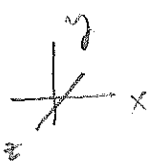
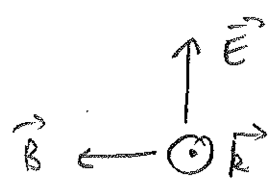
Polarized light

An electromagnetic wave in which the $\vec{E}$ field is confined to one plane and the $\vec{B}$ field to a perpendicular plane is called "plane polarized light"

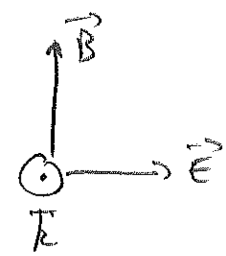
Plane of polarization = plane spanned by $\vec{E}$ and $\vec{k}$

[Consider light coming toward you]
+z direction

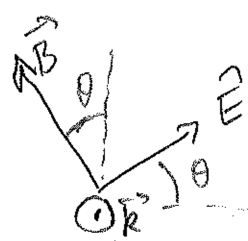




polarized in yz plane



polarized in xz plane



← also plane polarized

DEMOS

"Ordinary" light is unpolarized
[random mixture of polarizations]

A polarizing filter (ideally) absorbs the component of $\vec{E}$ field in one direction and transmits the rest.

[DEMO: big filter against white screen:
It's grey because only lets through 50%]

[HAND OUT POLARIZERS]

[Look through polarizer at the big filter]

[Look around room. Look at calculator.
If rotating makes a difference, then you are looking at partially polarized light.
E.g. glossy reflection from wooden beams.]

[HI sign]

[HRK 5e, 38-6]

Energy and intensity of EM wave

Takeaways:

1) Energy of an electromagnetic wave is characterized by the Poynting vector $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$

   - direction of $\vec{S}$ same as direction of wave travel $\vec{k}$
   - magnitude of $\vec{S}$ measures power per unit area carried by wave

2) Intensity I is the time-average of $|\vec{S}|$

Recall: Since $c^2 = (\text{wave speed})^2 = \frac{1}{\mu_0 \epsilon_0} \Rightarrow \frac{1}{\mu_0} = \epsilon_0 c^2$

$$\Rightarrow \boxed{\vec{S} = \epsilon_0 c^2 \vec{E} \times \vec{B}}$$

Recall: magnitude of a cross product is $|\vec{u} \times \vec{w}| = |\vec{u}||\vec{v}| \sin\theta$

θ = angle between $\vec{u}$ & $\vec{w}$

$$|\vec{S}| = \epsilon_0 c^2 |\vec{E}||\vec{B}| \underbrace{\sin(90°)}_{1}$$

Maxwell's equations predict that EM wave obeys $\boxed{|\vec{B}| = \frac{|\vec{E}|}{c}}$

$$\Rightarrow \boxed{|\vec{S}| = \epsilon_0 c |\vec{E}|^2}$$

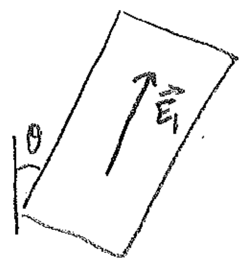
Therefore intensity of wave I proportional to $|\vec{E}|^2$

Consider two back-to-back polarizers w/ relative orientation θ

Malus's law: ratio of intensity emerging from second one to intensity entering it is $\cos^2\theta$

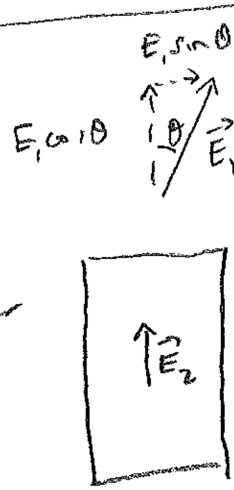
[let's see why]

First filter



$\vec{E}_1$ = electric field of (polarized) light emerging from first filter (light coming toward you)

$I_1 \propto |\vec{E}_1|^2$



Second filter

Second filter absorbs horizontal comp. but passes vertical component

$\vec{E}_2$ = electric field of (polarized) light emerging from second filter

$|\vec{E}_2| = |\vec{E}_1| \cos\theta$

$I_2 \propto |\vec{E}_2|^2 = |\vec{E}_1|^2 \cos^2\theta$

$$\frac{I_2}{I_1} = \cos^2\theta$$

$\theta = 0 \Rightarrow I_2 = I_1$

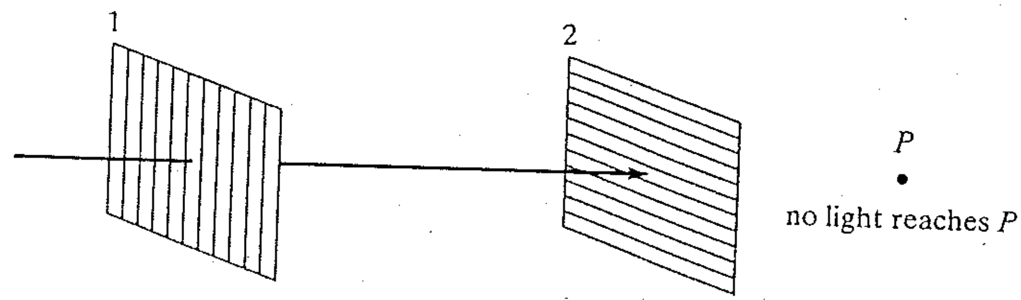
$\theta = 90^\circ \Rightarrow I_2 = 0$

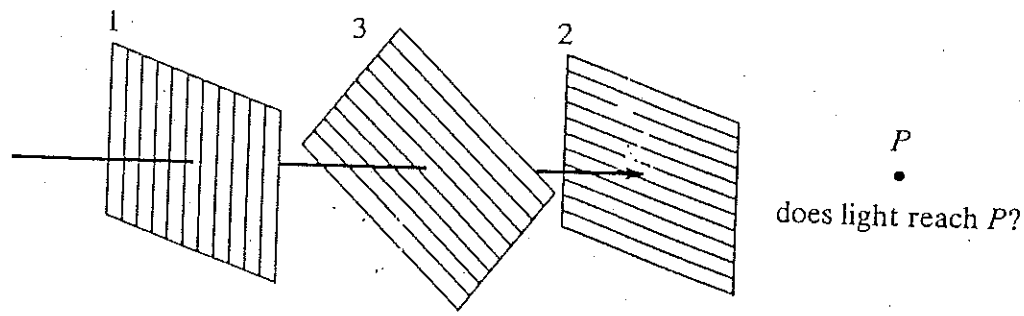
$\theta = 45^\circ \Rightarrow I_2 = \frac{1}{2} I_1$

H5

on

When a ray of light is incident on two polarizers with their polarization axes perpendicular, no light is transmitted. If a third polarizer is inserted between these two with its polarization axis at 45° to that of the other two, does any light get through to point P?

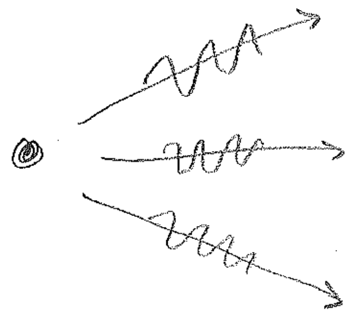




[DEMO 73 filters]

[explain qualitatively. HW quantitative]

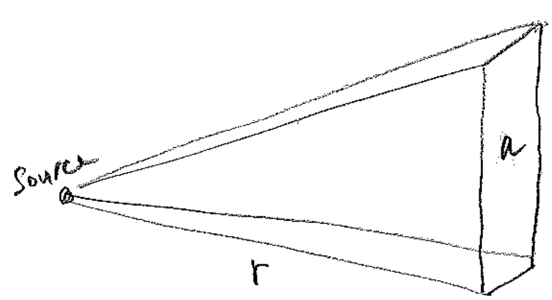
Consider EM waves travelling radially outward from a point source



[Recall]

Intensity I = time avg of $|S|$ = $\frac{\text{power}}{\text{area}}$ = $\frac{\text{energy}}{\text{time} \cdot \text{area}}$

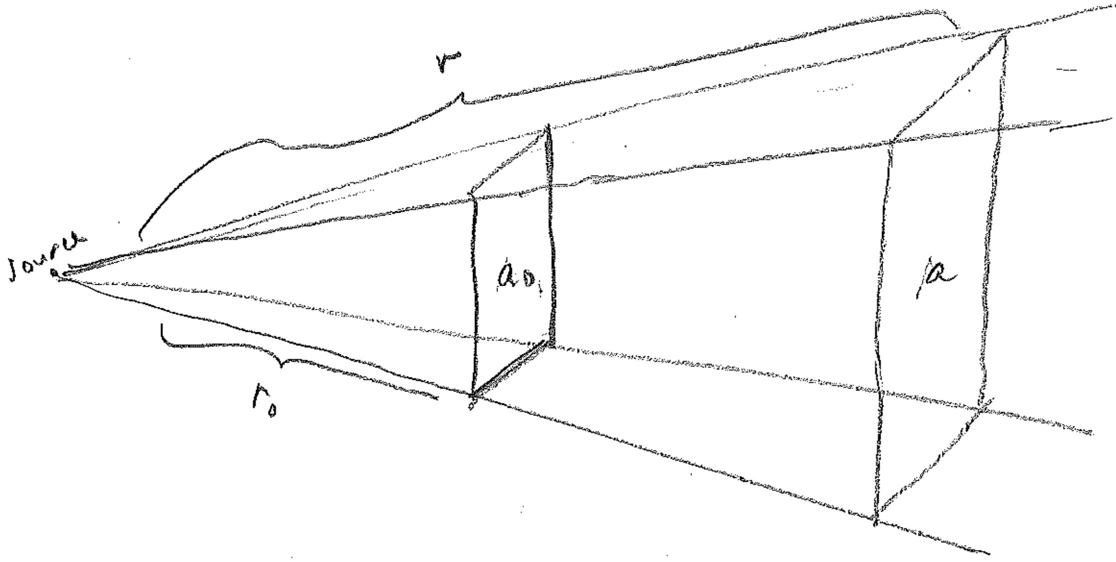
e.g. sunlight at earth's surface has $I = 1380 \frac{W}{m^2} = 1380 \frac{J}{m^2 \cdot s}$



The power transmitted through area a is $P = Ia$

If a source emits isotropically (ie same in all directions) the intensity through a sphere of radius R surrounding it is

$I = \frac{P}{4\pi r^2}$ because $a = 4\pi r^2$ = surface area of sphere)



By energy conservation, power thru a = power thru a_0

$$P = P_0$$

$$I a = I_0 a_0$$

$$I = I_0 \frac{a_0}{a}$$

But $\frac{a_0}{a} = \frac{r_0^2}{r^2}$ so

$$I = I_0 \left(\frac{r_0}{r}\right)^2$$

Intensity diminishes by inverse square of distance

Since $I \propto |\vec{E}|^2 \Rightarrow$ $|\vec{E}|$ of a <u>travelling</u> wave diminishes by $\frac{1}{r}$.

[not $\frac{1}{r^2}$!]