The Crystal Structure of Pond Ice Observed with Polaroid Spectacles

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NEARLY everyone has worn Polaroid spectacles at one time or another and noticed that the sky appears to change its brightness and color when the head is tilted from side to side. If a slab of ice cut from a pond is held up to the sky and examined while one's head is tilted to the angle at which the sky appears darkest, the ice crystals are revealed in colorful contrast.

This is a phenomenon of polarization. Certain objects appear strongly colored when examined in polarized light because of their anisotropism or property of "double refraction." Many natural crystals are anisotropic—calcite is exceptionally so—and most transparent substances will become so if they are subjected to mechanical strain. Within anisotropic substances, the velocity of light is different in different directions and for different frequencies of vibration and varying directions of approach. Therefore it commonly happens that several wave trains interfere destructively with each other while others interfere constructively. The destructive interference subtracts certain frequencies from the beam of light that finally gets through, with the result that it is colored. The depth of color (more precisely, the order of interference) is a direct function of the degree of anisotropism and thickness of the substance. In order to observe the interference color, the light entering the substance must be plane polarized, as from the sky, and the light emerging from the substance must be examined through a plane polarizing medium at right angles to the first. In this manner only the interference colors produced in a single plane are observed. Were it otherwise, the transmitted light would be practically white again due to the great variety of angles and velocities producing a confusion of colors simultaneously.

The sky looks dark when observed in the proper way through Polaroid spectacles because light from the sky is partly plane polarized. Since light which has passed through Polaroid lenses is also considerably plane polarized the amount of light reaching the eyes depends upon the angle between the two planes of polarization. When they are parallel, almost half of the light from the sky reaches the eyes. When they are perpendicular only the small unpolarized component of the sky light gets through. It can be shown by computations from Brewster's Law that sunlight, reflected from molecules of air overhead, is maximally polarized at an angle of very nearly 45°. Since the angle of reflection is equal to the angle of incidence, it is evident that one will observe maximal polarization in sky light when he looks at right angles to the incoming sunlight. A rule for observing the maximum dimming of the sky with Polaroid spectacles: point the top of the head at the sun while looking upward. The angle is frequently awkward, but in this position the plane of polarization of the sky light is at right angles to the plane of transmission of the Polaroid lenses; hence a minimum of light gets through the lenses. This is called the extinction position. Extinction in plane polarized monochromatic light is almost black. But light from the sky is composed of all wave lengths and not all of it is polarized in the same plane; hence the extinction is rather imperfect. Herepathite (tetraiodo quinine sulfate), the crystalline polarizing compound in Polaroid, is slightly less efficient in polarizing deep red and deep blue light than it is for the yellows and greens. Therefore the sky will appear rather a deep gray-blue at extinction, the gray being due to the unpolarized component of the sky light itself, and the blue cast a result of the less perfect action of Herepathite in polarizing blue light. It is this small degree of imperfection which makes the interference phenomena observed in this manner more than usually colorful and spectacular.

One other factor involved in this observational technic is the fact that light from the sky converges strongly upon the pupil of the eye. Therefore, if one examines a section of pond ice which is approximately plane-parallel, the light passing through the center of the sheet, when held squarely, travels a shorter path through the ice than the light entering obliquely. Recalling that the interference color is a function of the thickness of the section, it is evident that the colors in different parts of the section will vary. They will be arranged in concentric rings around the ray traveling the shortest path. Each successive ring is composed of the spectral colors, which grow fainter and more confused as the diameters of the rings increase. Across the rings of color, dark bands will be seen which correspond to the planes of polarization of the sky light and the Polaroid glasses. These dark bands are called isogyres, and by their means the crystallographer can tell the orientation of the crystal he is observing.

In pond ice, for instance, there are two distinct modes of orientation. When the pond first freezes over, the ice crystals grow from the colder water near the shore into the cooling water in the middle. Ice crystals grow with their principal axes parallel with the temperature gradient. Therefore the first skin of ice will be composed of horizontal crystals in roughly convergent array toward the center of the pond. A section of this early ice held up to the sky for examination in polarized light will show colored rings but the isogyres will move across each of the crystals in the section very swiftly as it is rotated on the line of sight. This is the flash figure which indicates that the principal crystallographic axis is perpendicular to the line of sight. If one waits for the later growth of ice which develops straight downward into the cooling interior of the pond after it is completely covered with crystals, and then cuts a section, he will observe in each of the crystals a pair of isogyres resembling the Maltese cross. These isogyres remain relatively stationary when the section is rotated.

The pattern is the optic axis figure which indicates that one is looking along the principal axis of the hexagonal ice crystal. Upon closer scrutiny of the crystal sections one may see the undulatory extinction pattern which is caused either by strains due to unequalized pressure within the ice or to discontinuous crystallization at the time the ice was formed. Large "single crystals" of ice may in this way be found in pond ice when the conditions of crystallization have been favorable.