THE EFFECT OF SHORT ELECTROMAGNETIC WAVES ON A BEAM OF CATHODE RAYS

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SYNOPSIS

Much has been written concerning discontinuous wave fronts of electromagnetic radiation. Sir J. J. Thomson and A. Einstein have definitely developed such theories. As an experimental test, apparatus[1] was devised by means of which electrons were projected through a compact beam of radiation, such as ultra violet light or X-Rays. In order to magnify any possible effect the electron beam was twisted into a long spiral of about 3 cm. pitch and 1.5 cm. mean diameter, by means of a strong magnetic field. The helical beam thus formed was about 70 cm. long, and the path of each individual electron much longer. If the electron beam was permitted to fall on a photographic plate, traces made on the plate when the radiation was turned off should be different from those made when the radiation was present if any effect occurred. The results recorded photographically may be summarized as follows:

1. When a strong beam of radiation of wave lengths from 8000 to 1300 Angstrom units fell across a stream of rapidly moving electrons, there were indications of a slight decrease in the velocity of the electrons. This effect, however, was smaller than the errors of measurement.

2. With the above radiation wave lengths the evidence is very strong that there was a scattering of the electrons in the beam.

3. When hard X-rays were used instead of the radiation given in 1, there was a distinct decrease in the velocity of the moving electrons, as is shown by the decrease in the diameter of the electron trace.

4. It was also found that X-rays caused a decided scattering of the electrons in the beam.

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1. J. J. Thomson, "Electricity and Matter", Ch. 3, pp. 53-70; Phil. Mag. v. 335, Feb. (1910).

INTRODUCTION

Some years ago J. J. Thomson advanced a theory of light which had properties characteristic of both the emission theory and the usual form of the undulatory theory. While lecturing in 1911, he proposed as an experimental test to the theory that if a stream of electrons had a strong beam of light thrown directly across their path slight deflections of the electrons might be expected. C. T. Knipp,[1] who was a student with Thomson at the time, saw the possibilities of such a research and soon after his return to Illinois attempted the experiment. He used a cathode beam twisted into a spiral, by means of a magnetic field, which fell on a photographic plate leaving a trace in the form of a circle. Although much work was done at that time by Knipp and later by O. A. Randolph (1912), and also by C. F. Hill (1915), yet the difficulties of obtaining high vacua, together with the great mechanical complications, prevented conclusive results from being obtained.

Owing to the fact that since that time some prominent physicists[2] have modified their views concerning the electromagnetic theory of light[3] and much has been written concerning non-continuous electromagnetic wave fronts, it was thought that it might be profitable with the modern methods of producing high vacua to carry forward the experiment. To that end the old apparatus was redesigned and entirely rebuilt in an attempt to determine whether or not electromagnetic radiation has an effect on rapidly moving electrons when thrown across their path.

DESCRIPTION OF APPARATUS

The general arrangement of the apparatus is shown in Fig. 1. The electron discharge chamber was constructed from a cylindrical glass jar 9.2 cm. in diameter and 76 cm. long, inside measurements. A powerful mag-

1. C. T. Knipp, Phys. Rev., Vol. 34, p. 477.
2. H. Bateman, Phil. Mag., Vol. 250, p. 405 (1917); A. Einstein, Phys. Zeitschr., V. 18, p. 121, (1917).
3. J. Kunz, Phys. Rev., 2d Ser., V. 3, p. 464; J. J. Thomson, Proc. Camb. Phil. Soc., V. 14, p. 421, Presidential Address, Brit. Assoc., Winnipeg (1909); Phil. Mag., Feb. (1910), Oct. (1913); H. S. Allen, Phil. Mag., Oct. (1921), p. 523.

netic field was produced by an electric current flowing through a solenoid on the outside of the chamber. The electrons were obtained from a microscopic spot of oxide deposited on a platinum strip.[1] When the magnetic field was on, and the electrons were projected at an angle with the axis of the tube, they were twisted into a spiral

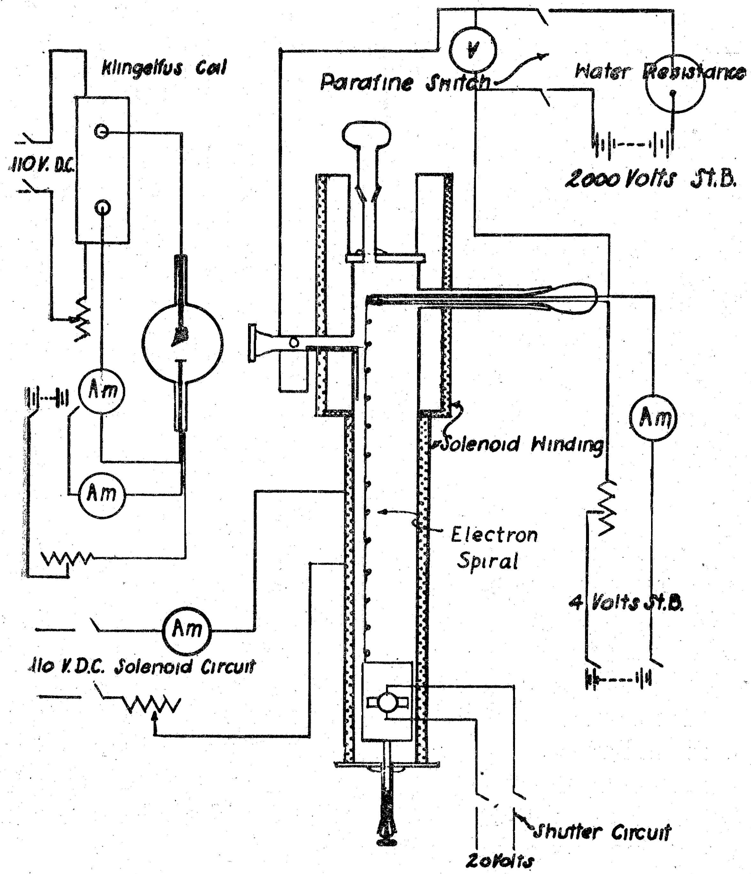

Fig. 1. General Arrangement of Apparatus.

which struck on a photographic plate at the opposite end of the discharge chamber.

The radiation used in the experiment was admitted just in front of the cathode through a side tube with a quartz window and thrown directly across the path of

1. C. J. Lapp, Trans. Ill. Acad. Sci., V. 14, p. 305.

the moving electrons. Two sources of radiation were used,—a ninety degrees carbon arc, and a Coolidge X-Ray tube. They were placed about 40 cm. from the beam of electrons upon which the radiation was to fall. The X-Ray tube used was the universal type Coolidge tube with a broad focal spot. This was excited by a Klingelfuss induction coil with a six-inch spark gap. The electron beam was maintained by a potential difference of about 2,000 volts from a small high potential storage battery.

A camera was placed within the discharge chamber at the end opposite the cathode and connected through a ground glass joint to the outside in such a way that the photographic plate could be rotated, making it possible to take six exposures on a single plate. The camera shutter was operated by a magnet, but was designed so that the time lag between the tripping and the opening of the shutter permitted the magnetic effects of the operating magnet to disappear before the photograph was taken.

III. OPERATING CONDITIONS

Due to the fact that the experimental operations of this research were very critical, the exact conditions under which the results were obtained are definitely stated. The vacuum was always 0.00001 mm. of mercury or less when the exposures were started. At the end of a series of exposures the pressure was measured and it was seldom higher than at the beginning. The discharge chamber was freed of water and mercury vapors by a P_2O_5 bulb, a large charcoal bulb, and a liquid air trap, the last two being immersed in liquid air.

The Wehnelt cathode was heated to a temperature gained by experience until a beam of electrons of sufficient intensity was obtained to make an impression on the photographic plate. Because of the high vacuum used and the absence of any trace of mercury vapor, it was sometimes very difficult to start the discharge even on the application of 2000 volts. It could, however, usually be induced to start by heating the cathode very hot for an instant. After the beam was started the cathode was rotated until it was projected against the side of the tube. When the current was turned on in the solenoid circuit, the beam was caught in an intense magnetic field and wound into a spiral which traversed the length of the discharge chamber, striking on a willemite screen on the outside of the camera shutter.

The intensity, size, shape and position of the phosphorescent spot could be changed by adjusting or regulating the pitch of the cathode ray spiral, the temperature of the hot cathode and the solenoid current. A focusing coil enabled the final adjustment to be made, after which a series of photographs were taken.

Six photgraphs were taken on each plate. A practice was made of taking the odd numbered exposures without, and the even numbered ones with the radiation falling on the electron spiral. The time between exposures was five to six seconds.

IV. MEASUREMENTS

After the photographic plates had been developed and numbered, they were carefully examined to see which ones could be subjected to measurements. A plate, to be of value for measuring, had to possess certain qualifications adopted as standard. First, the electron trace had to be of sufficient intensity to be seen easily with the naked eye, since faint traces could not be seen under the microscope used in measuring the photographs. Second, the trace had to form an arc of a circle of sufficient length to measure its diameter. Third, the edges of the circle had to be sharp so that the error in measurement might be small. Fourth, the six traces on a plate had to be similar so that corresponding measurements could be taken on each one.

A short table has been prepared as typical of the total results from data taken from consecutive plates. In this series the electron beam making the traces was alternately exposed to hard X-Rays. Fig. 2 shows Plate No. 720 listed in Table I.

TABLE I.

Plate	Electrode Voltage	Cathode temperature	Vacuum in mm. Hg.	Effect	Scattering
710	.....1800 Volts	900°C	0.00001 mm.	Positive	Yes
720	1900	1150	0.00001	Positive	Yes
730	2100	1150	0.00001	Positive	Yes
740	.....Plate was a blank				
750	2000	1150	0.00001	Positive	Edges fogged
760	2000	1150	0.00001	Positive	Yes
770	2050	1150	0.00001	Positive	Edges fogged
780	2000	1150	0.00001	Positive	Yes
790	2000	900	0.00002	Positive	Yes

When the even numbered circles—those taken with the radiation turned on and numbered 2, 4, 6—have a smaller average diameter than the odd numbered ones—those taken while radiation was off—the effect is defined as positive. This decrease in the diameter of the electron traces on the photographic plate is due to a collapsing or a falling together of the spiral. This is caused by a decrease in the velocity of the electrons in the beam. The effect is noted in the fourth column of the table above.

Another effect is present, that is, a scattering of the electrons or a diffusion of the electron beam. This effect, which shows mainly on the edges of the traces, can be noted even when the traces are not complete circles. When it is present the table indicates the fact by ''yes'' in the last column. Plates 750 and 770 were so imperfect that the effect was covered up, hence no record was made for them.

A large amount of data was also taken where radiation of wave lengths from 8000 to 1300 Angstrom units fell across the stream of rapidly moving electrons. There were indications of a slight decrease in the velocity of the electrons. This effect, however, was smaller than the errors of measurement. Evidence of a scattering effect when the above radiation wave lengths were used was very strong.

At the time the photographs were measured, the data were put into graphical form in order that they might be easily interpreted. Because the time intervals between exposures were approximately equal, the diameters of the circles have been plotted as ordinates, while

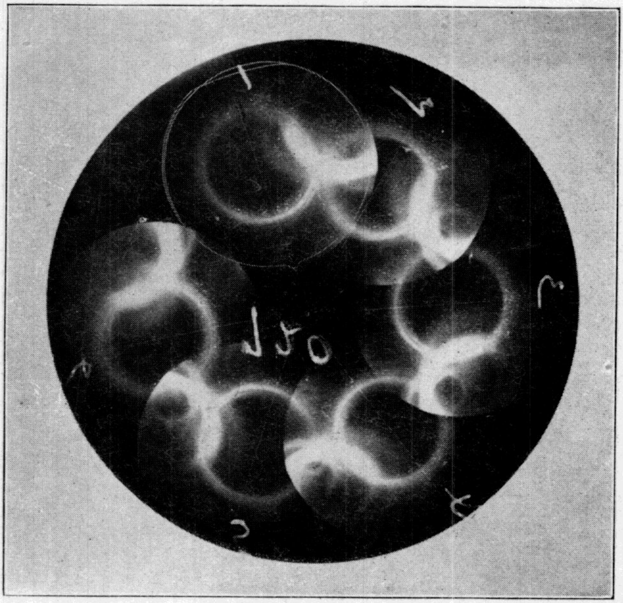

Fig. 2. Plate No. 720, Showing the Difference in the Diameter of the Electron Traces.

the traces numbered 1, 2, 3, etc., have been used as abscissae. Two of these graphs have been selected as typical and are shown in Fig. 3 and 4.

V. DISCUSSION

No formal attempt will be made to explain from a theoretical point of view the results obtained in this research. It seems, however, that it would not be out of place to suggest possible lines along which explanations might be found. Thomson remarked when he suggested

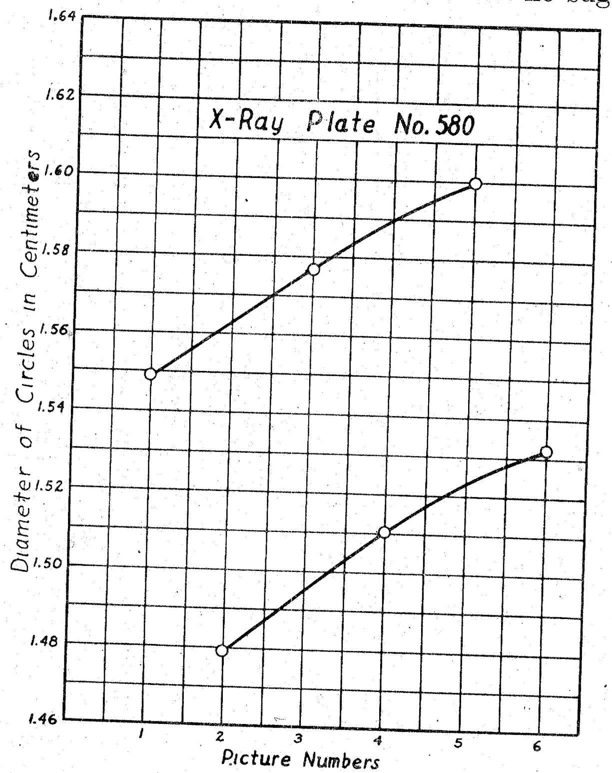

Fig. 3. Graphical representation of the difference in the diameters of the electron traces.

the experiment, that if a diffused pattern of the electron trace was found when radiation was thrown across the path of the electrons, the result might be taken as indicative of the correctness of a theory of light which he had advanced. Einstein[1] has developed another electro-

1. A. Einstein, Phs. Seitschr., V. 18, p. 121.

magnetic theory along the same lines. In fact, if any kind of a wave theory is postulated in which the wave front is discontinuous, it is evident at once that an appreciable scattering effect would be expected under the condition of the experiment.

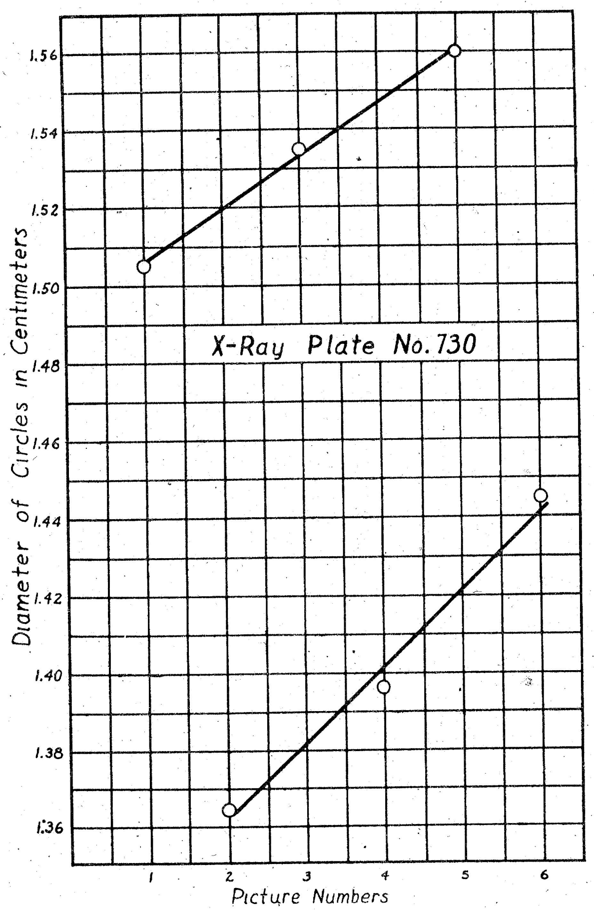

Fig. 4. Graphical representation of the differences in the diameters of the electron traces.

Why the velocity of the electron should be decreased when they pass through short electromagnetic waves is difficult to see in the light of our present theories. So far as is known, the usual form of the undulatory theory cannot give an explanation.

In conclusion, the author wishes to recognize the help received from the early work of Professor C. T. Knipp on this problem, and to express his thanks to him for his advice and aid throughout the research, and to Professor A. P. Carman for the facilities of the department.

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