Optics, Spring 2024

Submit your answers as a PDF file via Google Classroom before deadline (15.02.2024 at 10.00).

If problems, contact the course assistant joonas.mustonen@helsinki.fi.

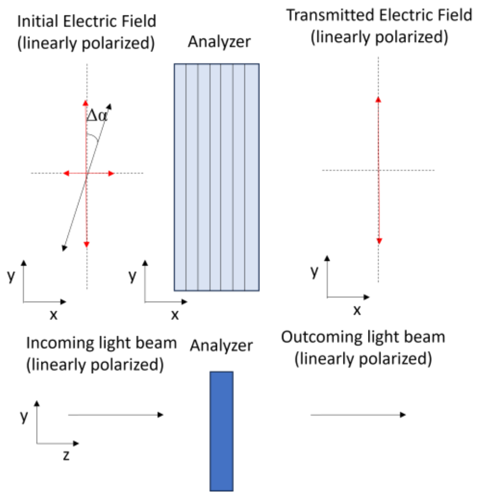
Exercise 3

1. Malus' law (7p.)

As briefly discussed in the previous exercise, as a vector quantity, electric field **E** can be expressed as a superposition of two perpendicular components, noted here as $E_{\perp}$ and $E_{\parallel}$. If the electric field oscillates only in a single plane, light is considered as polarized.

a) (1p.) Consider linearly polarized light propagating through an analyzer (behaves as wire grid polarizer). The angle between planes of transmission of initial polarized light and analyzer is Δα. Derive the irradiance after the analyzer as a function of initial irradiance I_0 and the angle.

$$\boldsymbol{I_0} = \frac{c\epsilon}{2}\boldsymbol{E_0}^2$$



b) (1p.) Consider an optical system, in which unpolarized light propagates through two analyzers. The angle between the axes of first and the second analyzers is 90°. Calculate the irradiance after the last analyzer.

c) (1p.) Consider the previous optical system but add there a third analyzer between the first and the second analyzer. Now, the angle between axes of two consecutive analyzers is 45°. Calculate the irradiance of the light beam after the last analyzer as a function of the irradiance after the first analyzer.

d) (1p.) Consider an unpolarized light beam, propagating through an analyzer. Let's assume that the distribution of polarizations of photons is a continuous uniform distribution. Estimate the irradiance after the last analyzer.

Hint. The irradiance after the analyzer can be estimated by calculating the average irradiance over the angles as follows.

$$\frac{1}{180^{\circ}}\int_{0}^{180^{\circ}} \frac{c\epsilon}{2}\boldsymbol{E_0}^2 \cos(\alpha)^2 \, d\alpha$$

e) (1p.) What kind of assumptions/approximations are there behind previous calculations and evaluate, how realistic the numerical results are.

f) (1p.) Explain the difference between linear, circular and elliptical polarizations.

g) (1p.) In wire grid polarizer, what would be the ratio between the wavelength of the incident light and grid spacing (meaning the distance between adjacent wires)? Why is this ratio important

2. Brewster's angle (2p.)

Consider a case, in which unpolarized light is incident at an interface between two dielectric media. As special case, the incident angle is called a polarization angle if the sum of incident and refracted angles is 90°. At this angle, the reflected light is fully polarized.

a) (1p.) Derive this angle at an interface of two dielectric media with different refractive indices using Snell's law.

b) (1p.) Estimate the Brewster's angle at air-glass interference and air-water interference.

3. Polarization by scattering (3p.)

Scattering is a physical phenomenon, in which a straight-propagating wave is forced to deviate by localized non-uniformities, such as particles. Basically, scattering arises from multiple reflections. Moreover, scattering is a third option, how unpolarized light can be polarized.

a) (1p.) Explain qualitatively the concept of polarization by scattering.

b) (2p.) The polarization by scattering is a consequence of Rayleigh scattering, which can be described as follows.

$$I = I_0 \frac{8\pi^4 N\alpha^2}{\lambda^4 R^2}(1 + \cos^2\theta)$$

, in which N = number of scatterers, λ = wavelength, α = polarization constant, R = distance from scatterers, θ = scattering angle.

Based on the equation, explain, why the sky looks blue most of the time, but during sun sets, the sky looks more red.

source: Wikicommons