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Thermal opalescence in crystals and the colour of ice in glaciers

In a previous communication to *Nature* (**109**, page 42) it was pointed out that the thermal agitation of the atoms in crystals causes optical heterogeneity which should give rise to a noticeable scattering when a beam of light is sent through the substance, and that this effect may actually be observed with suitable arrangements in clear quartz or rock-salt. I have recently found that the same phenomenon is conspicuously exhibited by ice. If a block of clear ice, free from air bubbles, striae, or other obvious inclusions, and having flat sides, be held squarely and a narrow pencil of sunlight concentrated by a lens be passed through it, the track of the pencil shows a beautiful blue opalescence. It is advisable not to use a very highly-condensed cone of rays, as this would cause internal melting of the ice with formation of cavities which reflect white light and distract the eye. A dark background should be provided against which the track may be viewed. With small or irregular lumps of ice, the observation may easily be made by immersing the ice in clear distilled water contained in a glass flask which is painted black outside, windows being provided for ingress and egrees of light and for observation of the opalescent track. Even with ice which at first looks unpromising owing to internal flaws or inclusions, portions in which the blue opalescence is not overpowered by disturbing effects may be picked out. A suitable orientation of the block with reference to the direction of the incident rays is often useful in avoiding reflections from cavities in the ice.

A comparison of the relative scattering powers of clear water and of ice at 0° C is instructive. According to the measurements of Bridgeman, the compressibility of ice is 35×10^{-6} per atmos, and its refractive index is 1·310, while the corresponding figures for water are 52×10^{-6} per atmos, and 1·334. The Einstein–Smoluchowski formula gives the scattering power of water at 0° C as 144 times that of dust free air, and if it could be applied in the case of solids, the scattering power of ice should be 79 times that of air. As has already been pointed out, however, the formula has to be modified in the case of crystalline solids and a revised calculation indicates the scattering power of ice as about 30 times that of air, which is of the order actually observed in experiment.

The atomic scattering of light in block-ice demonstrated and measured in these experiments should certainly be capable of being observed on a large scale under suitable natural conditions. Indeed, it is well known that masses of ice in glaciers and icebergs often exhibit a blue colour, and it appears to the writer very significant that the circumstances in which natural ice shows a blue colour are precisely those found to be necessary in the laboratory in order that the blue opalescence due to internal scattering may be satisfactorily observed, that is, that the ice should be of the maximum clearness and transparency; in either case, air-bubbles, striae, and other inclusions obscure the effect sought for. The inference that the phenomena arise in the same way seems legitimate.

I am aware that a different explanation of the colour of natural ice has been put forward by Tyndall and other writers, that is, that the colour is simply an absorption effect. To me, however, it appears that the latter view presents fundamental difficulties. *Prima facie*, no substance can exhibit colour *in its own body* except as the result of internal diffusion or scattering. Colour due to simple absorption can only be perceived when a luminous object is viewed through the substance, and even then it is the source, not the absorbing medium, that appears coloured.

The absorption theory thus leaves it unexplained why clear ice should exhibit any colour at all. Indeed, it would appear that the colour of ice is often very conspicuously observed when the light traversing it has no chance of reaching the observer's eye directly. Thus, for example, in his lecture on ice and glaciers, Helmholtz describes very vividly the experience of the Alpine traveller who, traversing the broken surface of the glacier along a narrow ridge, looks down into the crevasses on either side and views with mixed feelings of pleasure and awe their dark blue walls going down to the depths. It is obvious that in such a case as this, the light filtering *down* into the solid mass of transparent ice forming the glacier through the superficial layers or otherwise, has no possibility of returning to the observer above except as the result of internal scattering.

The natural view to take is therefore that the blue opalescence is the real cause of the colour of transparent ice observed under such conditions, the absorption of light in traversing the medium tending merely to diminish its intensity and make it of a more saturated hue.

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