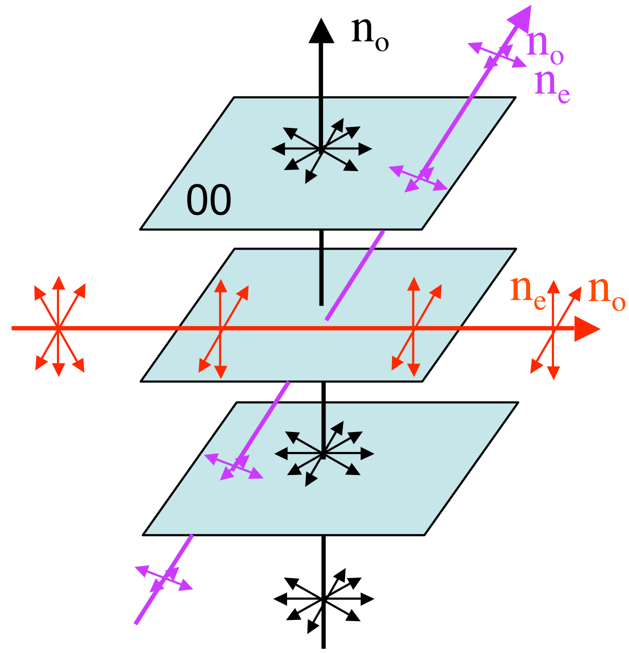
Notes on Birefringence

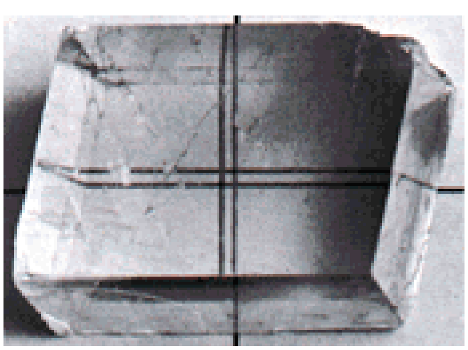
Sources: Hecht, Optics, 1998, vide infra

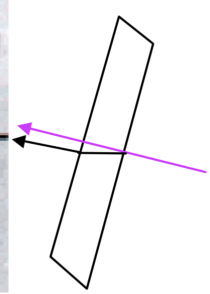
Birefringent materials are optically anisotropic (their properties depend on the direction a light beam takes across them) because their molecules do not respond to the incident light evenly in all directions. This arises from their molecular (bond strengths) and crystal (arrangement) structures (F06: Problem Set 2; #5). However, in all such materials there is at least one optic axis (some materials have two) along which propagating light can travel with no consequences to either (any) component of its electric vector (black ray in figure). This axis serves as a kind of reference. Light traveling in any other direction through the crystal experiences two different refractive indices and is split into components that travel at different speeds and have perpendicular polarizations. When light travels perpendicular to the optic axis (red ray in figure) the component polarized perpendicular to the optic axis experiences the ordinary refractive index ($n_o$). The component polarized parallel to the optic axis experiences the extraordinary refractive index ($n_e$). When light enters the crystal at an oblique angle (purple ray in figure) there is a component that experiences $n_o$ vibrating in a plane perpendicular to the optic axis. The other polarization vibrates perpendicularly to the ordinary ray in a plane that makes an angle with the optic axis.




Adapted from
http://www.brocku.ca/earthsciences/people/gfinn/optic

The quintessential example of a birefringent material is calcite, shown below. This image shows the light entering the crystal being split into two components. The ray that obeys Snell's law (component travels straight across crystal at normal incidence) is polarized perpendicular to the direction of the optic axis. The ray that does not (deviated ray in spite of normal incidence) is called the extraordinary ray and has the opposite polarization. The birefringence is $\Delta n=(n_e-n_o)$. This figure shows that two images of the crossed lines are transmitted by the calcite. The diagram on the sides illustrates the image paths.





http://webphysics.davidson.edu/alumni/MiLee/JLab/Crystallography_WWW/birefringence.htm

The significance of the birefringence is that optical materials can be cut to impose specific changes in the polarization of incident beams. For example half-wave plates are cut to impose 180° ($\frac{1}{2}(2\pi)$) phase shifts. When linearly polarized light travels in a birefringent crystal, the phase difference imposed on the two components depends on the birefringence, incident angle, $\theta$, crystal thickness, L. and free-space (vacuum) wavelength, $\lambda_0$: $\Delta\phi = \frac{2\pi L}{\lambda_0}\left[n_e(\theta) - n_o\right]$.