# Polarization control

Anisotropic optical materials – different refractive index values in different orientations
Uniaxial crystals – linear birefringence

After travelling through a linear birefringent material a linear polarization can
- rotate (half-wave plate)
- become circular (quater-wave plate)
- become elliptical and rotate (in general)

Photoelasticity – matereals develop birefringence under stress
Optical activity – Circular birefringence
In these materials the refractive indices for right- and left-handed polarizations are different. Such materials are <u>chiral</u>

Sugars and amino acids rotate polarization to the right
Many (natural) antibiotics rotate it to the left
This is a really big research challenge in Biology/pharmocology: ~~our bod~~ our bodies are prepared to "digest" only the molecules with correct chirality, and during an artificial synthesis this usually does not happen, and both chiralityes are produced.

Chiral medium rotates linear polarization

Let's say we start with a linear polarization

$\vec{E} = E_0 \vec{e}_x \cos(kz-\omega t)$

we can present it as a combination of two opposite circular polarizations

$$\vec{E}_{in} = \frac{1}{2} E_0 \left( \vec{e}_x \cos(kz-\omega t) + \vec{e}_y \sin(kz-\omega t)\right) +$$
$$+ \frac{1}{2} E_0 \left( \vec{e}_x \cos(kz-\omega t) - \vec{e}_y \sin(kz-\omega t)\right)$$
$$= \frac{1}{2} E_0 \vec{\sigma}_+ + \frac{1}{2} E_0 \vec{\sigma}_-$$

Inside the chiral material $k_+ \neq k_-$

$$k_+ = \frac{2\pi n_+}{\lambda_0}, \quad k_- = \frac{2\pi n_-}{\lambda_0}$$

phase difference $\Delta\varphi = (k_+ - k_-)\cdot d = \frac{2\pi d}{\lambda}(n_+ - n_-)$

So after the chiral material

$$\vec{E}_{in} = \frac{1}{2} E_0 \left( \vec{e}_x \cos(kz-\omega t) + \vec{e}_y \sin(kz-\omega t)\right) +$$
$$+ \frac{1}{2} E_0 \left( \vec{e}_x \cos(kz-\omega t+\Delta\varphi) + \vec{e}_y \sin(kz-\omega t+\Delta\varphi)\right) =$$

$$= \frac{1}{2} E_0 \vec{e}_x \left( \cos(kz-\omega t) + \cos(kz-\omega t+\Delta\varphi)\right) + \frac{1}{2} E_0 \vec{e}_y \left( \sin(kz-\omega t) - \sin(kz-\omega t+\Delta\varphi)\right)$$

$$\boxed{\begin{aligned} \cos\alpha + \cos\beta &= 2\cos\frac{\alpha+\beta}{2}\cos\frac{\alpha-\beta}{2} \\ \sin\alpha - \sin\beta &= 2\sin\frac{\alpha-\beta}{2}\cos\frac{\alpha+\beta}{2} \end{aligned}}$$

$$= E_0 \vec{e}_x \cos\left(kz-\omega t+\frac{\Delta\varphi}{2}\right)\cos\frac{\Delta\varphi}{2} + E_0 \vec{e}_y \cos\left(kz-\omega t+\frac{\Delta\varphi}{2}\right) \times \sin\Delta\varphi/2$$

$$= E_0 \underbrace{\left( \cos\frac{\Delta\varphi}{2}\vec{e}_x + \sin\frac{\Delta\varphi}{2}\vec{e}_y \right)}_{\text{polarization rotation by } \Delta\varphi/2} \cos\left(kz-\omega t+\Delta\varphi/2\right)$$

still linear polarization

Active control of polarization

Induced birefringence : normally isotropic optical material becomes birefringent under the action of external fields

a) Kerr effect : ~~birefrin~~

linear birefringence is induced by external transverse electric field $E$

$$n_e - n_o = \lambda_0 K E^2$$

$\lambda_0$ - wavelength in vacuum

$K$ - Kerr constant

b) Pockels effect

linear birefringence is induced by external longitudinal electric field $E$

$$n_e - n_o = \frac{1}{2} n^3 r E$$

$r$ - pockels constant

$n$ - average refractive index

c) Faraday effect

circular birefringence is induced by external longitudinal magnetic field

$$n_e - n_o = n^3 r_B \cdot B$$

Rotation angle $\varphi = VB\ell$

$V$ - Verdet constant

$\ell$ - the length of the medium