPg-a11 hy Kta ll11g- l hn l I n 18!11, I n 1:x1wrl-me11ll11i.; to 1lt>it•rm l11e 1he 1wll11le 11<:t lon of phosphort>s1· 1•11t light emn nn t l11g f rom vncmuu t uhcs, he Juul fom11l ll m t tlw nctl nlc power of Crnokrs t uhes vn r lcd grcntly, n ud ln t he most n11omn lo11s mn mw1'. 'l'h ns I'ilhcs c111I'1tlng tl :;;Iron)! ligh t hn11 very Hii ie n0l lon on plwl og-ra phi<: 11ln11•s, wh ll1 :-:miw :-:lln w-lng n f1ehle ligh t wl r•1l V<'l'Y st rongly 011 Rllch pl:t t1•s. A Jn re 1111mher of t hese plnfos, 111n1le hy 'rotmele for t ho Omit m·y l\lnga:1.hw, w1 r1 slor1•1l I 11 l\lr. 'l'Nda's la hora t ory wl w11 lt w11::1 dc::;troym1 hy llre, tuul .llms l w wns n nn hle 11n w lo ex11ml11e them ro1· t he lWntgim effe<:ts. He helleve1l t hn t he hml just missed the 1Hscovery which mntle H.iintgen famous a nd t hough he was thoroughly f nm lllnr with Lmuud's WOl'k, he did not see far enough.

Mr. 'l'esla t hen rev lcwe1l his work In the direction of ohtnl n-n reliable nppamtus for gcuerntlug h igh frequency cur-wh ich he rccogn!F;rnl ns the keynote to t he prodnctlon or YllClllllll lnhc lighting. He tohl l1ow he hnd met with <l!Ui-ld llcfl a t 1ve1·.v poi nt ; bo w n f<m n ll bubble of nlr would de· Rlrny t he vnl nc or t he <:oil, or how oue-q u:n·l.cr· or :rn I nch or wi re too m uch u t· too lit tle woulll Ut row :t coll out or bnlnnce; Iww 011c lln y a coil wimhl ru n coltl nrnl 011 :mol bc1· <lny hot, etc, By li unlly c1111!11g lo his n hl the comlenscr, l'IIr. Tesl:t staled, he Juul sn«ccede<l ln olJla i u lng the desired nctlon nml no w noth ing si ornl I n t he wn y o(mill lons 0f vlhrn-tluns from 01·11i1mry t•l l'cllils. The k•du l'cr then briefl y ex· pin l11e1l Ihe ptl11clple of the comlN1ser tllscl111 rgc ns n11pllctl to h igh £rnc1 ncncy e111·1·("11l1-1. n nd 1wi11lcd to nt rlous types of np-pn rntus 011 the foctu re trthle <lesli;nctl to n tlllze Um in·luclplc.

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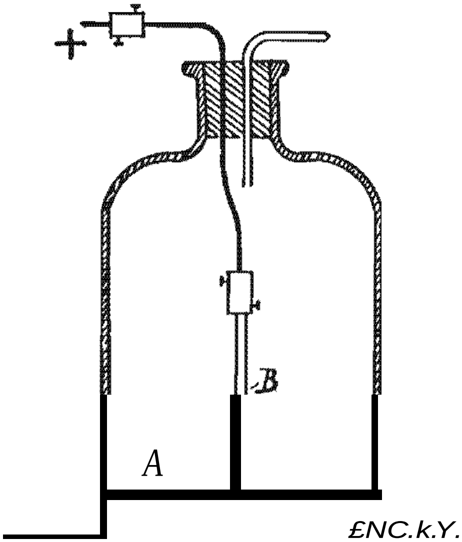

TESLA'S ARC X-RAY GENERATOR.

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l\lr. Tmdn showed n vncu u m tulle lit from the termlnnls of anotlier high freque machine. Ile nli::o sllowed n coll consisting of a single turn of heavy wire which f ormed the core, as it were, of a small coil of a few turmi wound on n paper cylinder surrounding the wlrc. 'Vhen con nected to a high frequency generator, this nppnmtus gnve n 4-lncll spark with an expenditure of e e11mtl to tlmt taken by one ln m p. l\l r. st nted that high freq uency genern- tors wer<' so conslructecl that lhey could be con nected to nny existing circuit:. di rect or alternating.

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THE NEW YOK ACAOEMV OF SCIENCE.

A N 1 1'TE R V.STI Nll F.!.t:<"TRlf ',\ I, R X ll 1· ll l l'I O N — A l•l•R EH:< ll Y N I KO L.\ TEHL,\ , A N N Oll NCl 1'0 R tta:H A Cll l E \' t:ll Y. NTH.

The New York •.Ac11demy or Sciencee ga\'e its fou rth 0.1111 ual recep- tion a11d exhi bit o[recent progreRs i n science in t he A meri ..an lll nscn m or Nntu ral History, New York , A pril !i and 1;.

In tho cli Yision devoted to chem is- try, in chnrge of Ch11rloR A. Dorcm n . were exh i bited a n u m ber of electric fo mnces, and i n the electrical d i vision, i11 charge or 0. F. Sovcr. wore to bo &eo11 1ummher or h ilnric11l collections of inc1mdORCOllt 11.llU RrC)am pR, inetrn meu te of precision, Crookes tu he , i nduction coils, etc. !\Ir. W. IL Me111dowcro" u· h ibi t1•1l a ThomRon 14 i nch Rpnrk i nd uctori u m, and tu bt•R 1111<1 llnoro- soopeR, am! llr. 1\1. I. l'11pi n hRd on view an i nd uction coil and ci r- onit breaker for the p;eneration or Roen tp;on rays. Dr. l\fu ot.cr bcrg rxh ibi d eome epecfviens or Germ1111 tubes, and Dr. Dorem us ehowed one of the origim1.I Hen ry ind uction coile.

Tuesday evoni ng a IRrge audience 111111mbled to liRten to an add ress by Nilola Tesla OD "The Streams or Lenard flQd Hoeotgen and Novel Apparatus for their Prod uc. tion". The lectu rer had on ex- h ibi tion a nu m ber. or h ie per- rected 'olrctric111 ORCilJ11tors, d!'· signed pnrtic11larly to bCl ned .ill pl1&ce or the induction coilR or old type. Ile exhibit<><! 1111mer- 011s diagrams illnsl rati ng results obtained by h i m in hie ex peri- ments, to ascertai n the natu re or t he Hoen tgen mys. There were over 100 d ifferent work i ng d rnw- i ngR or bulbs, 111howi ng the cx- tent or the grou nd covered by the leetn rer i n th is field. There were, hesiiles,a n u m ber of remarkable photo- graph111 exh i bited, wh ich were. tukeo by means of one or the small oscilla- tors exh i bited. These i natrn mentR

and photograpb11 we re e:ii:am ined with the keenest i nterest af ter the lectu re a hare n11 m ber who remai ned 1md i niRted on a Ru pplemen tuy leotu re, w hich Mr. 'l'eela ki nd ly consen ted to give, notwit het11nding that, a he playfully remarked , be h&d not yot had hie din ner.

Mr. Tesla introd uced the subject or hill lectu re by stating that at the olol!e of 1894 he iovestigaled the aoti11io power or phosphorescent bodies, and d u ring t hese e:1pori mente, which were carried ob by the aaeiatanoe of Tonnel6 ⨙ CompRny, photographers or this working for the *Cent!Ar!J Magat infl,* a great n u mber of plate& showed cu rious mark11 and defect@, whioh were noted both by the apeaker and t he photographera, but not recognized a being due to the Roentiten rays. J uat as be w11s beginning to look in to the nature of the phenomena hie laborato.,. w1111 burned, and befort> his work was &boroughly rH11med in his oew laborRtory Roentgen's diecovery wa11 811DOllDCOO.

Mr. Tesla fir11t descri bed !.1111in1<lrn· mente exhibited. d welling on *liw* princi ples underlying them. 11.ml ht> illuetratrd, i n a few !'triki ng o p•·ri. me11t11, the pra•:tical 11.11<1 ecooomi!"nl featn res of thQ machine. :,!'he greatest inl<'reRt Ree med to be evinol'd hy the aurlicnce w h1•11 ho liRhlfldbrilli1u1Uy a rncn n m t n bo with one or h is mnch ine, gi ri nJ!:, &R he P11i1l, ROU.000 vihHtion a sucoml. W h11t rendn<'•I lheru p11rtic11larly Vl\l1111blt>, bl' Mlllll'<I. WUR thnt tb11y work<'tl l'qnnl ly well 011 11tcrnAl· i n p: or <lirect-cu rrrn t cirn1if P, a ml tri1rrnform lhe1<(' cn rrt>lll w it h hil!h economv i11to hij.!h frt>•1'1ency d1·c· tri1il tcihr11tio11P.

lllr. Teltu\11nm111c<'<l hro im11ort:m1 <l icoveriee n•l11ti11J? t o the lfoe11tie«'11 rnye. Firet, he llid he l uul d ieco,·en•l A DOW Rnii pOW{'TrllJ ·RO!ITCe or I h!' rny11 in 1m eledrif! u rc. fonm•l u ml N J'l'Cll l i11r coud itionR. · Tho •l'<'.Hllll d i•covery w11 the ddlr:lim1 of llw Hoent1ten rny11 hy meanR of 11 m n,:tnet. This dicm·cry iR p11rlicu lnrh i m pornmt i11 eet11.l1li,h i11g t he i1l t11l ilJ of t hn l!rn· 11l.gP11 r111·e, u ml 1lH>Hc 1liiwov!'re1l liy l,1m11r1l i n 18!!1, nn•I iH. ll11•mfor11, Oii<' of tl11• mo t ,·nlnnhlc "'"'· t ribn tiOllS lo OU f k tl!l'll'lt•fl j.!C o£ l h reP rays.

TeRlll d W!'lt 11leo on Rome phenom!'lla of rotation of hodie11 in 1111 l!.11, n ml , Among ot her th i nf! . dcNc rihPrl h i R method of clclC'rr11i11i111! e 11dly llu· speed o(a dy namo wh1111 tnk ing readings.

To " few intereRted scient ilic ·m<'n fr. 're11i& showed II great 1111mher of di11 mme ilh1stmti n1?: ex peri men ts Im h11d performed which l<'nded to prom the CO'l'rectnes11 of ll1<' view h" holtl in regard to I.lie Ho('11lg1•11 11hc11m1w1tll bei ng cmn@ed hy mntl'riul parl icl projcctl'd with great velocity.

Th!l 1':1.ITTU!f'.\t, H t:\· u:w hop1•s lo ho 11hle to 11ree,.nl i11 full. i u a n 1·n rly iHlll', Mr. 'J'e11l11'1; fQct11re.

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L.I.A.

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SCIENCE $12.95

Nikola Tesla:

Lecture Before the New York Academy of Sciences - April 6, 1897

"Suddenly, without any preparation, Roentgen surprised the world..." So begins one of the most sought after of Tesla's treasures - his unpublished 1897 X-Ray lecture before the New York Academy of Sciences. Several puzzles become clear with this historical document. Tesla's independent discovery of X-Rays, unlike Roentgen's, was primarily based on sources which produced X-Rays by vacuum high field emission and the process now known as bremsstrahlung. While Roentgen employed a gaseous discharge tube utilizing electron avalanche, Tesla's cold cathode tubes worked best with high vacuum. Tesla's distinctive approach presaged the way for high energy particle accelerators, permitting the utilization of megavolt potentials, single electrode tubes, atmospheric bremsstrahlung, and a variety of intense beam techniques. As usual, he was years ahead with his inventions: Fowler and Nordheim's quantum mechanical considerations, necessary to understand Tesla's sources, were not available for another 32 years! (By then Tesla was developing a macroscopic charged particle beam.)

This broad lecture provides a remarkable amount of collateral information. He not only discussed his approach to X-Ray experimentation, but also included a surprising amount of information on high frequency RF techniques, coupled oscillators, magnetic receiver technology, the development of fluorescent lighting, and the creation of a stroboscopic measurement apparatus. The stroboscopy, tachometry, and chronography alone would have made the lecture a classic! The lecture demands careful study and balanced evaluation.

Drawing on a lifetime of historical investigation and scholarship, Leland Anderson has once again contributed a splendid record of documentation to the scientific community. His unique insight into electrical history has not only furnished us with another unusual primary source in the history of science but, in this critical publication, Mr. Anderson has molded a singular instrument for the serious analysis of Tesla's professional activities.

Kenneth and James Corum

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