THE POLARIZATION OF CHARACTERISTIC X-RAYS

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Abstract

Primary x-rays from a molybdenum target Coolidge tube were allowed to impinge upon a carbon block and the intensity of the scattered radiation proceeding from this secondary source was compared in two directions mutually perpendicular to the primary rays and parallel to and perpendicular to the cathode stream respectively as the tube was rotated. When the tube was operated at 29 KV peak and the primary radiation made to pass through a suitable filter of zirconium, the radiation was rendered practically monochromatic and was composed mainly of the K-alpha lines. The ratio of the intensity of the secondary beam proceeding in a direction parallel to the cathode stream to that proceeding in a direction perpendicular thereto was then taken as a measure of the polarization of the alpha lines. This ratio was found to be about .74. Operating the tube under the same conditions as stated above but using a filter of strontium, which served to cut out the alpha lines, the corresponding ratio was .84. These results indicate that the alpha lines of molybdenum are partially polarized.

Introduction

On THE basis of J. J. Thomson's ether pulse theory[1] it was predicted that the general radiation proceeding from the target of an x-ray tube should be partially polarized. In order to test the validity of this theory Barkla[2] in 1905 and 1906, performed his classical experiments on the polarization of x-rays and, as is well known, found that there was indeed a favored direction of vibration of the electric vector in the primary beam, which direction was parallel to the cathode stream. Though all other experiments on the polarization of x-rays save one—a photographic investigation carried out by Haga[3]—have confirmed Barkla's results, it is difficult for the purpose of comparison to correlate the results of the various experiments prior to 1923, for the fundamental reason that in general little has been reported concerning the voltages applied to the tubes used by the various observers. A knowledge of this is important, not only because of the variation of the degree of polarization with generating voltage as found by Kirkpatrick,[4] but because it alone indicates whether or not there was present in the radiation studied the characteristic spectrum of the target. Kirkpatrick[4] in his work did not use voltages sufficiently high to generate the line spectrum.

[1] Conduction of Electricity through Gases, p. 657.

[2] C. G. Barkla, Roy. Soc. Proc. **77A**, 247 (1906); Phil. Trans. **A204**, 467 (1905); Nature **69**, 463 (1904).

[3] H. Haga, Ann. der Physik **28**, 439 (1906).

[4] P. Kirkpatrick, Phys. Rev. **22**, 226 (1923).

Although evidence is furnished in Barkla's[2] experiment (note his use of iron as the material for the secondary radiator) and later confirmed by the experiments of Mark and Szilard[5] that the fluorescent radiation when excited by polarized x-rays is itself unpolarized, it should be pointed out that a fundamental difference exists between the experiment here to be described and those of Barkla and of Mark and Szilard. It is that in the case of the latter two experiments the fluorescent radiation was excited outside the x-ray tube by means of polarized, or at least partially polarized *x-radiation*, of frequency slightly in excess of the critical frequency. No intense electric or magnetic fields were present. While in the present investigation the characteristic radiation which was examined for polarization was generated within the target of the x-ray tube itself by *electronic impact* and obviously under the influence of fairly strong electric fields.

It is significant that experiments [6,7] in the optical region have yielded evidence which indicates that the resonance radiation of sodium and of mercury vapor when excited by electronic impact is partially polarized. The work here to be described was undertaken to determine whether or not a similar condition of polarization exists in the case of the characteristic x-ray spectrum.

Experimental Procedure

Failure to obtain measurable intensity when using a crystal grating made it necessary to resort to the use of filters, a discussion of which will be presented in a subsequent paragraph. A brief description of the experimental procedure which was finally adopted follows.

A molybdenum-target water-cooled Coolidge tube* was so mounted that it could be rotated about an axis nearly prependicular to the cathode stream and passing through the center of the focal spot (Fig. 1). Primary radiation from the target, limited by slits S_1 and S_2, each 2.5×0.6 cm and 10 cm apart, was allowed to strike a carbon block C. The secondary radiation proceeding from this source and limited by a pair of slits similar to S_1 S_2 (not shown in figure) but separated by a horizontal lead strip into two sections to prevent cross fire, was allowed to enter an ionization chamber A parallel to the cathode stream when the tube was in a horizontal position. A portion of the direct beam, suitably

[5] Mark and Szillard, Zeits. f. Physik **35,** 743 (1926).

[6] Ellett, Foote and Mohler, Phys. Rev. **27,** 31 (1926).

[7] H. W. B. Skinner, Nature **117**, 418 (1926).

* Kindly placed at the disposal of Professor Richtmyer by Dr. W. D. Coolidge of the General Electric Research Laboratory.

limited by an adjustable shutter, was allowed to pass through C and to enter another ionization chamber B. This beam made an angle of 85° with the cathode stream for all positions of the tube.

Immediately behind S_1 was situated an arrangement F by means of which any desired filter, e. g. a filter of zirconium or strontium, might be inserted in the path of the direct ray. Both ionization chambers were similar in design and capacity and each was connected to its own Compton electrometer. The two electrometers were also alike in design and capacity and were regulated for sensitivity by varying the potential applied to the needle.

The voltage applied to the x-ray tube was furnished by a 220—50,000 volt transformer.† The voltmeter which indicated the voltage applied to the tube could easily be read to one part in two hundred and during a run showed no variation. The filament of the x-ray tube was heated by current from a storage battery, with adjustable rheostat, so that the current through the tube did not vary by as much as a half percent.

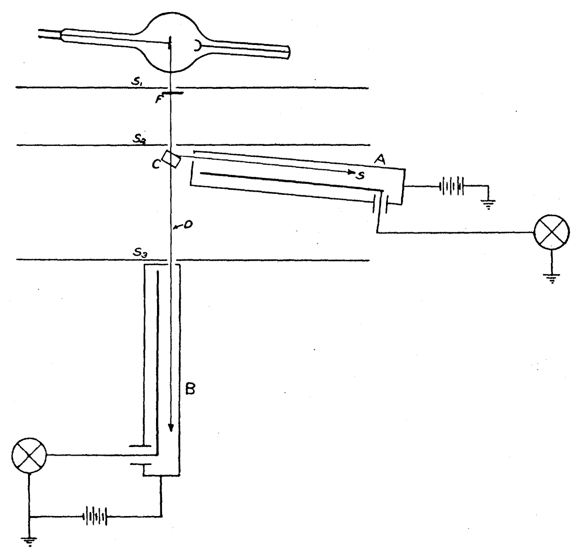

Fig. 1. Diagram of apparatus.

The manner in which observations were made is as follows: With the tube in a horizontal position, i. e. with the cathode stream parallel to the beam—marked S in Fig. 1—entering chamber A, simultaneous rates of drift of the two electrometers were recorded. The tube was then rotated to a vertical position and a similar set of observations recorded.

† Kindly lent by the Department of Electrical Engineering of Cornell University.

Each observation yields a measure of the intensity of the scattered beam relative to the direct beam, and thus each two-fold observation gives a measure of the relative intensities of the beams scattered parallel

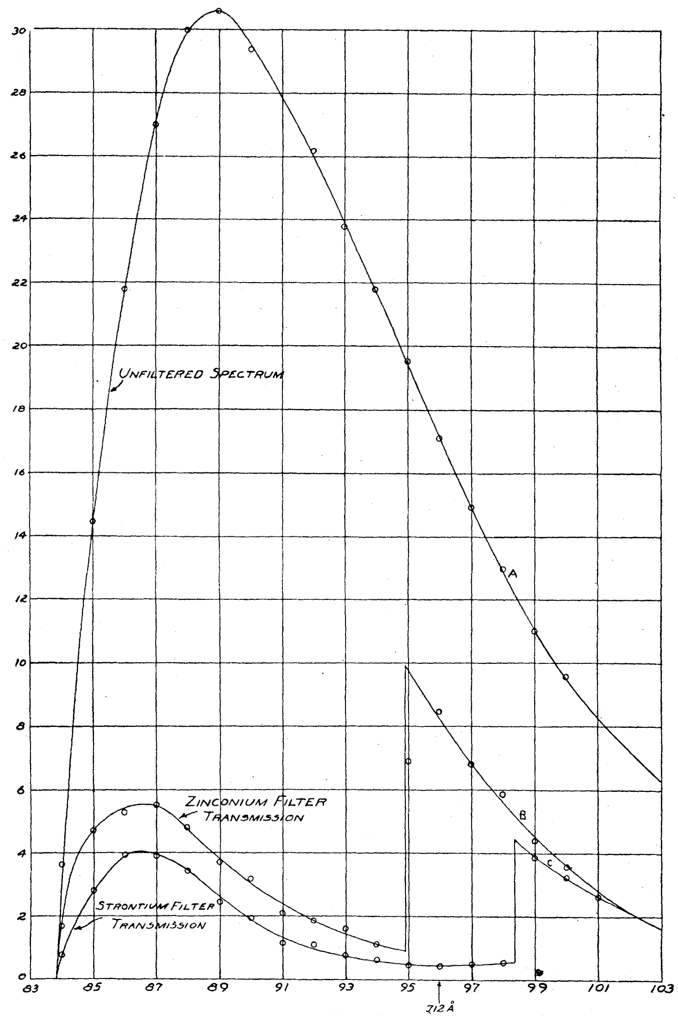

Fig. 2. Curve A shows the energy wave-length spectrum of the unfiltered radiation from a tungsten target tube operated at 29 kv. peak. Curves *B* and *C* show the same spectrum filtered through *Zr* and *Sr* filters, respectively.

to and perpendicular to the cathode stream respectively. This intensity ratio $I_{\text{II}}/I_{\text{I}}$ may be taken as an arbitrary measure of the degree of polarization. In Table I are given sample data which indicate the manner in which computations are made.

Curve A of Fig. 2 shows the energy wave-length spectrum of the unfiltered radiation from a *tungsten* target tube operated at 29 kilo-volts peak, while B and C show the same spectrum filtered through zirconium and strontium filters respectively. One observes that B and C do not radically differ from each other except in this one particular, viz; the zirconium filter is highly transparent in the neighborhood of the alpha lines of molybdenum, (712A), while the strontium filter very effectively absorbs in this neighborhood. From a consideration of Hull's[8] data one concludes that were these spectra obtained by using a molybdenum target tube, the intensity of the alpha lines transmitted by the zirconium filter would reach the ordinate 98 in Fig. 2. In other words, the radiation transmitted by the zirconium filter is a very fair approach to monochromatic radiation of 712A. In the light of the evidence presented in Fig. 2 it becomes at once evident that the polarization measured, when the radiation from a molybdenum target tube operated at 29 kilo-volts peak is allowed to pass through such a zirconium filter, is the polarization due in large part to the prescnce of the alpha lines.

A comparison of two such sets of observations as outlined above, using in the one case the zirconium filter and in the other the strontium filter, gives them an accurate qualitative, if not quantitative, measure of the degree of polarization of the alpha lines.

Results

Table I

Sample data obtained on the polarization of the alpha lines using a zirconium filter.

	DIRECT BEAM (D)			*SCATTERED BEAM (S)*			
Position of tube	mm div.	time sec.	rate mm/sec.	mm div.	time sec.	rate mm/sec.	ratio S/D
Hor.	100	27.85	3.591	110	31.70	3.470	.9675
Hor.	100	28.00	3.571	120	34.00	3.530	.9880
Hor.	100	28.15	3.552	120	35.00	3.430	.9670
Hor.	100	28.25	3.540	120	35.75	3.360	.9500
Hor.	100	28.00	3.571	120	34.80	3.450	.9660
						Mean	.9677
Vert.	100	34.80	2.874	150	39.80	3.770	1.311
Vert.	100	34.60	2.890	150	39.35	3.815	1.318
Vert.	100	34.70	2.882	150	39.60	3.790	1.313
Vert.	100	34.65	2.886	150	40.10	3.740	1.295
Vert.	100	34.60	2.890	150	39.80	3.770	1.304
						Mean	1.306

$$\frac{\text{Mean value of } S/D \text{ for horizontal position} \quad .9677}{\text{Mean value of } S/D \text{ for vertical position} \quad 1.306} = 0.74$$

In Table I, column 1 represents the number of arbitrary scale divisions passed over by the "direct beam" electrometer in the time indi-

[8] A. W. Hull, Phys. Rev. **10**, 666

cated in column 2. Column 3 indicates rate of drift and is therefore proportional to the ionization current in chamber B. Columns 4, 5 and 6 bear the same respective relation to the scattered beam that 1, 2, and 3 do to the direct beam. Column 7 is the ratio of column 6 to column 3 and is the ratio of the two ionization currents A/B. The mean value of column 7 obtained with the tube in a horizontal position divided by the mean value of that part of column 7 obtained with the tube in vertical position gives then the ratio $I_{\parallel}/I_{\perp}$ and hence is a measure of the degree of polarization. Attention is called here to the fact that a low value of the ratio $I_{\parallel}/I_{\perp}$ indicates high precentage polarization.

Numerous determinations of this ratio $I_{\parallel}/I_{\perp}$ carried out in the manner indicated above and with the zirconium filter in place, gave values which are represented in Table II under the heading "zirconium filter." The mean value of all these is seen to be about 0.74. Under the heading "strontium filter" are similar data obtained by using the strontium filter and indicate a means component ratio of 0.84.

TABLE II

Values of the ratio $I_{\parallel}/II_{\perp}$

Zirconium filter		Strontium filter
.760	.729	.857
.772	.723	.812
.720	.726	.840
.730	.760	.836
.728	.758	.832
.757	.731	.852
.703	.733	.828
.758	.722	.827
.723	.741	.851
.733	.740	.882
Mean	.737	Mean .841

One observes that the ratios $I_{\parallel}/I_{\perp}$ obtained when the radiation is filtered through zirconium are consistently lower than the corresponding ratios which were obtained with the zirconium filter. They are lower by an amount which is certainly outside the limits of experimental error; hence we conclude that the radiation which includes the alpha lines is considerably more polarized than is the radiation, in the same neighborhood, which does not include the alpha lines. In brief, the alpha lines are at least partially polarized.

In order to compare this work with the work of previous observers it seemed desirable to make measurements on the polarization of the general ratiation when excitation is effected by voltages below the value necessary to excite characteristic emission. Kirkpatrick[4] has shown that the ratio of component intensities in the general unfiltered radiation decreases with decreasing voltage, not quite linearly but following along a smooth curve slightly concave toward the voltage axis. Unfortunately his observations do not extend as far down as the critical voltage of molybdenum (about 20 kv.). Since, however, there is no obvious reason why one should expect a radical departure from his curve extrapolated to lower voltage values, it seemed admissible to make this extension.

Two such polarization measurements were therefore recorded; at 18 kv. and 21.2 kv. respectively. Ten determinations were obtained for each voltage. Their values are compared below with those predicted from Kirkpatrick's work.

	Ratio of component intensities	
	At 18 kv.	At 21.2 kv.
Present results	.65	.68
Results predicted by Kirkpatrick	.71	.735

Both present results are about seven percent lower than the corresponding values predicted by Kirkpatrick but show the same relative increase with increasing voltage.

Discussion

A factor of fundamental importance in the present work is to make sure that the ratio of component intensities observed is indeed a measure of the degree of polarization and that the variation in observed intensities is not due to such spurious effects as: (1) stray radiation; (2) a variation in the quality of the primary radiation for different positions of the tube; (3) asymmetric bombardment of the carbon block by the direct beam when the tube is rotated, due possibly to improper alignment of the tube relative to the slit system.

Regarding (1), it was found that neither ionization chamber received any measurable amount of radiation when the chamber windows were covered by a strip of lead 1/100″ thick. Regarding (2), it was shown in the following way that the quality of the radiation did not alter for different tube positions. In the path of that portion of the direct beam entering ionization chamber B was interposed a thin strip of aluminum and the rate of drift of the direct beam electrometer recorded. The aluminum was then removed and the new rate of drift recorded, taking care that in both these observations the position of the tube remained fixed. From these data a quantity proportional to the mass absorption coefficient of aluminum was obtained. The tube was then rotated through 90° and a similar set of observations recorded. These observations are shown below and indicate that there is no change in the quality (hardness) of the direct beam for the two positions of the tube.

Tube position	*Absorber*	*Time to drift* 100*mm*	I_0/I	*Mean*
Horizontal	in	49.7 seconds	3.65	3.62
Horizontal	out	13.6 seconds		
Horizontal	in	48.6 seconds	3.59	
Horizontal	out	13.53 seconds		
Vertical	out	15.4 seconds	3.64	3.63
Vertical	in	56.12 seconds		
Vertical	out	15.33 seconds	3.61	
Vertical	in	55.34 seconds		

Regarding (3), it is to be noted that pin hole photographs of the focal spot as viewed from the carbon block showed that as the tube was rotated, the center of the focal spot did not deviate from the desired line axis D (Fig. 1) by more than 1.5 to 2 mm, and further, since the opening at S_2 was immediately in front of C, the same region of the carbon block was radiated for both tube positions.

Conclusions

In the light of the evidence furnished by this experiment, one concludes that the alpha lines of molybdenum are at least partially polarized. The polarization is in the same sense that has previously been found to exist in the general radiation, viz., there is a greater concentration of the eectric vector parallel to the cathode stream than at right angles to this direction. Whether or not this polarization is peculiar to the alpha lines of molybdenum alone, or is common to all the characteristic lines of all the elements is a matter yet to be determined. The importance of further investigation along this line can scarcely be over-estimated, for certain it is that our knowledge of the true nature of the characteristic emission process is far from complete and needs to be augmented by more facts. It seems highly probable that unambiguous data concerning the condition of polarization of the complete line spectrum would be helpful to this end.

In conclusion, I wish to express my sincere thanks to Professor F. K. Richtmyer for his continued interest and many helpful suggestions in connection with this investigation.

Rockefeller Hall,
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