Lecture 18:
Polarisation of light, introduction

Lecture aims to explain:

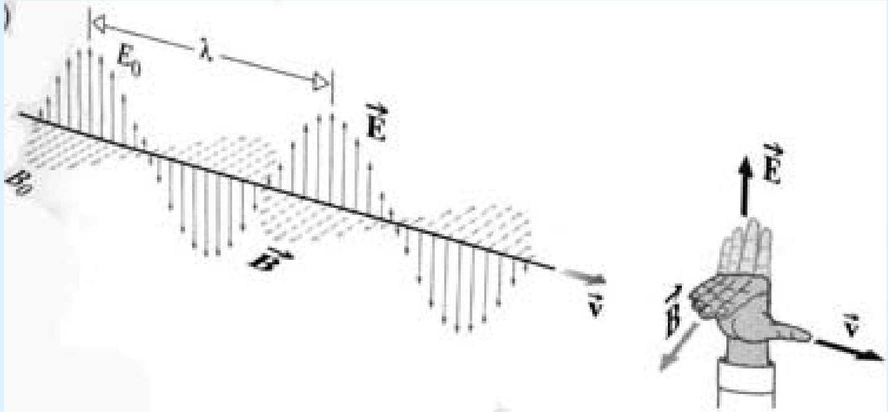
1. **Light as a transverse electro-magnetic wave**
2. Importance of polarisation of light
3. Linearly polarised light
4. Natural light
5. Linear polarisers and **Malus' law**

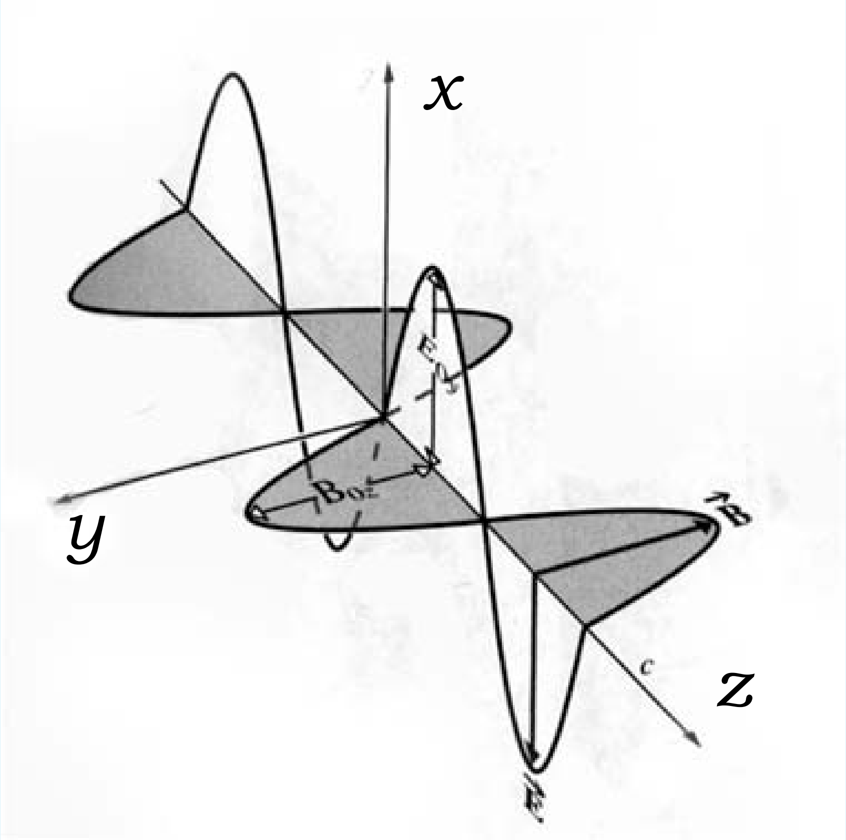
Light as a transverse wave

Light as a transverse electro-magnetic wave

E and **B**- fields are orthogonal

The wave propagates in the direction **E**x**B**





Oscillating electric field of the wave:

$$\vec{E}(z,t) = \hat{i}E_{0x}\sin\left(kz - \omega t\right) + \hat{j}E_{0y}\sin\left(kz - \omega t + \varepsilon\right)$$

Polarisation state of light

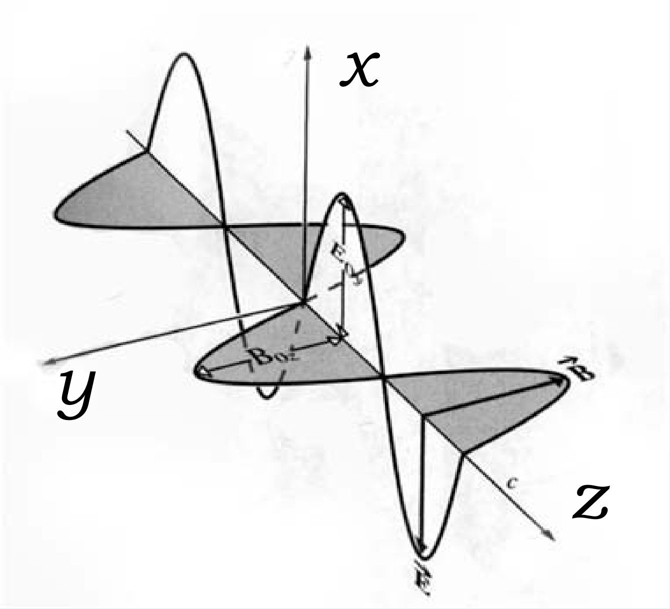
The polarization of light is described by specifying **the orientation of the electric field at a point in space over one period of the oscillation**

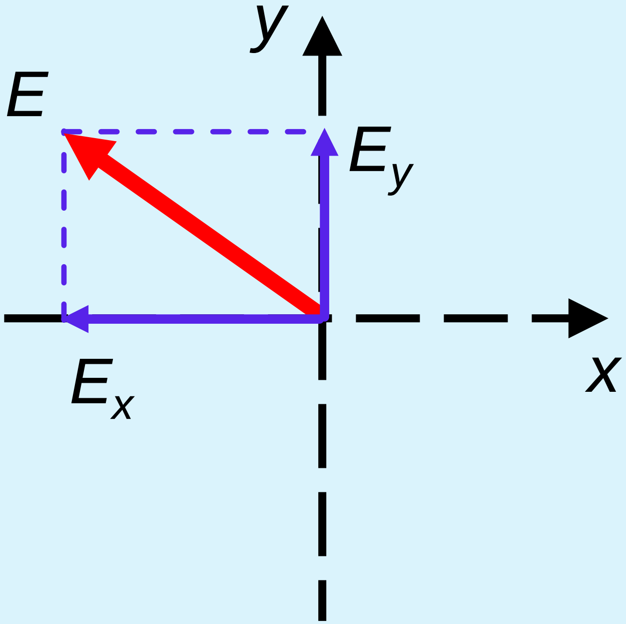
Practical approach: (i) neglect the spatial term, (ii) consider time evolution of projections of the electric field on two orthogonal axis

$$\vec{E}_x(t) = \hat{i}E_{0x}\sin(\omega t)$$

$$\vec{E}_y(t) = \hat{j}E_{0y}\sin(\omega t + \varepsilon)$$

The shape traced out in a fixed plane by the electric field vector is a description of the **polarization state**





Importance of polarisation of light

Examples in everyday life and nature

Light reflected from dielectrics is partially or fully linearly polarised

Polarisation by scattering occurs as light passes through atmosphere

Many natural crystalline materials exhibit birefringence, dependence of the refractive index on the direction of light propagation in the crystal, leading to interesting polarisation effects

Atoms, molecules, semiconductor nanostructures emit polarised light, effects particularly pronounced when magnetic field is applied

Some animals (insects, octopuses etc) are capable of detecting polarised light, possibly used for communication

Polarisation in applications

Communication and detection systems: fibre optics (waveguides), fast light modulators, lasers, radars, satellite communication

Liquid crystal display technology

Optical microscopy: medicine, biology, geology, physics, chemistry

Optical spectroscopy: physics, chemistry, medicine, biology, geology

Material science

Photography, sunglasses, 3D movies

Linearly polarised light

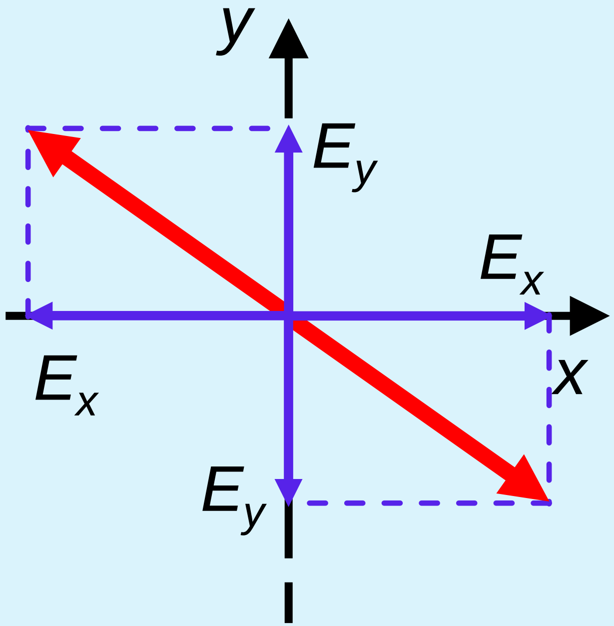
Linearly polarised light

Light is called linearly polarised if the plane of E-field oscillation is fixed

Both Ex and Ey components oscillate with a **phase difference $\varepsilon=\pi m$**

$$E_x(t) = E_{x0}\sin(\omega t)$$

$$E_y(t) = E_{y0}\sin(\omega t + \pi m)$$



“The shape traced out in a fixed plane by the electric field vector is a description of the ***polarization state****”*

Natural light

Natural light

Light sources consist of a very large number of randomly oriented atomic emitters which emit polarised light randomly every 0.1-1 ns

This results in a very quick change of polarisation and an undefined polarisation state of light

Natural light can be represented by two independent (with random relative phase i.e. incoherent) **orthogonally linearly polarised waves of the same amplitude**

$$E_x(t) = E_0 \sin(\omega t) \qquad E_y(t) = E_0 \sin(\omega t + \varepsilon)$$

In this case the intensity measured by the detector is $A=E_0^2$. Each linearly polarised component contributes $E_0^2/2$ of the total irradiance (see Lecture 9 for detailed calculations)

Linear polarisers and Malus’ law

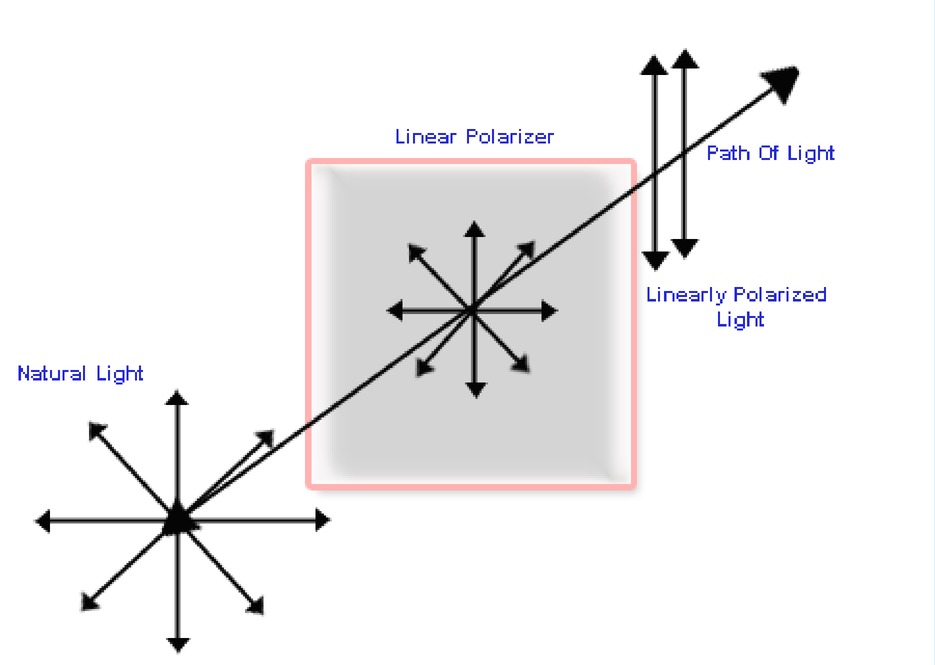
Linear polarisers

Device whose input is light of any polarisation state and output is linearly polarised light

Underlying property of the polariser material is **anisotropy associated with transmission of light having different linear polarisation**

Physical mechanisms: (i) dichroism, or selective absorption; (ii) reflection; (iii) scattering

After the linear polariser, light will be linearly polarised parallel to the **transmission axis** of the polariser



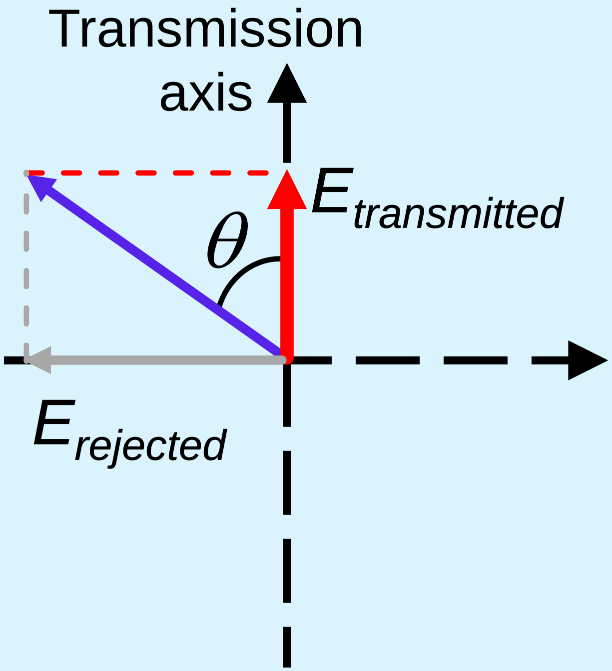
Malus' Law

Describes transmission of linearly polarised light through a linear polariser

The transmitted intensity after an **ideal linear polariser** is described as

$$I(\theta) = I(0)\cos^2\theta$$

Here θ - angle between the plane of light polarisation and transmission axis



Etienne-Louis Malus (1775-1812) was a French officer, engineer, physicist, and mathematician. His discovery of the polarization of light by reflection was published in 1809 and his theory of double refraction of light in crystals, in 1810.

EXAMPLE 18.1

Unpolarised light of intensity I_o is incident on an ideal linear polariser (no absorption). What is the transmitted intensity.

EXAMPLE 18.2

Four ideal linear polarisers are placed in a row with the polarising axes vertical, 20^0 to vertical, 55^0 to vertical and 90^0 to vertical. Natural light of intensity I_0 is incident on the first polariser.

(a) Calculate the intensity of light emerging from the last polariser.
(b) Is it possible to reduce the intensity of transmitted light (whilst maintaining some light transmission) by removing one of the polarisers?
(c) Is it possible to reduce the intensity of transmitted light to *zero* by removing a polariser(s)?

Summary

Light is a transverse electromagnetic wave

Linearly polarised light: Ex and Ey components oscillate with a phase difference $\varepsilon = \pi m$

Natural light can be represented by two independent orthogonally linearly polarised waves of the same amplitude

Malus law: the transmitted intensity after an ideal linear polariser is described as $I(\theta) = I(0)\cos^2\theta$

θ - angle between the plane of light polarisation and transmission axis

See Hecht pp 325-333