Polarization of light

Basic Information:

Light

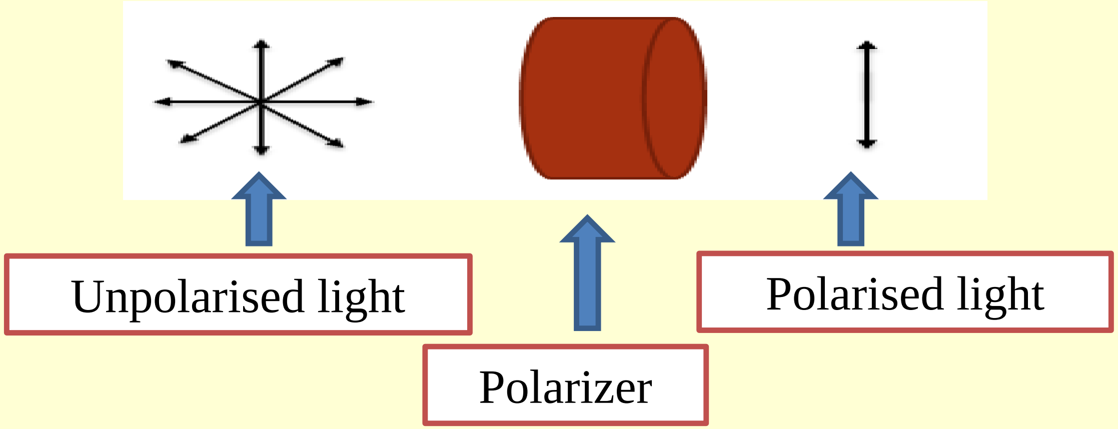
a transverse electromagnetic wave

Unpolarised Light

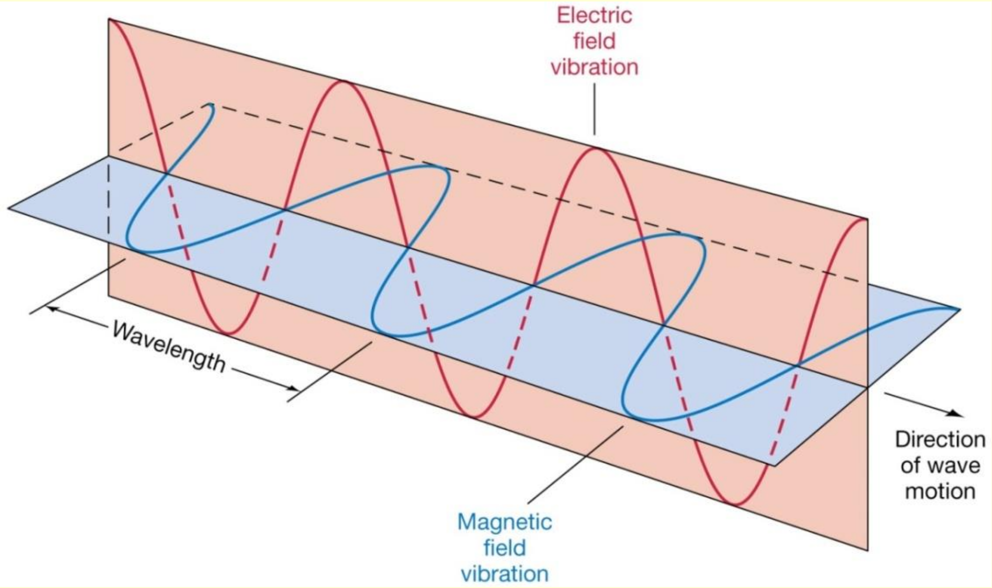
oscillations of electric fields are occurring in all possible directions

Polarised light

oscillations of electric fields are occurring in a particular direction



Polarization of EM wave



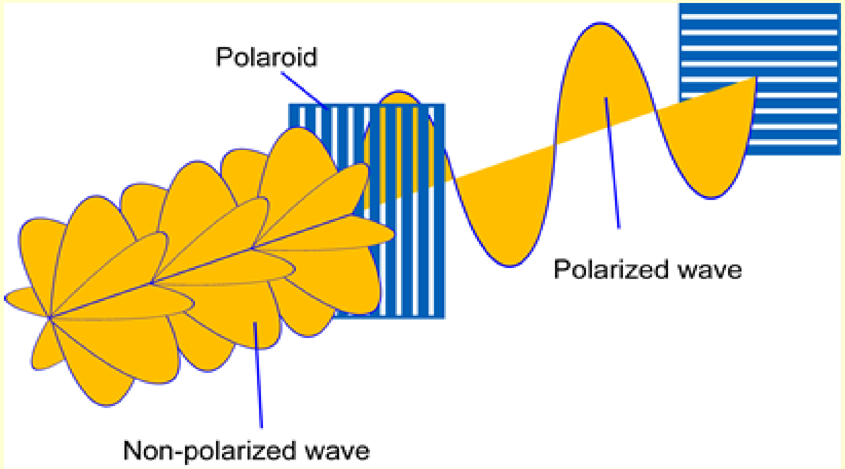
Direction of E-polarization

- Light is considered polarized along Electric field
- Unpolarized light has random polarization direction

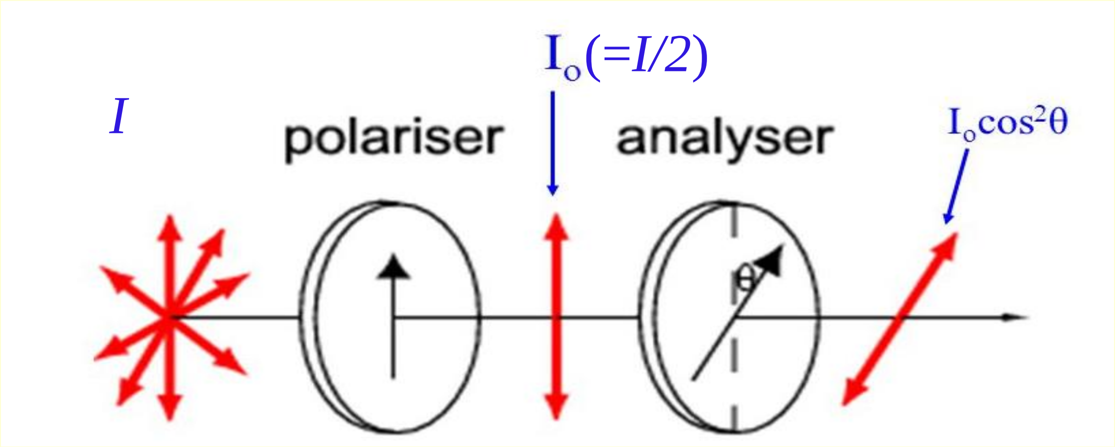
Polarizer or polaroid:
A system that allows one direction of E-vibration unperturbed.
Allows other polarizations as well, but with reduced intensity

An unpolarized light is polarized by a polaroid

The polarised wave may be blocked by making *pass-axis* of the polaroid perpendicular to direction of polarization



Malus' Law



1) **The 1st polarizer is used to polarize unpolarised light in a plane**
2) **The 2nd polarizer (analyzer) is rotated w.r.t. the 1st polarizer by an angle θ**

Unloparised light through polariser

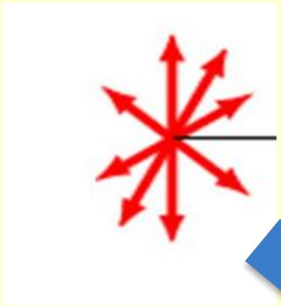
The intensity of an unpolarized light across a plane polarizer also reduces following the relation $I_0 = I cos^2\theta$, I is the intensity before polarizer

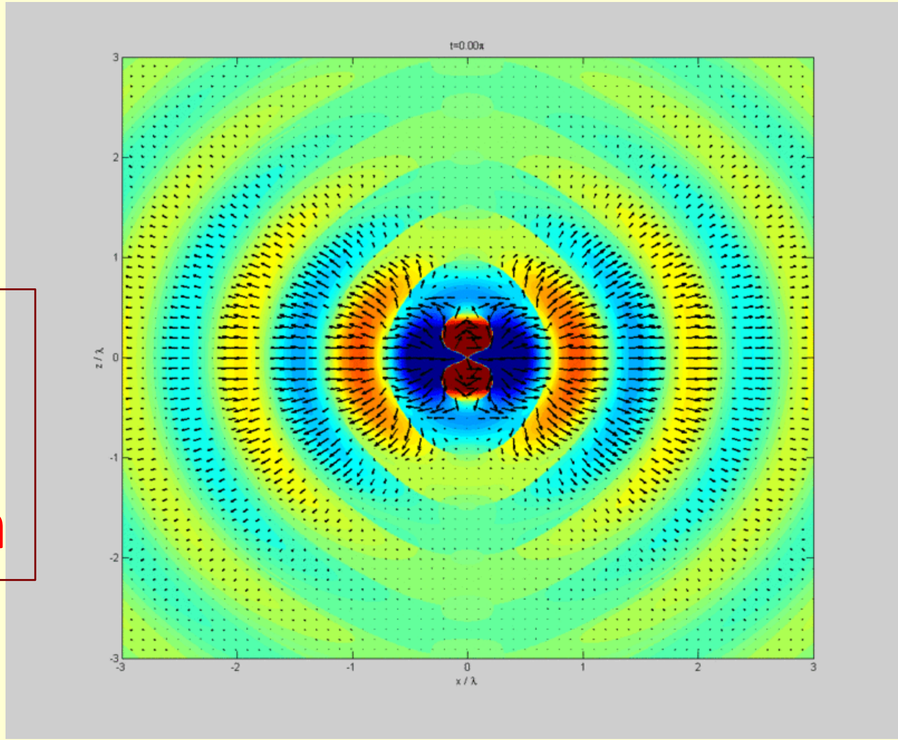
When averaged over all possible angles, the total intensity reduces by half

$$I_0 = I < cos^2\,\theta > = \frac{I}{2}$$

Polarization by reflection

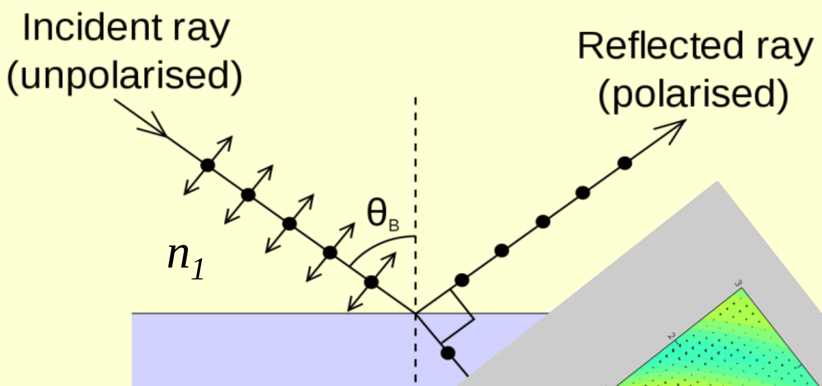
Unpolarized incident light on the surface of a material

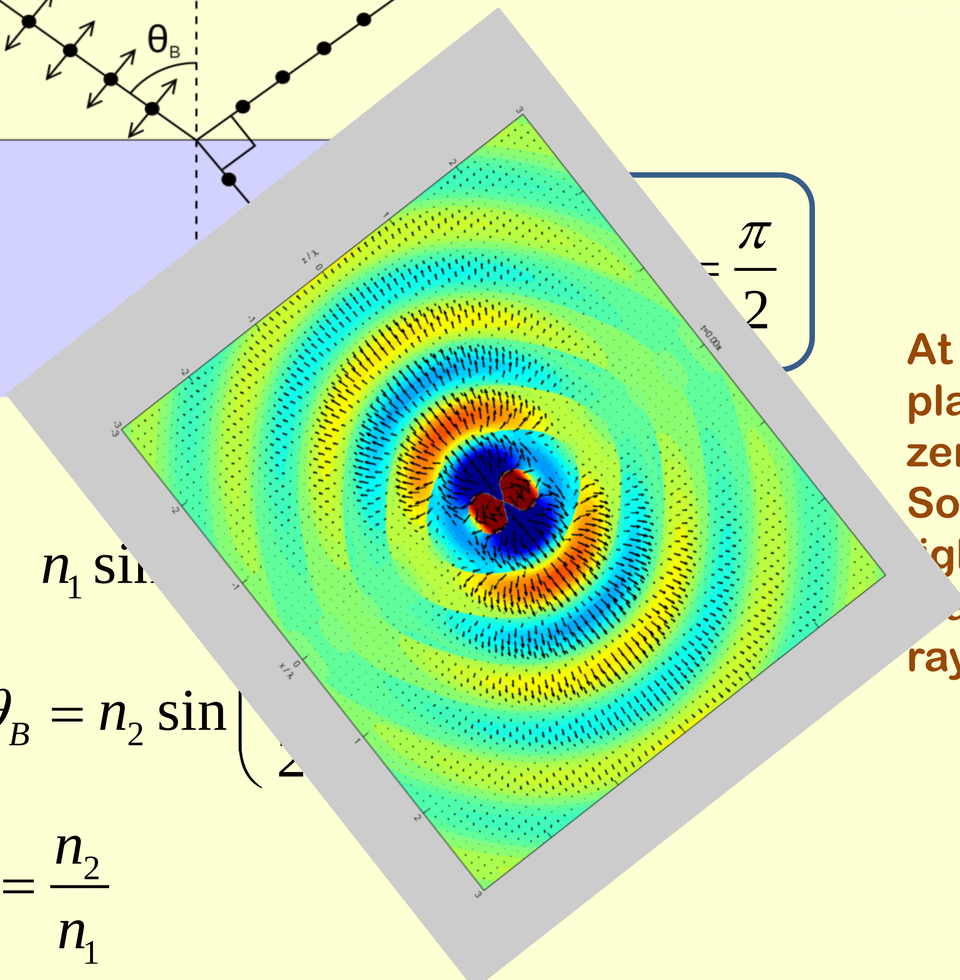




Dipoles oscillate with the E-field and emits radiation

Polarization by reflection: Brewster's law





$$\theta_B = tan^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \frac{\pi}{2}$$

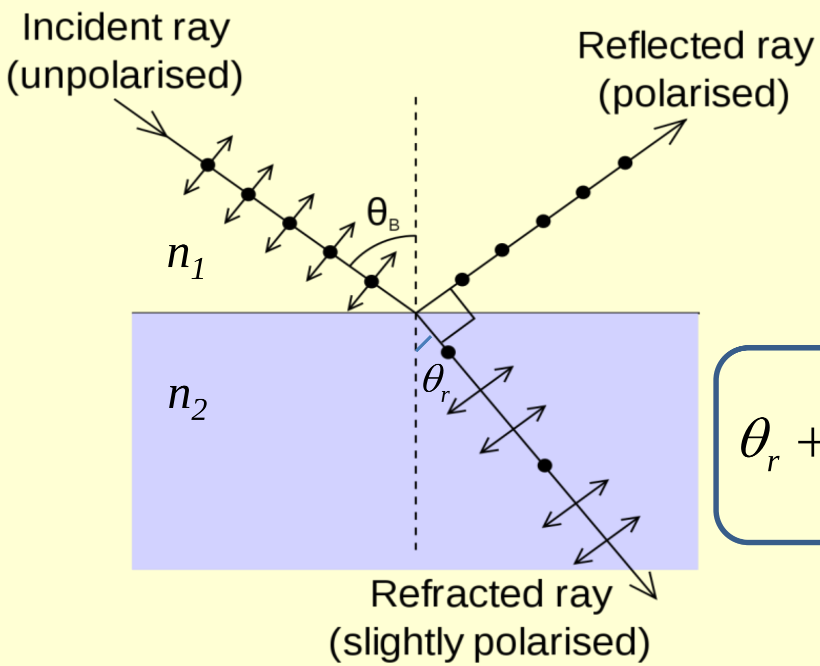
n_1 si

$$n_1 \sin\theta_B = n_2 \sin\Big(\quad 2$$

$$\tan\theta_B = \frac{n_2}{n_1}$$

At this angle of incidence, a plane π-polarized light has zero reflection coefficient. So, for unpolarized incident light, the reflected ray will be plane polarized and refracted ray will be partially polarized

Polarization by reflection: Brewster's law



$$\boxed{\theta_r + \theta_B = \frac{\pi}{2}}$$

Brewseter's angle

$$\theta_B = tan^{-1}\left(\frac{n_2}{n_1}\right)$$

$$n_1 \sin\theta_B = n_2 \sin\theta_r$$

$$n_1 \sin\theta_B = n_2 \sin\left(\frac{\pi}{2} - \theta_B\right) = n_2 \cos\theta_B$$

$$\tan\theta_B = \frac{n_1}{n_2}$$

At this angle of incident, a plane polarized light has zero reflection coefficient. So, for unpolarized incident light, the reflected ray will be plane polarized and refracted ray will be partially polarized

Examples of polarization by reflection

Look at the window!!

Superposition of two plane polarized wave

$$\vec{E} = \hat{i}E_x + \hat{j}E_y$$

$$E_x = E_{x0}\cos(\mathrm{kz} - \omega \mathrm{t})$$

$$E_y = E_{y0}\cos(\mathrm{kz} - \omega \mathrm{t} + \delta)$$

$$\Downarrow$$

$$\frac{E_y}{E_{y0}} = \cos(\mathrm{kz} - \omega \mathrm{t})\cos\delta - \sin(\mathrm{kz} - \omega \mathrm{t})\sin\delta$$

$$\frac{E_y}{E_{y0}} = \frac{E_x}{E_{x0}}\cos\delta - \sqrt{1 - \frac{E_x{}^2}{E_{x0}{}^2}}\sin\delta$$

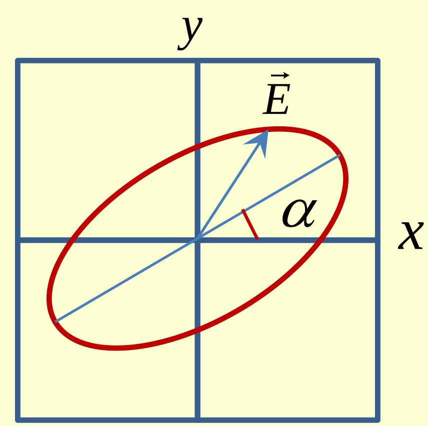
$$\left(\frac{E_y}{E_{y0}} - \frac{E_x}{E_{x0}}\cos\delta\right)^2 = \sin^2\delta - \frac{E_x{}^2}{E_{x0}{}^2}\sin^2\delta$$

$$\boxed{\frac{E^2{}_y}{E^2{}_{y0}} - 2\frac{E_x}{E_{x0}}\frac{E_y}{E_{y0}}\cos\delta + \frac{E_x{}^2}{E_{x0}{}^2} = \sin^2\delta}$$

$$\frac{E^2{}_y}{E^2{}_{y0}} - 2\frac{E_x}{E_{x0}}\frac{E_y}{E_{y0}}\cos\delta + \frac{E_x{}^2}{E_{x0}{}^2} = \sin^2\delta$$

This is an equation of ellipse whose major axis is making an angle say α

$$\tan 2\alpha = \frac{2E_{x0}E_{y0}\cos\delta}{E_{x0}{}^2 - E^2{}_{y0}}$$

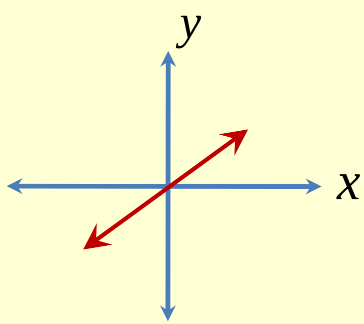


Linearly polarized

$$E_x = E_{x0}\cos(\mathrm{kz} - \omega\,\mathrm{t})$$

$$E_y = E_{y0}\cos(\mathrm{kz} - \omega\,\mathrm{t} + \delta)$$

$$\delta = 2m\pi \qquad m = 0, 1, 2, 3....$$



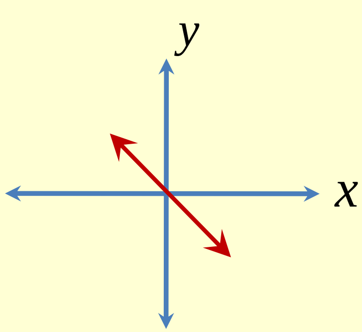
$$\frac{E_y}{E_x} = \frac{E_{y0}}{E_{x0}}$$

$$\theta = \tan^{-1}\left(\frac{E_{y0}}{E_{x0}}\right)$$

$$E_y = E_{y0}\cos(\mathrm{kz} - \omega\,\mathrm{t} + 2m\pi)$$

$$E_y = E_{y0}\cos(\mathrm{kz} - \omega\,\mathrm{t})$$

$$\delta = (2m+1)\pi \qquad m = 0, 1, 2, 3....$$



$$\frac{E_y}{E_x} = -\frac{E_{y0}}{E_{x0}}$$

$$\theta = -\tan^{-1}\left(\frac{E_{y0}}{E_{x0}}\right)$$

$$E_y = E_{y0}\cos(\mathrm{kz} - \omega\,\mathrm{t} + 2m\pi + \pi)$$

$$E_y = -E_{y0}\cos(\mathrm{kz} - \omega\,\mathrm{t})$$

Elliptically polarized

At $z = 0$

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

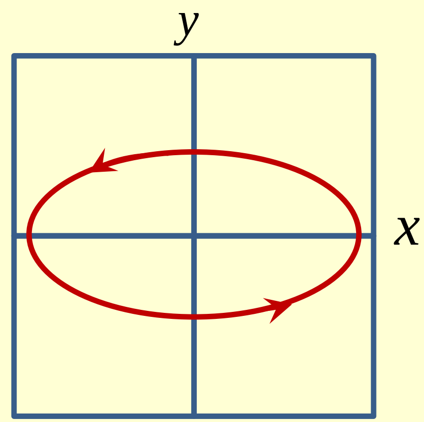
$$E_y = E_{y0}\cos(\omega t - \delta)$$

$$\delta = (2m+1)\frac{\pi}{2} \qquad m = 0,1,2,3.... \Rightarrow \frac{E_y^2}{E_{y0}^2} + \frac{E_x^2}{E_{x0}^2} = 1$$

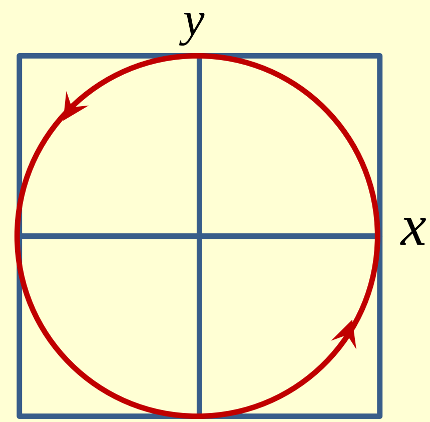
For $\delta = \frac{\pi}{2};\ 5\frac{\pi}{2}; 9\frac{\pi}{2}........$

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

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



Counter-clock wise rotation with time

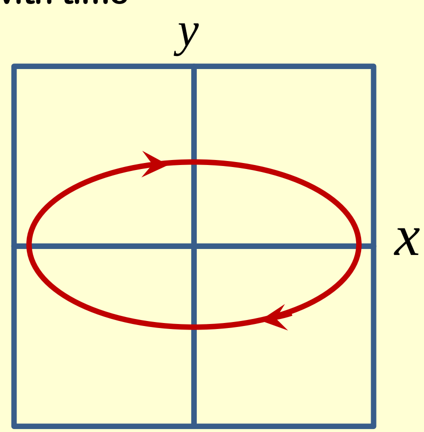


$E_{x0} = E_{y0}$

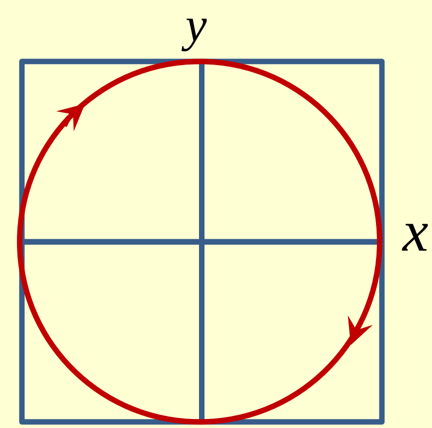
For $\delta = 3\frac{\pi}{2};\ 7\frac{\pi}{2}; 11\frac{\pi}{2}........$

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

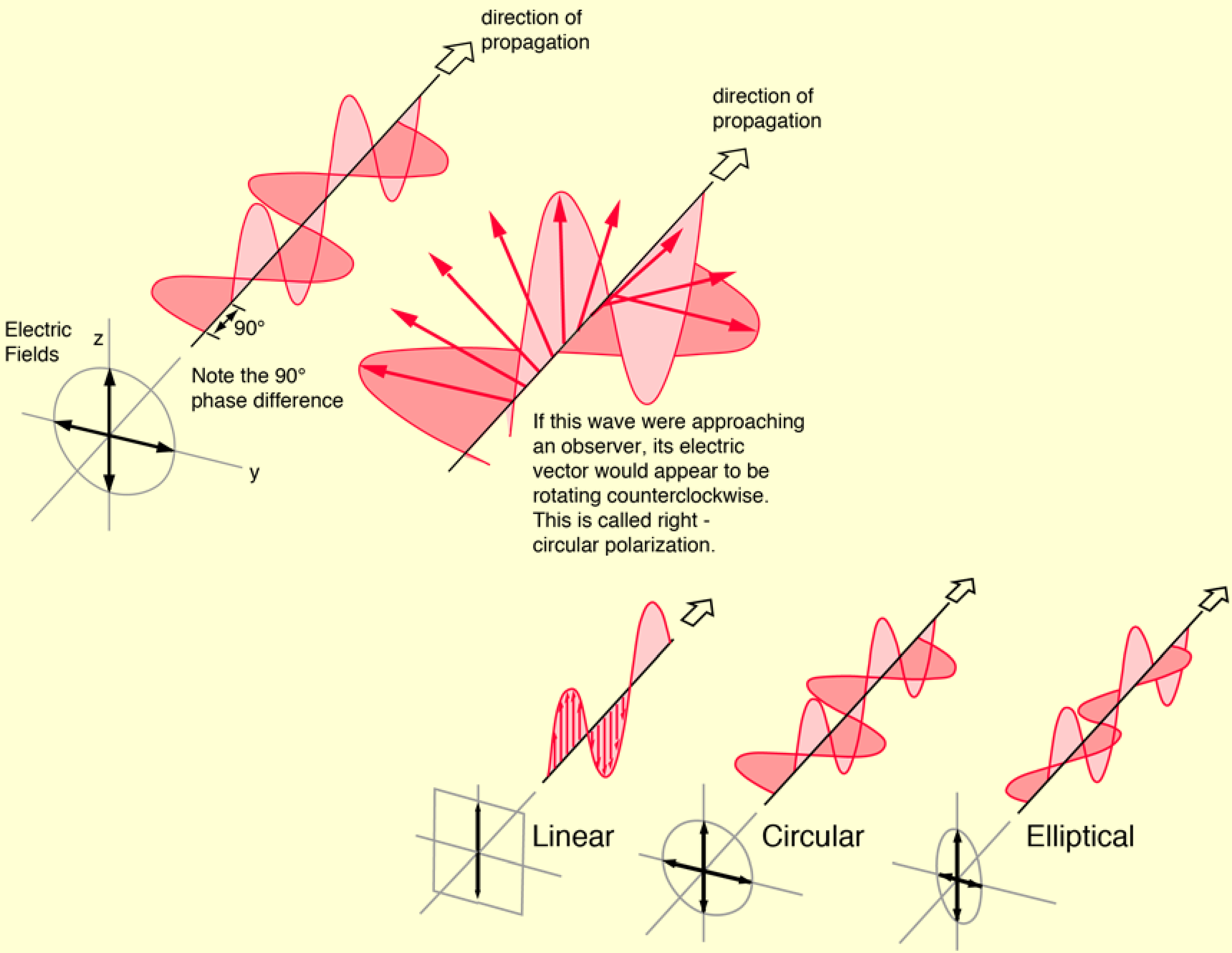
$$E_y = -E_{y0}\sin(\omega t)$$



Clock wise rotation with time

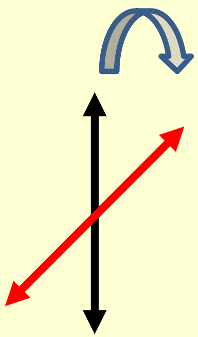


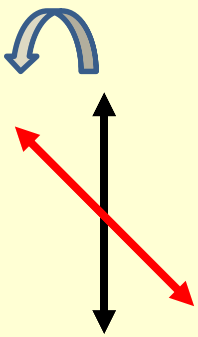
$E_{x0} = E_{y0}$


direction of propagation
direction of propagation
Electric Fields
z
y
90°
Note the 90° phase difference
If this wave were approaching an observer, its electric vector would appear to be rotating counterclockwise. This is called right - circular polarization.
Linear
Circular
Elliptical

A substance is Optically Active if it rotates the plane of polarized light.

Optical Activity





Dextrorotatory

Rotation is clockwise

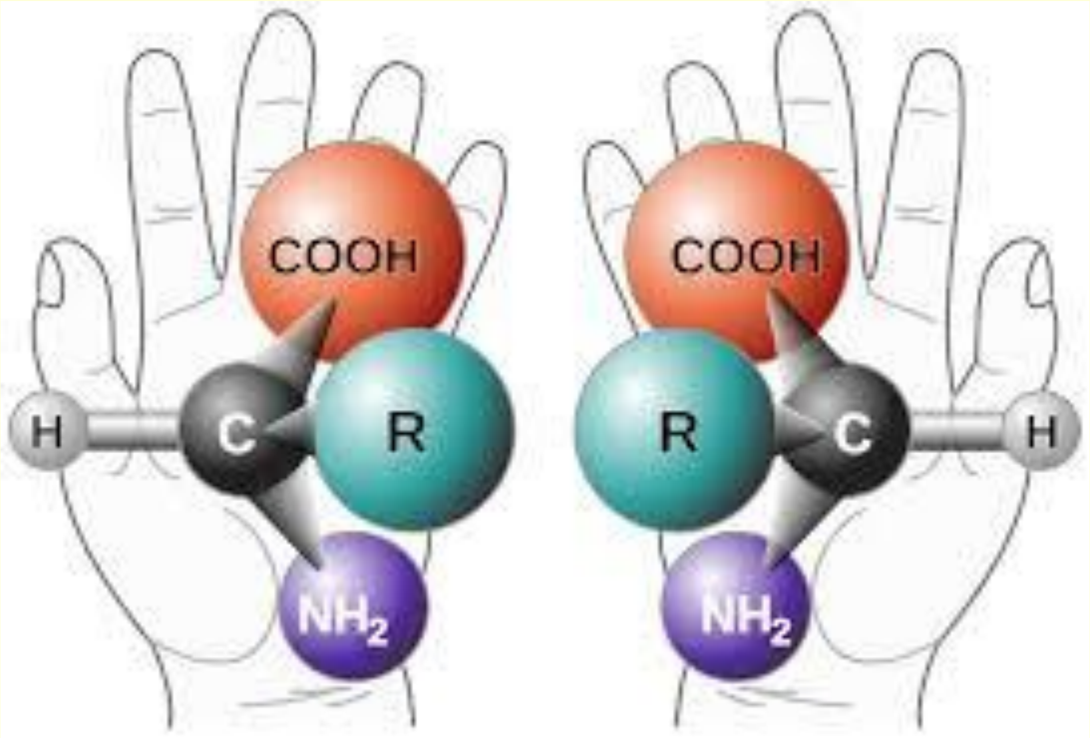
Example: Glyceraldehyde

Levorotatory

Rotation is counterclockwise

Example: D-fructose

Chiral molecules



Source of image: Wikipedia

There is no set of translation and rotations that can map the left-hand molecule into the right-hand side molecule

A solution containing one form of such asymmetric molecule may rotate the plane of polarized light

Specific rotation [S] of a chiral substance

If θ is the angle of rotation for a solution of concentration c and length L, where

- Length (L) measured in dm.
- θ is the angle of rotation.
- c measured in gm/cc

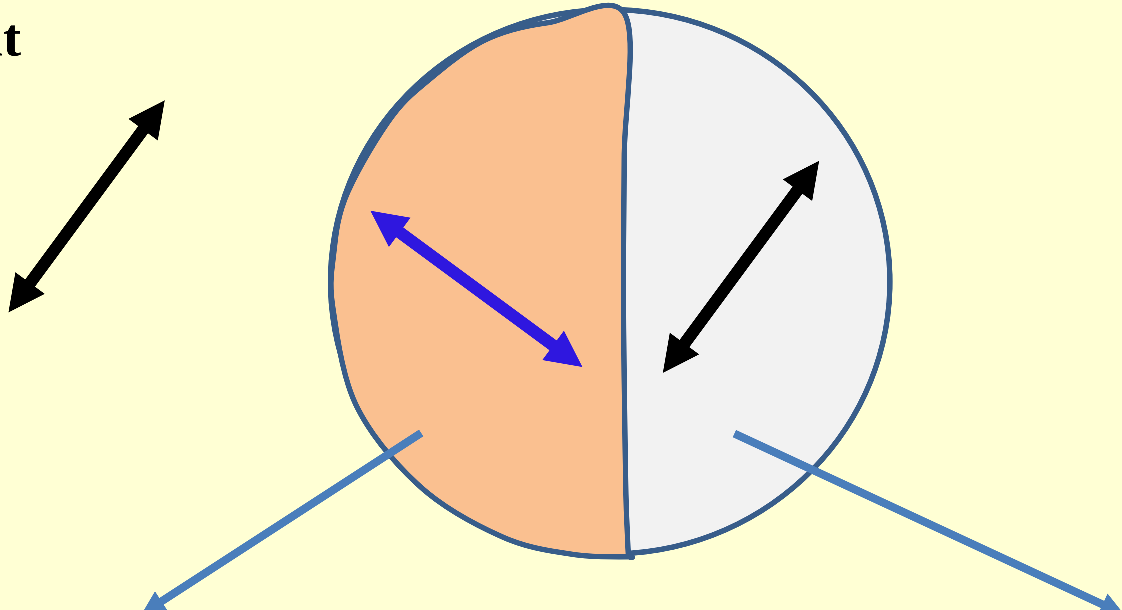
$$S = \frac{\theta}{L\,c}$$

S is the rotation produced by a column of solution of length 1 decimeter and containing 1 gm of the active substance per cm^3 of the solution at a particular **temperature and for a given wavelength of incident light:**

S is a function of temperature and wavelength

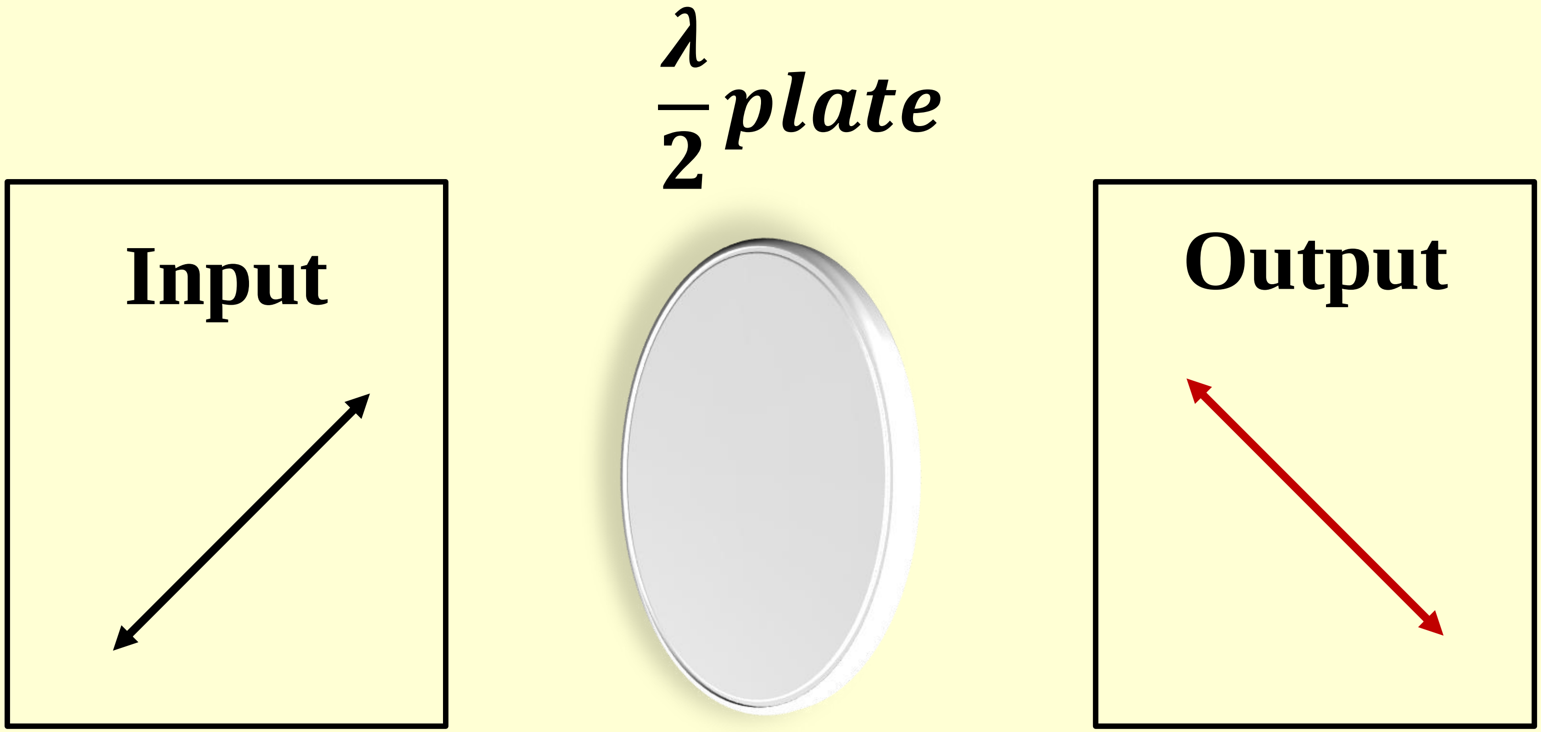
Half-Shade Plate

Incident light polarization

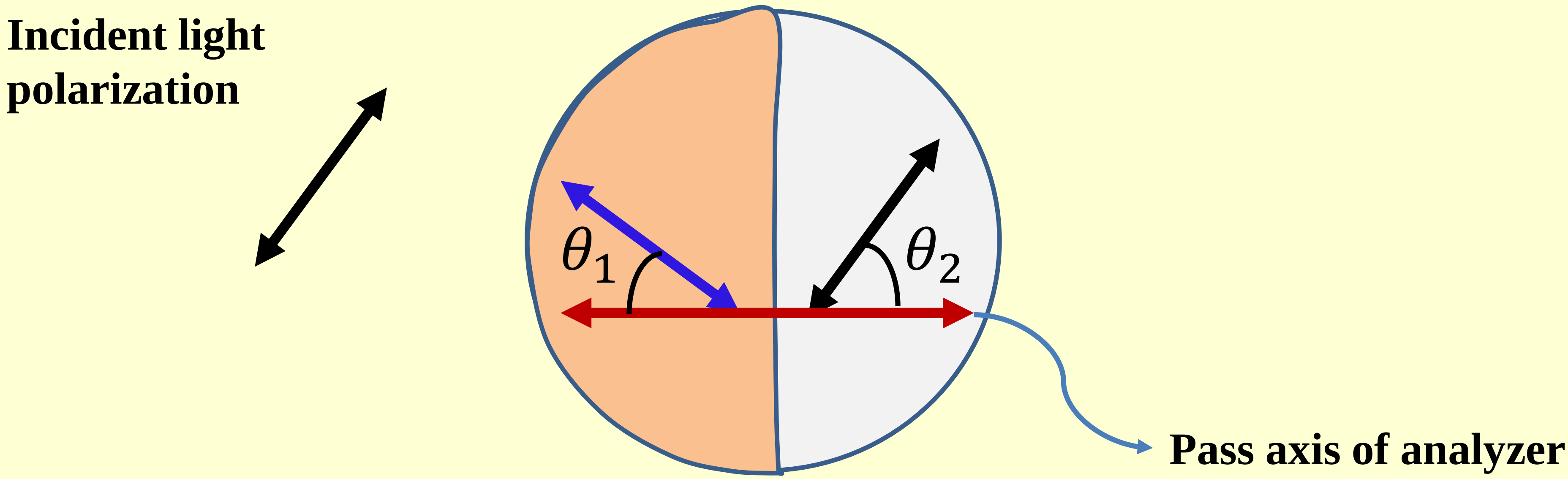


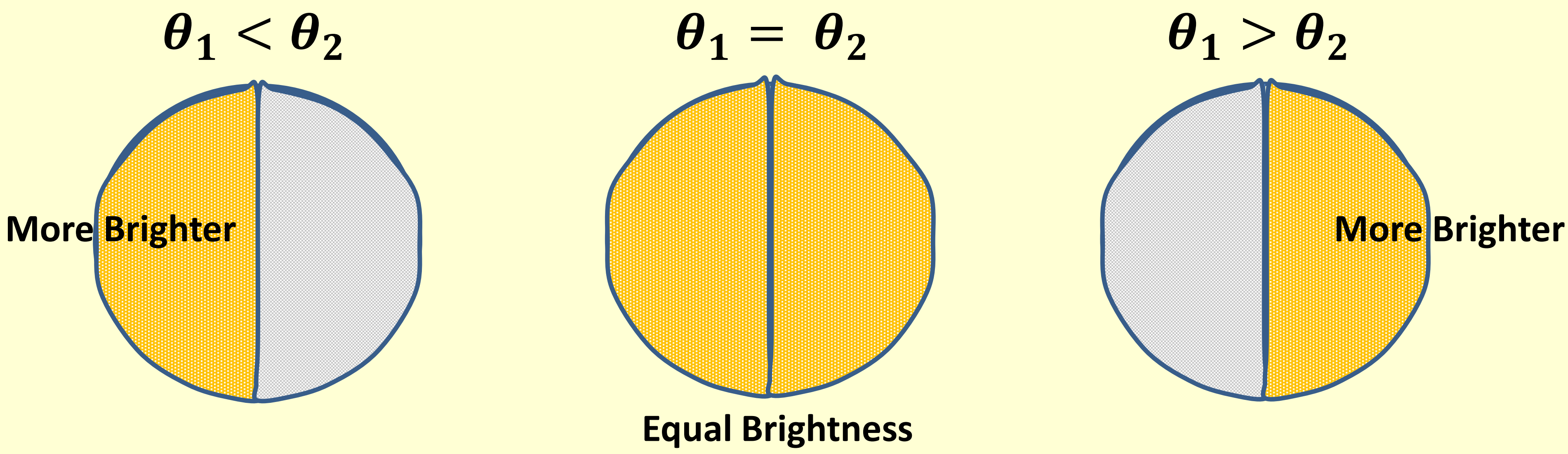
Quartz of thickness such that a path difference of $\frac{\lambda}{2}$ or a phase difference of π is introduced between two perpendicular components of electric field, one parallel to optic-axis and another perpendicular to it.

Other half made of glass, of adequate thickness so that light intensity is same as coming from the quartz side, when pass axis of analyzer (discussed in the slide 18) lies in the plane of polarization of light coming from half-shade plate.

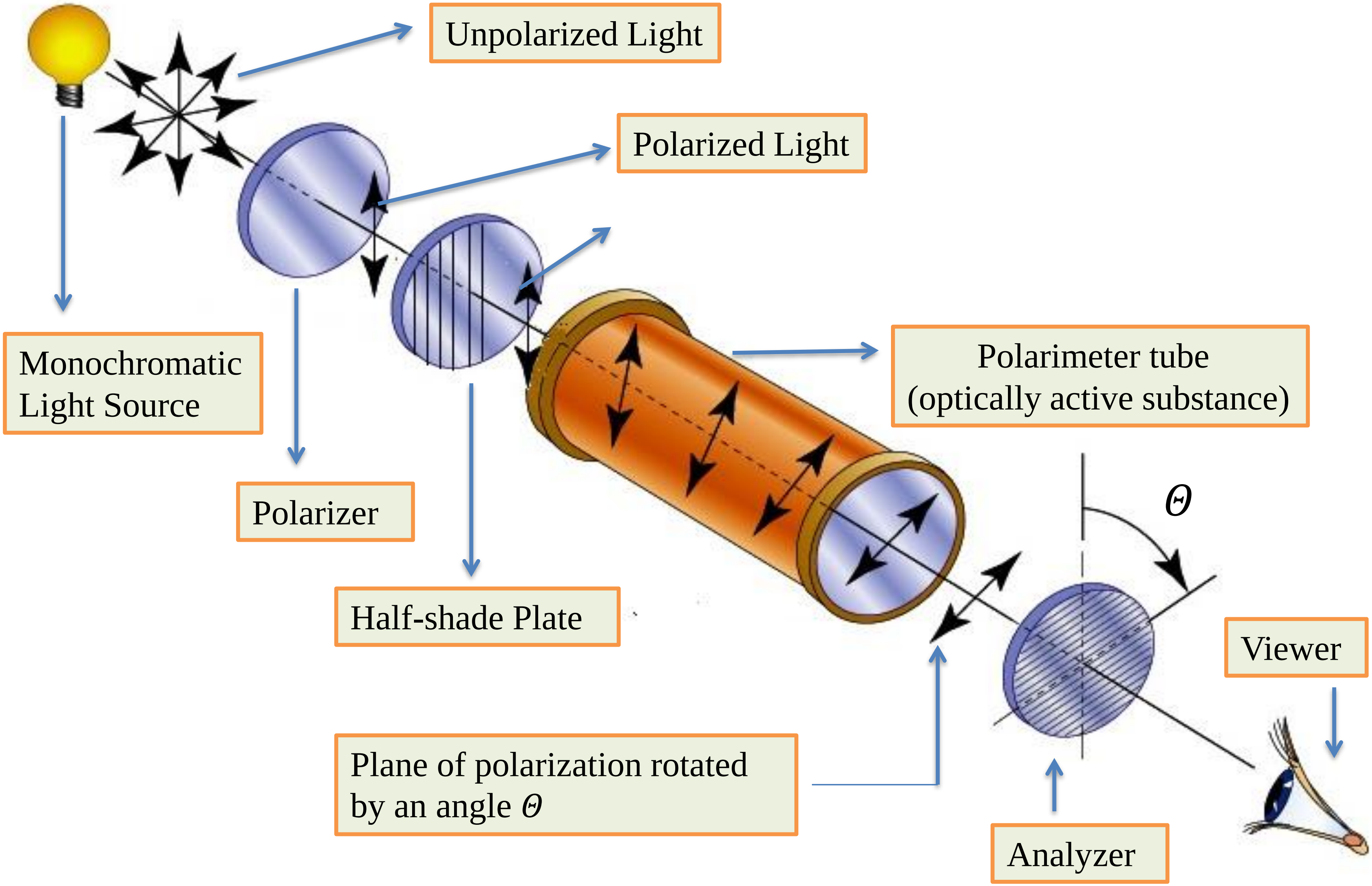

$\frac{\lambda}{2}\,plate$
Input
Output

Half-Shade Plate





Experimental Setup



Experiment to determine S

- **Measure the change in analyzer pass-axis angle between distilled water and then with sugar solution**

- **Repeat it for several concentrations of sugar solution**

Plot a graph of θ vs c.

Table 3

Determination of the specific rotation of the solution from the plot

l (cm)	c (gm/cm^3)	θ (degree)	$s = \frac{10\theta}{lc}$ (degree cm^3 decimeter^{-1}gm^{-1})

S is determined