THE EFFECT OF TEMPERATURE ON THE SCATTERING OF X-RAYS BY CRYSTALS.

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Synopsis.

Variation of the Scattering of X-Rays by Rocksalt and Calcite with Temperature.—Using x-rays from the *W* target of a Coolidge tube operated at 95 kv., the ratio of the radiation scattered from a crystal at 295° C. to that scattered at the same angle from the crystal at 17° C. was found to be: 1.33 and 1.18 ± .10 for rocksalt and angles of 15° and 30° respectively, and 0.99 and 1.03 ± .04 for calcite and angles of 30° and 73° respectively. Thus there is a marked effect for rocksalt but apparently none for calcite, which seems to scatter x-rays like an amorphous substance. *Comparison with the Debye theory* shows that even for rocksalt the effect is considerably smaller than that theoretically predicted, whether zero-point energy is assumed or not, while for calcite the disagreement is marked.

Debye[1] has developed a theory of the scattering of x-rays in which he predicts that the intensity of the x-rays scattered in a direction ϕ with the primary rays should be proportional to $(1 - e^{-M})$, where

$$M = \frac{0.569 \times 10^{-12}}{A\Theta\lambda^2} \times (1 - \cos\phi) \times \frac{F(z)}{z}$$

for no zero-point energy, and

$$M = \frac{0.569 \times 10^{-12}}{A\Theta\lambda^2} \times (1 - \cos\phi) \times \left[\frac{F(z)}{z} + \frac{1}{4}\right]$$

for zero-point energy. In these expressions, λ is the wave-length of the x-rays, A the atomic weight, Θ the characteristic temperature of the crystal, z the ratio of the characteristic temperature of the crystal to its experimental temperature, and $F(z)$ is a function which Debye evaluates. As shown by the author in a previous paper,[2] Debye's theory falls far short of explaining the scattering curves for the crystals calcite and rocksalt obtained experimentally and it is therefore of interest to determine how the temperature affects the intensity of the x-rays scattered in a certain direction ϕ.

The crystal to be investigated was placed with its (100) face on the axis of a Bragg spectrometer as in the single crystal method described in the previous paper. In the present experiment, however, the crystal

[1] P. Debye, Ann. der Phys., Band 43 (1914), pp. 47–95.

[2] G. E. M. Jauncey elsewhere in this issue of the Phys. Rev.

was surrounded by a heating box, supplied with mica windows. The x-rays from a Coolidge tube with a tungsten target, which was operated at a potential of 95 kilovolts in most cases and at a potential of 70 kilovolts in one case, passed through the mica windows. The crystal face was set at an angle θ, and the ionization chamber at an angle ϕ, with the primary rays, care being taken that only diffusely scattered rays and no regularly reflected rays entered the chamber. A set of 10 readings was taken at the room temperature, which was 290° K., a second set was taken at a temperature of 568° K., and a third set when the crystal had cooled to room temperature again. The average of the second set was divided by the average of the first and third sets. The results are shown in the third column of Table I. The temperature was measured with a mercury-in-glass thermometer. In order to be sure that the crystal was at the temperature of the thermometer, the readings at the high temperature were not taken until one hour after the thermometer first registered 568° K. The change of the sensitivity of the electrometer during this time was measured and allowed for.

TABLE I.

$$\frac{\text{Scattered Intensity at } 568^\circ \text{ K.}}{\text{Scattered Intensity at } 290^\circ \text{ K.}}$$

Crystal	Scattering Angle.	Experimental Value.	Theoretical Value.	
			No Zero-Point Energy.	Zero-Point Energy.
Rocksalt [1].........	15°	1.33	1.87	1.65
Rocksalt [1].........	30°	1.18	1.37	1.26
Calcite[1]...........	30°	0.99	2.64	1.56
Calcite[1]...........	73°	1.03	2.03	1.25
Calcite[2]...........	73°	1.03	2.23	1.29

The theoretical values are calculated from Debye's formula. These are shown in the fourth and fifth columns of Table I. The mass absorption coefficient of the x-rays in aluminum was measured, the mean of the coefficients when the aluminum was placed in the primary and when it was placed in the scattered beam being taken. From the relation between the absorption coefficient and the wave-length given by Hewlett,[3] the effective wave-length of the scattered x-rays was found. The average atomic weight of $CaCO_3$ was taken as 20 and that of NaCl as 29. The characteristic temperatures of calcite and rocksalt[4] are 910° K. and 260° K.

[1] Wave-length 0.28 Å. U

[2] Wave-length 0.36 Å. U.

[3] C. W. Hewlett, PHYS. REV., Second Series, Vol. 17 (1921), pp. 284–301.

[4] A. H. Compton, PHYS. REV., Second Series, Vol. 9 (1917), p. 47.

It will be seen that rocksalt shows a temperature effect, but not so large as that predicted by Debye on the assumption of either no zero-point energy or zero-point energy. Calcite on the other hand shows practically no temperature effect. The ratios in the third column are correct to 8 per cent. in the case of rocksalt and to 4 per cent. in the case of calcite. It might be argued that one is not justified in taking 20 as the average atomic weight of calcite as the atomic weights vary from 12 to 40. The ratio for zero-point energy for a wave-length of 0.28 Å. U. and scattering angle 73° has been calculated to be 1.12 for an atomic weight of 12 and 1.45 for an atomic weight of 40. The experimental value is still much less than the smaller of these two values.

These results are in accord with the results of the previous paper. There is a very rough agreement between Debye's theory, assuming a zero-point energy, and the experimental results for rocksalt, but there is no agreement for calcite. Calcite seems to act very similarly to an amorphous substance as far as scattering is concerned. This seems to indicate that the electrons in the calcite molecule which cause the scattering act more or less independently of one another.

In a recent theoretical paper by Brillouin,[1] doubt is thrown upon the validity of the theory of Debye. Brillouin intimates that the scattering from crystals may be unaffected by the temperature.

Washington University,
St. Louis, Mo.,
June 8, 1922.

[1] L. Brillouin, Ann. de Phys., Tome 17 (1922), pp. 88–122.