

# PHY2208 Lecture 18

## Birefringence Quarter and half-wave plates

Pedrotti & Pedrotti sec. 15-4, 26-4

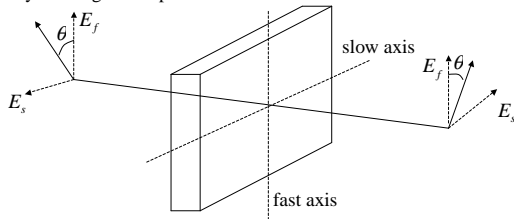
**Birefringence** is when a material displays different refractive indices for light of different polarization states.

Consider an incident beam comprising two orthogonal polarization components. If these components propagate through a slab of thickness  $d$  and experience two different values for  $n$ , they will experience different optical paths and this will alter their phase relationship.

In general, we can identify two orthogonal axes with a birefringent material (typically denoted **fast** and **slow**, or **extraordinary** and **ordinary**).

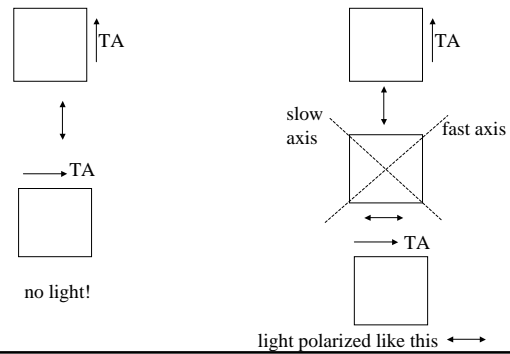
Linearly polarized light whose E-field is aligned with the fast axis experiences a ref. index  $n_e$ , while that aligned with the slow axis experiences a ref. index  $n_o$ .

Consider a linearly polarized beam with E aligned at an angle  $\theta$  to the fast axis. Suppose the slab is so constructed as to introduce an OPD of  $\lambda/2$  between the components of E resolved along the fast and slow axes. The result is to retard one component by 180 degrees of phase:



This **half-wave plate** flips the direction of  $E$  about the fast (or slow) axis.

e.g. consider cross polarizers, which are normally opaque. Placing a half-wave plate between them, with the fast/slow axis at 45 degrees to the TA's will render them transparent:



### Application: liquid crystal displays

Pockels and Kerr cells are devices whose birefringence can be altered by applying a voltage. Cross-polarizers can be rendered transparent or opaque under voltage control. Optical shutters with switching times as short as 100 fs can be built!

To construct a half-wave plate we require an OPD of:

$$\left(m + \frac{1}{2}\right)\lambda$$

where  $\lambda$  is the vacuum wavelength.

$$(n_e - n_o)d = \left(m + \frac{1}{2}\right)\lambda$$

where  $d$  is the physical thickness of the plate.

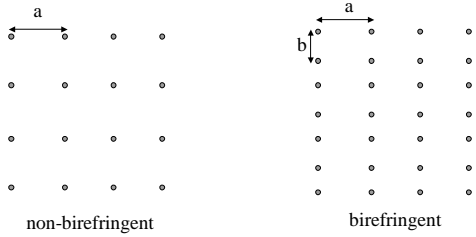
The quarter wave-plate is constructed using a plate whose thickness  $d$  satisfies:

$$(n_e - n_o)d = \left(m + \frac{1}{4}\right)\lambda$$

such a plate introduces a  $\lambda/4$  path difference and hence a 90 degree phase difference between the polarization components.

A quarter-wave plate whose fast axis is at 45 degrees to the orientation of  $E$  will convert linearly polarized light into circularly polarized light.

Birefringence has its origin in asymmetries in the microscopic structure of materials e.g. an orthorhombic crystal lattice will display birefringence:



Such asymmetries in a crystal structure affect the effective binding strength between an atomic nucleus and its electrons in various directions.

The refractive index of a medium arises through the induction of a periodic dipole moment in the medium by the incident EM wave (**see handout**).

Asymmetries in the structure make it easier or harder for the EM wave to induce these dipole moments. The net result is to make the refractive index appear different for different orientations of the incident E-field.

In any real 3D crystal lattice, we can always find at least one axis in space along which the lattice appears symmetric. When an incident EM wave propagates along this axis, it will not experience any birefringence. This defines the **optic axis (OA)** of the crystal.

Now do problem 6 on Problem Sheet 3