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THE SPECTRUM AND STATE OF POLARIZATION OF FLUORESCENT X-RAYS

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A brilliant series of experiments by Barkla and Sadler,[1] begun in 1907, showed the now well-known phenomenon of fluorescent x-rays, excited in the heavier elements when traversed by primary x-rays of shorter wavelength. They identified two series of such fluorescent rays, which they called *K* and *L* radiations. With the advent of crystal spectrometry, the Braggs[2] and Moseley and Darwin[3] showed that the absorption coefficients of the lines in the x-ray spectra were the same as the absorption coefficients which Barkla and Sadler had found for their fluorescent radiations, thus identifying the fluorescent *K* and *L* series radiations with the characteristic line radiation which comes directly from the target of an x-ray tube. This identification was made more definite when spectra of the fluorescent rays were obtained, which showed the same lines as those present in the direct rays. Such spectra have been published, for example, by Duane and Shimizu,[4] Clark and Duane,[5] Woo[6] and D. L. Webster.[7]

In Sadler's earliest studies of the fluorescent rays,[8] he finds by absorption measurements that under favorable conditions not more than 1 per cent of the secondary rays from a fluorescing radiator are scattered. The spectra of Clark and Duane,[5] however, indicate that with fluorescent radiators of barium, lanthanum, molybdenum and silver, excited by x-rays produced at about 90 kv., less than 4 per cent of the secondary radiation consists of the homogeneous fluorescent rays. Woo's spectra, on the other hand, show only a strong line spectrum with no indication of any continuous spectrum mixed with the fluorescent rays.

In figure 2 is shown a spectrum of the fluorescent x-rays from silver, excited by x-rays from a tube with a tungsten target, operated at 53 kv. The apparatus was arranged as shown in figure 1, which is drawn approximately to scale. In order to detect, if possible, any continuous spectrum, the slits collimating the beam incident on the crystal were made rather wide, as is indicated by the width of the α and β lines. Perhaps the most striking feature in the spectrum is the complete absence of any continuous spectrum. In fact an estimate of the ratio of the energy in the continuous spectrum to that in the line spectrum from these data gives 0.007 ± 0.01. New absorption measurements indicate also that the line radiation constitutes more than 99 per cent of the total radiation. These results are in complete agreement with the early findings of Sadler, and suggest that the greater part of the radiation studied by Clark and Duane was not really the secondary rays from the radiator under investigation.

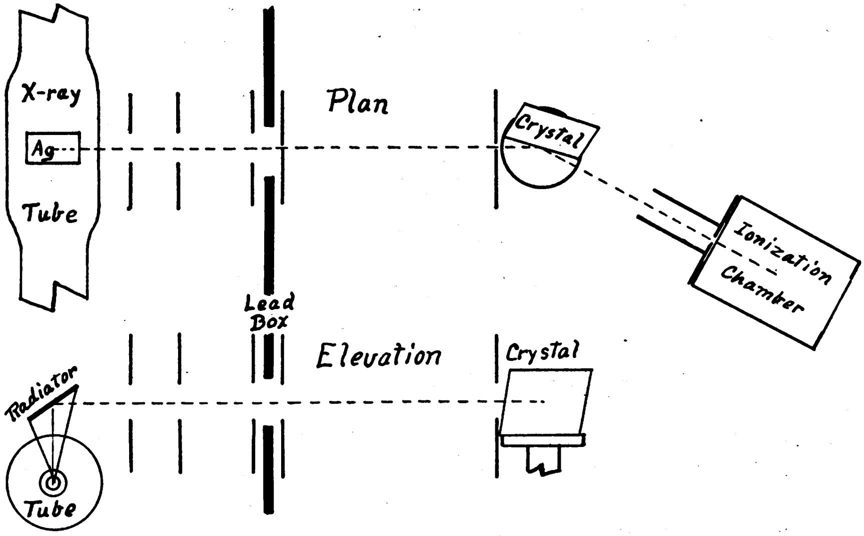

FIGURE 1

It is worthwhile calling attention again, as Barkla has done long ago, to the value of these fluorescent rays as a source of homogeneous x-rays. If the presence of the β and γ lines is objectionable, they can be removed by a suitable filter, leaving practically nothing except the $K\alpha$ radiation. The homogeneity thus secured is more complete than that usually got by crystal reflection. When homogeneity is sought by filtering the direct beam from a molybdenum target through a zirconium filter, under the best conditions only about 25 per cent of the transmitted radiation is of the $K\alpha$ type.[9] By filtering the fluorescent beam, on the other hand, the homogeneity may be made as great as 98 per cent.

Under the conditions of the present experiment, the intensity of the fluorescent rays as measured at the ionization chamber was approximately $^{1}/_{200}$ of that of the primary beam. The rays were easily visible with the fluorscope.

Ratio of the α to the β Lines.—The ratio of the area of the α peak to that of the β peak from these experiments is 4.58. When this is corrected for: (1) the difference in ionization per unit intensity for the two wave-lengths (the method of calculating this correction will be discussed in a later paper), a factor of 0.825; (2) the difference in the absorption of the α and β lines in the air and in the fluorescent radiator, factor 1.10; and (3) the difference in the reflecting power of the crystal for the two types of radiation, a factor of 1.08, the ratio of the energies of the two lines as emitted from the silver atoms in the radiator becomes 4.5. This agrees within the errors of experiment and correction with Unnewehr's ratio[10]

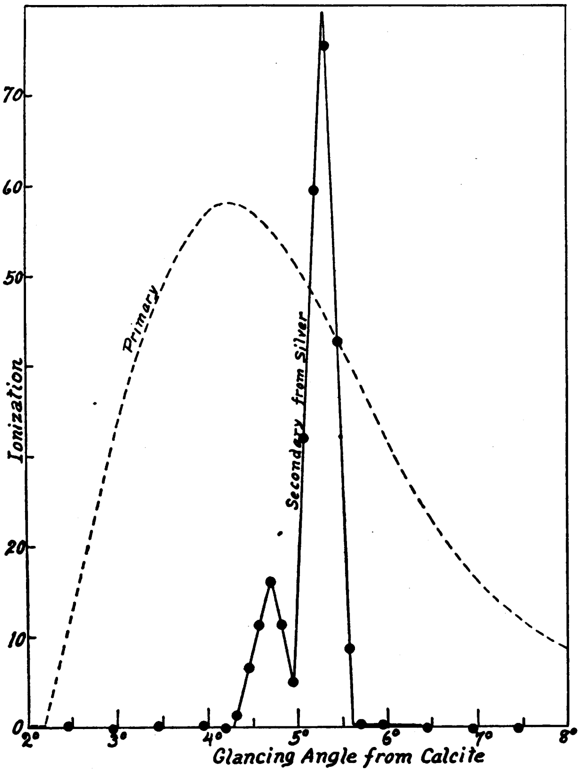

FIGURE 2

of 4.65 for the α and β lines from a silver target. Thus the relative intensity as well as the positions of the spectrum lines is approximately the same in the fluorescent as in the primary x-rays.

Unpolarized Character of Fluorescent X-Rays.—In their earliest experiments on the characteristic secondary radiation, Barkla and Sadler tested for a possible polarization of the rays by using a radiator which emitted strong fluorescent radiation as an "analyzer" for the direct rays from an x-ray tube.[11] A carbon scattering block used as analyzer reveals in this case some 15 per cent polarization of the primary beam. They were unable, however, to detect any polarization when a fluorescing radiator was used as analyzer. If the probable error of their measurements was 1 or 2 per cent, this would mean that the polarization of the fluorescent rays is probably less than about 10 per cent.

More recently, Mark and Szilard,[12] in a study of the x-rays polarized by reflection from a crystal, have found no indication of analysis of these rays by a fluorescing radiator except insofar as scattered rays were mixed with the fluorescent rays. Their method was a photographic one.

The question of the polarization of the fluorescent x-rays has acquired new interest as a result of Bishop's conclusion that the line radiation from the target of an x-ray tube, which is partly of fluorescent origin, is partially polarized.[13] Moreover, Raman has recently found a type of secondary light rays which are similar to fluorescent rays in that their wave-length differs from that of the primary rays, but which are strongly polarized.[14] It thus becomes important to make a more careful test than has hitherto been made for possible polarization of fluorescent x-rays.

The method employed was that used by Hagenow and the writer in examining the polarization of scattered x-rays.[15] A horizontal beam of x-rays struck a radiator R_1 placed above the axis of a Bragg x-ray spectrometer. The secondary rays proceeding downward fell on a second radiator R_2, also placed over the spectrometer axis, but on a level with the window of the ionization chamber. When both radiators R_1 and R_2 were plates of graphite, the ionization current with the chamber in the perpendicular position was only 0.09 of that in the parallel position, indicating almost complete polarization. When R_1 was silver and R_2 graphite,

$$\frac{i_\perp}{i_\parallel} = 0.968. \qquad (a)$$

When R_1 was silver and R_2 a plate of compressed ZrO, the observed ratio was

$$\frac{i_\perp}{i_\parallel} = 0.964. \qquad (b)$$

An auxiliary experiment showed that the zirconium oxide analyzer gave almost the same intensity in the $\parallel$ and $\perp$ positions even when struck by rays polarized by scattering from carbon. The ratio 0.964 observed in case b is thus to be ascribed to the lack of geometric symmetry in the $\parallel$ and $\perp$ positions. The corrected value of the intensities in the two positions is thus

$$\frac{\perp}{\parallel} = \frac{a}{b} = \frac{0.968}{0.964} = 1.004$$

with a probable error, estimated from the variations of the readings, of ±0.005.

This means that the characteristic fluorescent x-rays from silver are completely unpolarized, within a probable error of 0.5 per cent. It follows that any polarization in the line spectrum of the primary x-rays must be due to the portion of the rays resulting from the direct action of the cathode rays.

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AN INTERPRETATION OF DIRAC'S THEORY OF THE ELECTRON

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Dirac's[1] theory of the electron starts out with the following premises: (*a*) The wave-equation must be linear in form, (*b*) the equation must satisfy the requirements of special relativity and (*c*) for a free electron the results must be identical with those given by the Schroedinger-Gordon wave-equation. He finds it possible to satisfy all of these conditions by introducing into the wave-equation matrix-operators which are very similar to those used by Pauli[2] in the formulation of the theory of the spinning electron. As is well known, this theory of Dirac's is promising to be very significant because it eliminates the necessity of introducing assumptions