Original provided by Linda Lundström
Revised and translated by Per Jansson
Tel: 08-5537 8212
Mail: per.jansson@biox.kth.se

Optical Physics: Summary Session 5

Polarization

One usually speaks of four different **states of polarization** for light, and they can all be divided into two polarization states orthogonal to each other:

- $\mathscr{P}$ Linearly polarized: $\vec{E} = [E_{0x}, E_{0y}, 0]cos(\omega t - kz)$
- $\mathscr{R}$ Right circular polarized: $\vec{E} = E_0[cos(\omega t - kz), sin(\omega t - kz), 0]$
- $\mathscr{L}$ Left circular polarized: $\vec{E} = E_0[cos(\omega t - kz), -sin(\omega t - kz), 0]$
- $\mathscr{E}$ Elliptically polarized: $\vec{E} = [E_{0x}cos(\omega t - kz), E_{0y}cos(\omega t - kz + \epsilon), 0]$

When light is reflected by a surface at the **Brewster angle**, only light polarized with its $\vec{E}$-field normal to the plane of incidence will be reflected. The reflected wave is thus linearly polarized, even though the incident wave is unpolarized (this can be understood from Fresnel's equations). Brewster's angle θ_p fulfills the following condition:
$\theta_r + \theta_t = 90° \implies tan\theta_p = \frac{n_t}{n_i}$

Dichroism means that the absorption is different for the two orthogonal states of polarization.

Birefringence takes place in materials that have two different refractive indices for two states of polarization. The reason behind this is an unsymmetrical binding force between the electrons and the atom cores (the material is anisotropic). In a birefringent material the **optical axis** is defined as the direction with the extraordinary refractive index, n_e. All other directions have the ordinary refractive index, n_o. This means that light incident on the material with the $\vec{E}$-field orthogonal to the optical axis will feel n_o, whereas light with the $\vec{E}$-field parallel to the axis will feel n_e. A birefringent material with two different refractive indices has one optical axis and is therefore called **uniaxial**. There are also biaxial birefringent materials with three different refractive indices and therefore two optical axes.
Birefringence can be induced in some common materials by mechanical stress (photoelasticity), magnetic fields (e.g. Faraday effect) or electrical fields (e.g. Kerr effect).

Retarders are made of birefringent materials and they can change the state of polarization of a beam by giving one of the $\mathscr{P}$-components a phase difference $\Delta\varphi$. This happens when light is incident orthogonal to the optical axis of the material. The $\vec{E}$-component parallel with the optical axis experiences a refractive index n_e and the component orthogonal to the axis experiences n_o. This induces a phase difference between the polarization states. The phase difference induced between the parallel and orthogonal polarization state, if the material has a thickness d, is:
$\Delta\varphi = \frac{2\pi}{\lambda_0} d(n_e - n_o)$

Full-wave plate: $\Delta\varphi = 2\pi$
Half-wave plate: $\Delta\varphi = \pi$
Quarter-wave plate: $\Delta\varphi = \frac{\pi}{2}$

A retarder can have a phase difference that is the desired plus a multiple of 2π, a so called multiple-order retarder.

A material is **optically active** if it refracts the $\mathscr{R}$-component and the $\mathscr{L}$-component differently when light passes through the material. Thus the material has different $n_{\mathscr{R}}$ and $n_{\mathscr{L}}$, and is circularly birefringent. This effect is seen if the molecules are stereoisomeric, i.e. has a righthanded and lefthanded variant, which is the mirror image of the other.