Optical observation of the thermal agitation of the atoms in crystals

According to the theory of specific heats developed by Debye, Nernst, and others, the thermal energy of a solid is made up of the energy of elastic vibrations in its material, the frequencies of such vibrations ranging from very small values up to a maximum limit determined by the ultimate molecular or atomic structure. On this view it is clear that at ordinary temperatures the density of a solid, and therefore also its refractive index if it be of transparent material, would vary arbitrarily from point to point about its mean value. In other words, a transparent crystal cannot be regarded as optically homogeneous even with reference to the comparatively long waves which constitute ordinary light. It follows that a certain proportion of the energy of a beam of light traversing the medium would be deviated laterally and appear as scattered light, the intensity of such scattering being a measure of the thermal agitation within the crystal. That some such effect must occur has already been pointed out by Sir Joseph Larmor (*Philos. Mag.*, **37**, p. 163, 1919), but no theoretical discussion of its magnitude appears so far to have been put forward. It has occurred to the present writer that the effect to be expected may be found in the following way:—If the principles of statistical mechanics and the equipartition of energy were applicable in the case of solids, precisely the same considerations which determine the molecular scattering of light in fluid media would enter here as well, and the scattering coefficient would be given by the Einstein–Smoluchowski formula

$$\frac{\pi^2}{18} \frac{RT\beta}{N\lambda^4} (\mu^2 - 1)^2 (\mu^2 + 2)^2,$$

where β is the compressibility of the solid, μ is its refractive index, λ is the wavelength of the light, and R, T, N are the constants of the kinetic theory. It is known, however, that the heat content of solids at the ordinary temperature is much less than that indicated by the equipartition principle, the deficiency being most marked for substances, such as diamond, having a high "characteristic temperature". The scattering coefficient given by the preceding formula must therefore be diminished in the ratio which the actual heat content at the temperature of observation bears to the heat content indicated by the equipartition principle. This correction factor may be found from the experimental data for the specific heats at low temperatures given by Nernst, Lindemann, and

Calculations made in the way indicated above show that transparent quartz should scatter light $9\frac{1}{2}$ times as strongly as dust-free air at normal temperature and pressure. A scattering of approximately this magnitude in clear quartz was detected photographically by R J Strutt (now Lord Rayleigh) (*Proc. R. Soc. London*, **95**, p. 495, 1919), but was ascribed by him to inclusions which he assumed were present in the crystal. It is clear from what has been said above that the effect observed by him was actually due to the thermal agitation of the atoms in the crystal. The present writer has succeeded in demonstrating the scattering of light in clear quartz by direct visual observation. For this purpose a block of the crystal with smooth polished faces is immersed in a tank of clean distilled water to minimise surface-reflections and a converging lens is used to bring a beam of sunlight to a focus within the crystal. The blue track of the beam within the crystal may then be readily observed, and its intensity can be judged by comparison with the scattering of the beam in saturated ether vapour. The writer has had the pleasure of exhibiting the phenomenon to Sir W J Pope and other distinguished callers at his laboratory.

Transparent rock-salt which has a low characteristic temperature and shows a marked "Debye-effect" in experiments on X-ray reflection exhibits a very strong scattering of ordinary light. The increase of the scattering with rise of temperature may readily be observed with it.

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