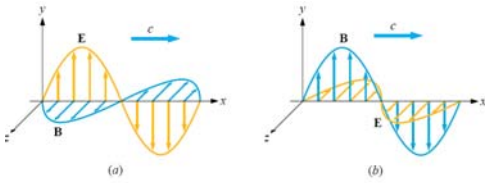
EM Waves
3.3

Polarization of light
Momentum of light

Polarization of light

- Light is a transverse wave.
- The E field vector can be polarized in either of two perpendicular orientation.
- Unpolarized light is a random mixture of two polarizations. The E field fluctuates between different polarization.
- Light may be polarized by physical processes such as absorption, reflection or scattering.
- Polarization of light can be used for electo-optical displays (e.g. liquid crystal displays).

Polarization



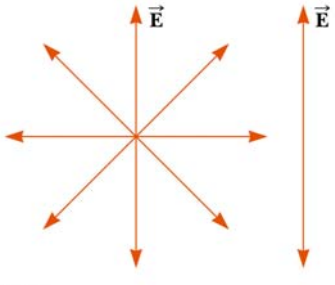
• Light can be polarized with E fields along two perpendicular orientations.

• We can consider light to be a mixture of waves with two perpendicular polarizations.

Unpolarized light

Light from a light bulb is unpolarized
The electric fields arise from independent random oscillator with different orientations in space.

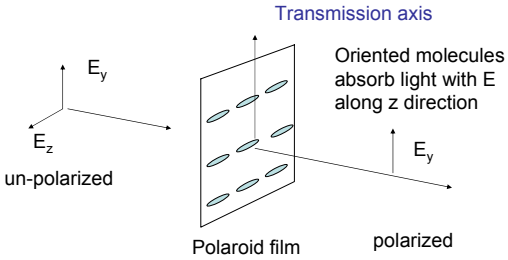
Polarized and un-polarized light



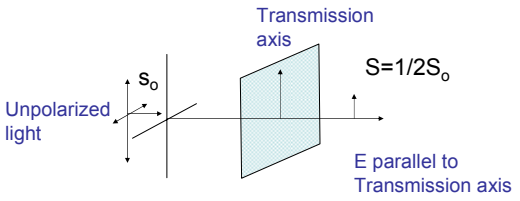
Unpolarized Light
has E field at any instant
can have E in any direction.

Polarized Light
has E field in a
certain direction

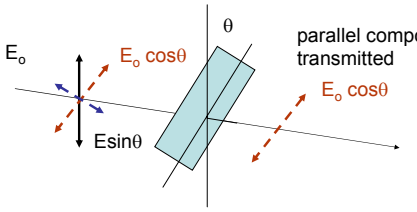
Polarization by absorption



Polarization of light



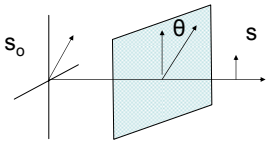
Polarized light passing through a polarizer at angle θ



But $S \propto E^2$

Therefore transmitted intensity
$S = S_o\cos^2\theta$

Law of Malus

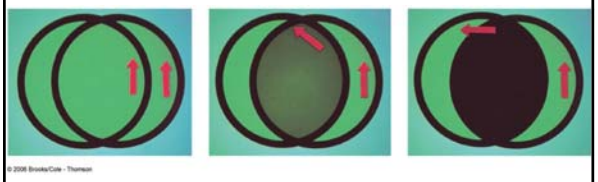


The intensity of a polarized wave S_o after passing through a polarizer with transmission axis an angle of θ from the field direction is reduced by a factor of $\cos^2\theta$

$$S = S_o \cos^2\theta$$

Two polarizers

$I=I_o\cos^2\theta$

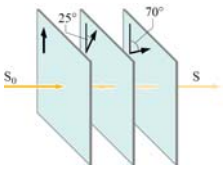


θ=0 θ=45° θ=90°

"Crossed-polarizers"

Example 34.3

A stack of polarizes has the orientation shown in the figure. Unpolarized light with intensity S_o is incident on the stack. Find the final intensity of the light transmitted.



After first polarizer $S' = \frac{1}{2}S_o$

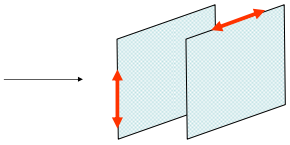
After second polarizer $S'' = S'\cos^2 25$

After third polarizer $S = S''\cos^2(70-25)$

overall $S = \frac{1}{2}S_o \cdot \cos^2(25)\cdot\cos^2(45) = 0.205S_o$

Crossed Polarizers

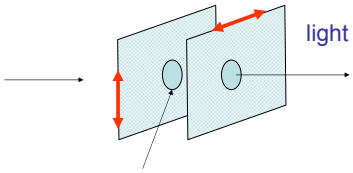
Two polarizers are oriented with their transmission axes at 90°.



no light transmitted

Crossed Polarizers

Two polarizers are oriented with their transmission axes at 90°.

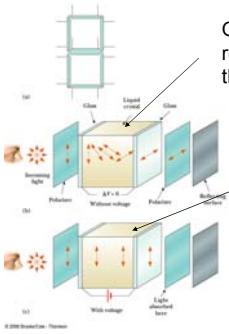


light is transmitted

Birefringent material-Rotates the plane of polarized light

Most materials are not birefringent but some materials can be made birefringent by orientation of molecules due to stress.

Applications – Liquid crystal display (LCD)



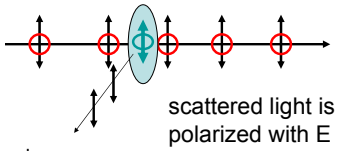
Oriented molecules rotate the plane of the polarized light

When an electric field is applied the molecules reorient so that the light is not rotated.

Polarization by scattering

Plane wave has no E field in the direction of propagation

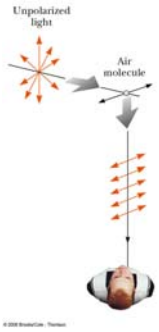
Scattering particle has oscillations partially polarized in the plane ⊥ to the direction of propagation



observer

scattered light is partially polarized with E field ⊥ to the direction of propagation of the incident light

Polarization of light by air



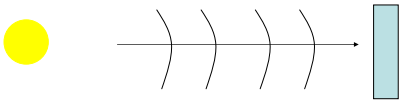
Polarization of scattered light

Light from the sky is partially polarized

no filter

polarizing filter

Momentum of light



Light waves carry energy and also carry momentum

The momentum transferred by the light to an object depends on whether the light is absorbed or reflected.

Momentum and pressure of EM radiation

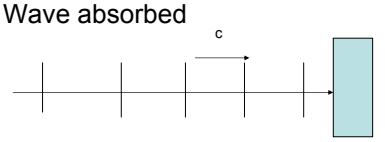
The momentum p is related to the energy of the wave U

$$p = \frac{U}{c}$$

Radiation Pressure is due to momentum transferred. If Light is absorbed the pressure is

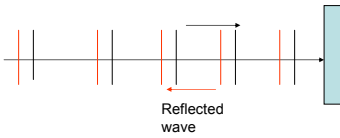
$$P_{rad} = \frac{\overline{S}}{c}$$

Wave absorbed



$$P_{rad} = \frac{\overline{S}}{c}$$

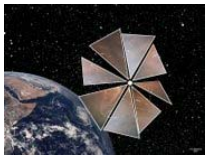
Wave reflected (twice the momentum is transferred)



$$P_{rad} = \frac{2\overline{S}}{c}$$

Solar Sail

Radiation pressure has been proposed a source of propulsion for space craft. For a reflecting "sail" of 1000 m^2 find the force exerted on the sail by sunlight S= 1kW/m^2
If the sail had a mass of 10 kg
what would be the acceleration?



$$F = A \cdot P = A \cdot \frac{2\overline{S}}{c} = (1000)\frac{2(1000)}{3x10^8} = 7x10^{-3}N$$

$$a = \frac{F}{m} = \frac{7x10^{-3}}{10} = 7x10^{-4} m/s^2$$

$$v = 60 m/s$$ in one day sail must be 0.1mm thick.