

ON THE ABNORMAL REFLECTION OF X-RAYS BY CRYSTALS

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Communicated, February 7, 1923

In the research described in this note we have examined in greater detail certain abnormal reflections of X-rays by crystals which we described (and which we called X-peak reflections) in a note communicated to the Academy on April 4, 1922, and printed in these PROCEEDINGS, May, 1922 (90-96).

We showed that under certain experimental conditions a crystal reflects rays that appear to have the wave-lengths characteristic of one of the chemical elements in the crystal itself. When one examines spectra by means of an X-ray spectrometer in the ordinary way the crystal reflects strongly rays belonging to the characteristic line spectrum of the target in the X-ray tube. In our experiments, however, the *abnormally* reflected rays appeared to have wave-lengths equal to those in the line spectrum of a chemical element in the crystal. We obtained evidence for these wave-lengths by determining the critical value of the voltage below which the reflections do not occur. In these experiments we used a crystal of potassium iodide and the critical voltage corresponded with the critical voltage for the K series of iodine. In certain experiments with photographic X-ray spectrometers, spots have been observed on photographic plates that did not correspond with normal reflections of the X-rays. No one has demonstrated experimentally, however, that the X-rays producing these spots had the wave-lengths corresponding to the line spectra of the chemical elements in the crystals. These photographic spots may, however, represent reflections of X-rays characteristic of chemical elements in a crystal, but they may, perhaps, correspond to certain reflections that we have observed but have not yet examined carefully. These reflections are represented by small peaks, some of which appear on the curves contained in fig. 1 (below). These small peaks correspond to reflections that are very much weaker than those that we are now discussing under the name of X-peak.

The X-peak reflection appears to be a very large phenomenon. Under certain experimental conditions it is stronger than the normal reflection from any of the principal planes of the crystal.

The normal reflection of X-rays by a crystal obeys the following two laws: firstly, the angle of incidence of the rays on a set of planes in the crystal equals the angle of reflection from these planes, and secondly, the equation

$$n\lambda = 2d \sin \theta \quad (1)$$

gives the wave-lengths, λ , in terms of the angle of incidence, θ , and the distance between the planes, d . We have been able to show experimentally

that the abnormal reflection of rays characteristic of a chemical element in the crystal does not obey either of these laws.

By setting the ionization chamber of the spectrometer in given positions and by turning the crystal until the abnormally reflected ray entered the chamber, we found that there is no plane fixed in the crystal that always makes equal angles with the incident and reflected rays, no matter what the position of the chamber may be.

In the following discussion we will call the angle drawn to the centre of the slit of the ionization chamber, α . It equals the total deviation produced in the path of the rays by the crystal. We have determined the

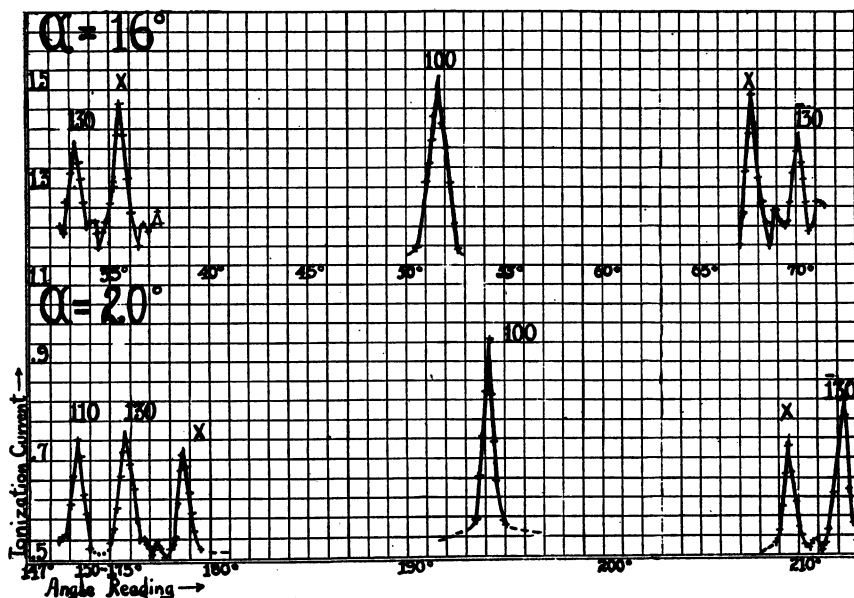


FIGURE 1

settings of the crystal required to reflect rays into the ionization chamber from the 100 planes, the 130 planes and the abnormal X-peak reflection for a number of values of the angle α . Fig. 1 represents the data obtained for two of these series of measurements; namely, for those in which α equals 16° and 20° . The reflections due to the 100 planes, the 130 planes, etc., and the X-peak are marked on the curves. In the original experiments described in the previous note, α equaled 11° and the X-peak fell very close to the 130 peak. As α increases, however, the X-peak moves away from the 130 peak toward the 100 peak.

The curves in fig. 2 give the results of eighteen sets of experiments at different angles, α . It will be seen that in the case of reflection by the 100 planes or by the 130 planes, the position that the crystal must occupy in

order to reflect rays into the ionization chamber changes half as fast as the position of the ionization chamber changes. If α increases by a certain number of degrees the crystal angle must be changed by half that number of degrees. In other words, the angle of incidence equals the angle of reflection, and each equals half the total angle of deviation of the rays. This, however, is not true of the X-peak.

For small angles, α , the X-peak lies outside of that due to reflection from the 130 planes. For larger angles, α , the X-peak lies between those due to reflection from the 100 and 130 planes. Further, there are always two X-peaks, on the two sides respectively of the peak representing reflection from the 100 planes and at equal angles from it. The same is true for the 010 planes and the 001 planes.

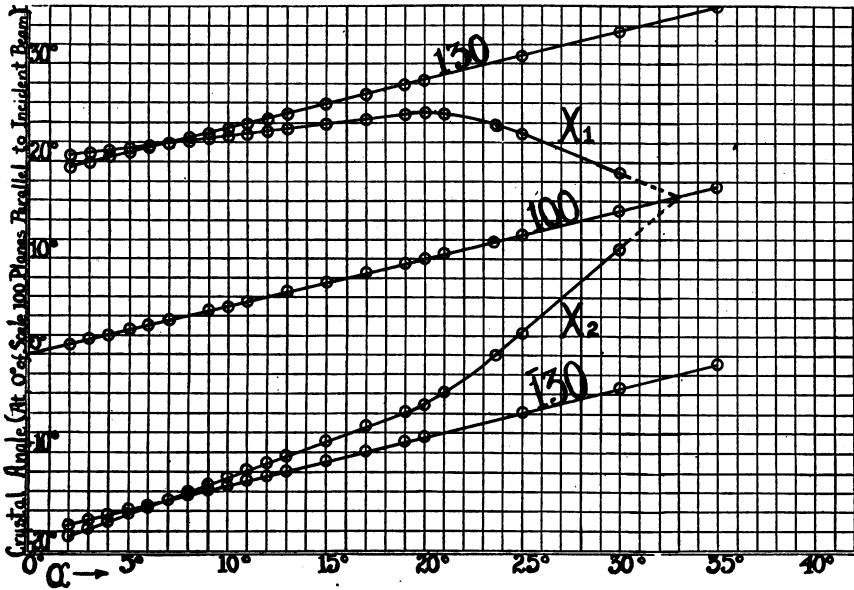


FIGURE 2

At an angle, α , equal to about $23^{\circ}-40'$ the X-peak appears when the crystal angle is 0; i.e., when the 100 planes lie parallel to the incident beam. This has been verified both by ionization spectrometer measurements and by Laue photographs which will be reproduced in a later paper. Corresponding to this, there is an X-peak for the same angle, α , when the crystal angle is $23^{\circ}-40'$, which means that in this case the 100 planes lie parallel to the reflected ray.

That the wave-lengths of the X-rays reflected in the X-peaks do not obey the law expressed by equation (1) may be inferred from the following experimental results: by setting on the X-peaks at various angles, α , and

by reducing the voltages applied to the X-ray tube we have determined in each case the critical voltage required to produce the reflection. This voltage substituted in the quantum equation

$$Ve = h\nu = hc/\lambda \quad (2)$$

gives us the wave-length of the reflected beam of rays.

The curves in fig. 3 represent the data for nine values of the angle, α . It appears that in each case the ionization current vanishes when the voltage applied to the tube is about 31.5 kilovolts. Substituting this in equation (2) we get $\lambda = .392$, which is a wave-length lying between the α and the β lines in the K series of iodine (namely $\lambda_\alpha = .437$ and $\lambda_\beta = .388$). It follows from these observations that the wave-lengths reflected in the

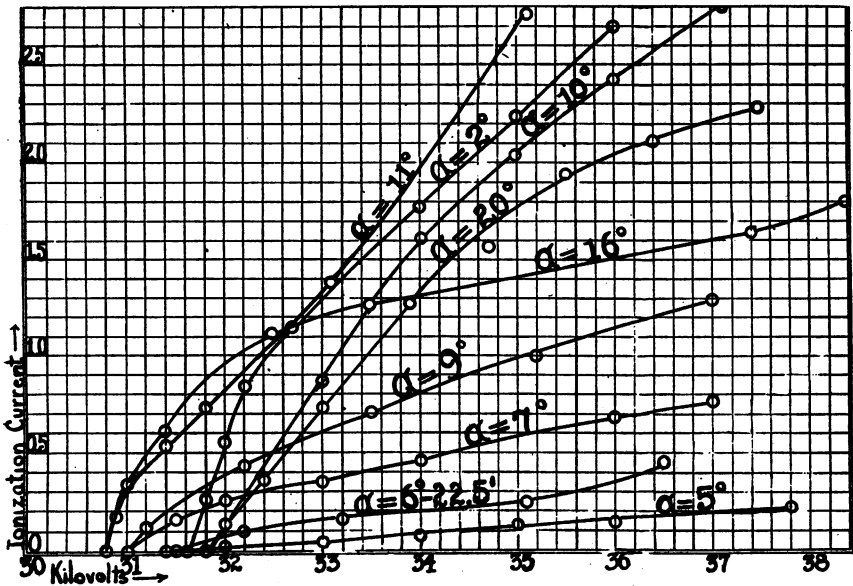


FIGURE 3

X-peaks are equal to each other, within the limits of error of the measurements, for all the total angles of deviation α and, therefore, that this characteristic reflection does not obey equation (1).

From our voltage measurements we infer that the crystal does not produce the X-peak reflection unless the incident beam contains X-rays of shorter wave-lengths than those in the K series of iodine. A sheet of copper placed in the path of the reflected beam reduces the ionization current in the spectrometer much more markedly than, if the copper is placed in the path of the incident beam. This furnishes additional evidence that the reflected rays have longer waves than the incident rays which produced them have.

The X-peak reflection is not a phenomenon peculiar to the particular crystal of potassium iodide employed in the experiments. We have used four different crystals of potassium iodide with the same results in each case.

No adequate explanation has, as yet, been found for this peculiar reflection in the X-peak.

McKeehan has published a theory of what he calls "Extraordinary Diffraction of X-rays" and he suggests that his theory may explain the X-peak reflection. His equations, however, contain the wave-lengths of the incident beam of rays whereas the position of the X-peak in our experiments does not appear to depend upon the voltage applied to the X-ray tube; that is, does not depend upon the wave-lengths of the incident rays, provided only that they are shorter than the critical absorption wave-length of iodine. Further, McKeehan's equations do not give the observed angles at which the characteristic rays are reflected.

Perhaps a way of looking at the phenomenon more consistent with modern conceptions of the mechanism of radiation may be found in the points of view we suggested in our original note.

ELECTRIC CONDUCTION: HALL'S THEORY AND PERKINS' PHENOMENON

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Communicated, January-9, 1923

1. The free electron theory of electric conduction developed by Drude and others and discussed at great length in standard treatises by Richardson¹ and Jeans² had in its early days much success but today encounters many objections. For example, Jeans points out that the optical phenomena require a far higher degree of ionization in metals than can be reconciled with the specific heats; and on the other hand a low degree of ionization requires a longer free path than seems possible. He suggests the necessity of quantum theory in the premises. For several years, however, Hall³ has been developing a dual theory of electric conduction where the ions play the preponderant rôle by favoring the advance of the state of ionization and the free electrons contribute comparatively little to the conductivity. According to this theory there need be no insuperable difficulty with the specific heats; but some other explanation than Schuster's⁴ and Nicholson's⁵ would have to be given for the optical phenomena. We are, however, by this time accustomed to the apparent necessity of dealing in quanta where radiation is concerned, and this need