

Anisotropy

Some physical properties, such as the density or heat capacity of a material, have values independent of direction; they are *scalar* properties. However, in contrast, you will see that many properties vary with direction within a material. For example, thermal conductivity relates heat flow to temperature gradient, both of which need to be specified by direction as well as magnitude - they are *vector* quantities. Therefore thermal conductivity must be defined in relation to a direction in a crystal, and the magnitude of the thermal conductivity may be different in different directions.

A perfect crystal has long-range order in the arrangement of its atoms. A solid with no long-range order, such as a glass, is said to be *amorphous*. Macroscopically, every direction in an amorphous structure is equivalent to every other, due to the randomness of the long-range atomic arrangement. If a physical property relating two vectors were measured, it would not vary with orientation within the glass; i.e. an amorphous solid is *isotropic*. In contrast, crystalline materials are generally *anisotropic*, so the magnitude of many physical properties depends on direction in the crystal. For example, in an isotropic material, the heat flow will be in the same direction as the temperature gradient and the thermal conductivity is independent of direction. However, as will be demonstrated in this TLP, in an anisotropic material heat flow is no longer necessarily parallel to the temperature gradient, and as a result the thermal conductivity may be different in different directions.

The occurrence of anisotropy depends on the symmetry of the crystal structure. Cubic crystals are isotropic for many properties, including thermal and electrical conductivity, but crystals with lower symmetry (such as tetragonal or monoclinic) are anisotropic for those properties.

Many (but not all) physical properties can be described by mathematical quantities called *tensors*. A non-directional property, such as density or heat capacity, can be specified by a single number. This is a *scalar*, or *zero rank tensor*. Vector quantities, for which both magnitude and direction are required, such as temperature gradient, are *first rank tensors*. Properties relating

two vectors, such as thermal conductivity, are *second rank tensors*. Third and higher rank tensor properties also exist, but will not be considered here, since the mathematical descriptions are more difficult.

Light transmitted by an anisotropic material

When monochromatic light is incident on the polariser, only the component of light with an electric vector parallel to the axis of the polariser will be allowed to pass through. When the plane polarised light arrives at the specimen it is refracted and, if the material of the specimen is anisotropic, it is split into two separate waves, one vibrating parallel to one permitted vibration direction and the other wave parallel to the other (orthogonal) permitted vibration direction. The velocities of these waves will be determined by the relevant refractive indices, which will be different for the two directions and therefore the waves will become progressively out of phase as they pass through the material. The phase difference can alternatively be expressed in terms of the *optical path difference*, the distance that progressively separates points on the two waves that coincided initially. Upon emerging, the two waves recombine; however the exact way they recombine will depend on the phase difference between, which depends on the difference between the two refractive indices, the *birefringence*, Δn , and the distance travelled by the light through the specimen. In general the resultant wave will have a component of its electric vector parallel to the analyser direction.

Plane polarised light has its electric vector vibrating along one direction, the *polariser direction*. When a material is orientated so that one of the permitted vibration direction lies parallel to the polariser direction, the light travels through the specimen without change in its polarisation state and therefore emerges from the specimen with its electric vector still parallel to the polariser direction and so perpendicular to the analyser direction. This light will not pass through the analyser. These settings are known as extinction positions and produce isoclinic fringes, fringes which occur wherever either principal stress direction coincides with the polariser direction.

The transmitted intensity will also be zero when the optical path difference is an integral number of wavelengths (the phase difference is an integral multiple of 2π). In this case, the beams recombine to give a beam with the same polarisation state as the incident beam, i.e. with the electric vector parallel to the polariser direction, and hence the transmitted intensity is zero.

We have seen that an applied stress can result in a change in the refractive index of a transparent substance. If a general system of stresses is applied in a plane, the optical birefringence, Δn , produced will be proportional to the difference, $\Delta\sigma$ between the two principal stresses in the plane. We can define the stress-optical coefficient C , such that

$$|\Delta n| = C\Delta\sigma$$

For a sample of uniform thickness, regions in which $\Delta\sigma$ [or equivalently $(\sigma_P - \sigma_Q)$] is constant show the same interference colour when viewed between crossed polars. Contours of constant principal stress difference are therefore observed as isochromatic lines. In order to determine the directions of the principal stress it is necessary to use isoclinic lines as these dark fringes occur whenever the direction of either principal stress aligns parallel to the analyser or polariser direction.

Source: <http://www.doitpoms.ac.uk/tlplib/anisotropy/intro.php>