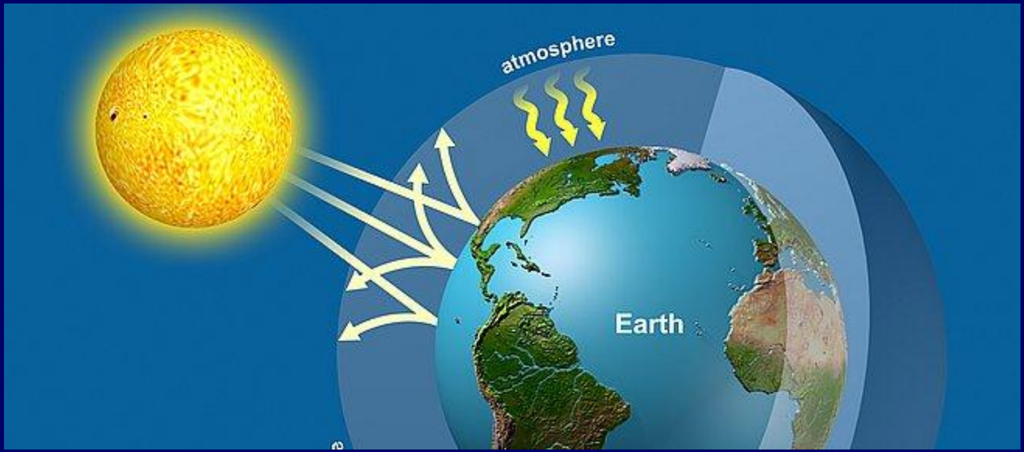
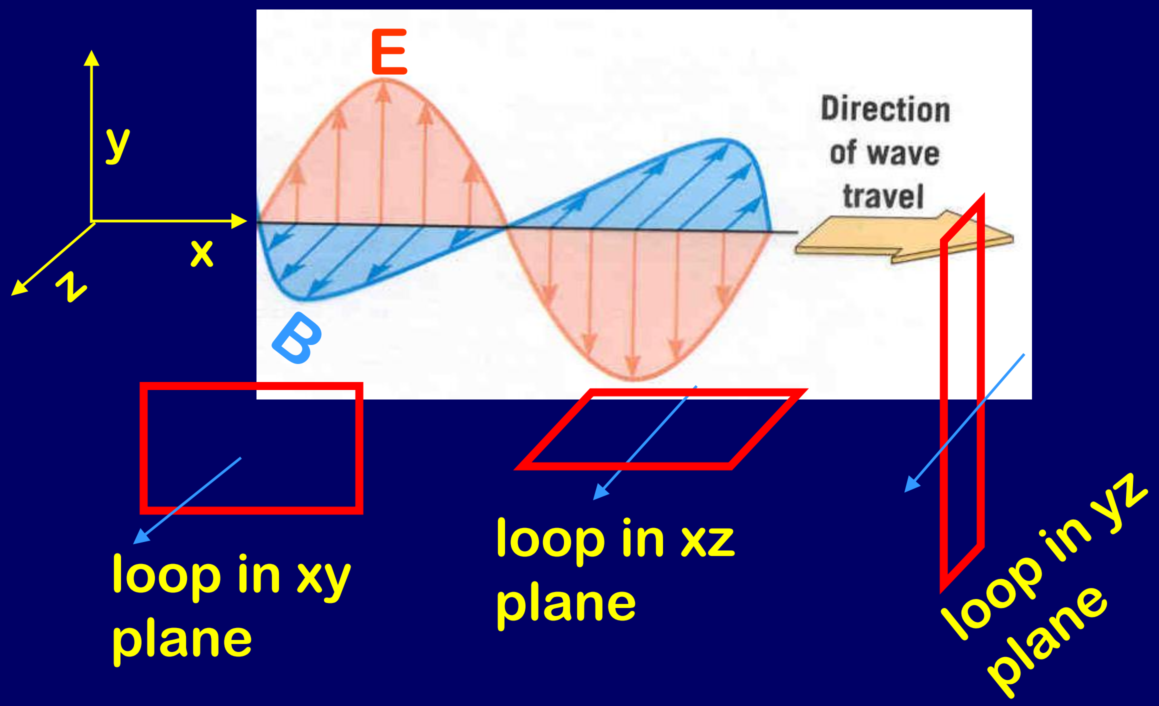
Physics 102: Lecture 15

Electromagnetic Waves

Energy & Polarization

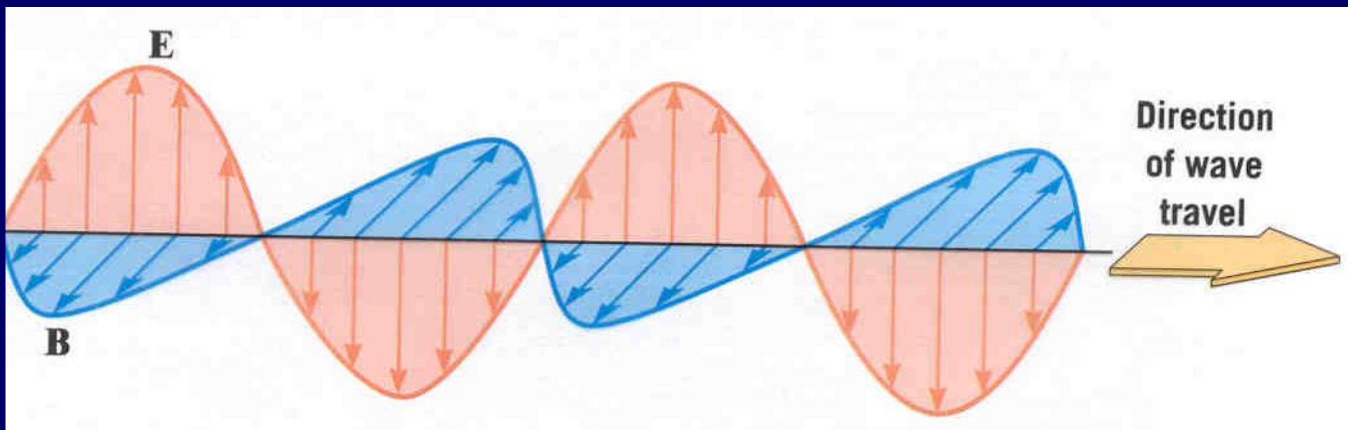


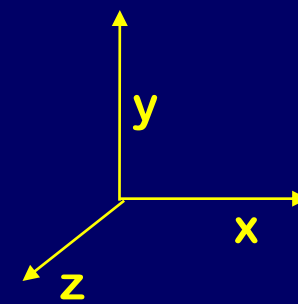
Checkpoint 1.1, 1.2



A B C

Propagation of EM Waves





- Changing B field creates E field
- Changing E field creates B field

$$\boxed{\mathbf{E = c\,B}}$$

If you decrease E, you also decrease B!

CheckPoint 1.4

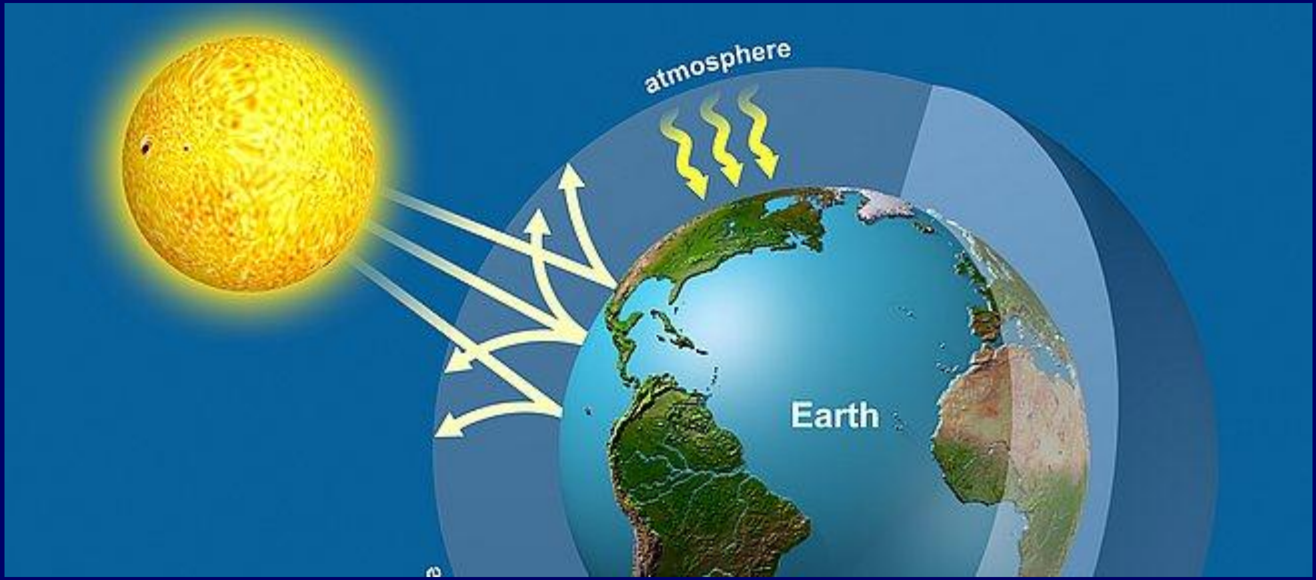
Suppose that the electric field of an electromagnetic wave decreases in magnitude. The magnetic field:

1 increases

2 decreases

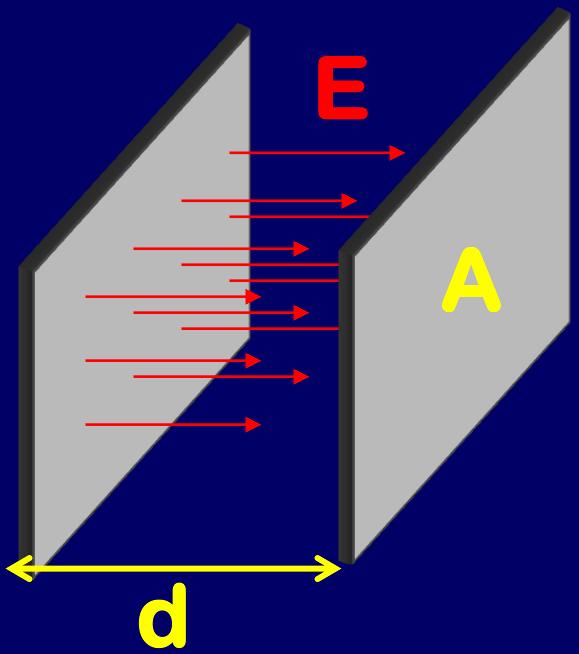
3 remains the same

There is energy associated with electric and magnetic fields and electromagnetic waves!



WHY?
It takes work to create electric and magnetic fields…

Energy in E field



Electric Fields

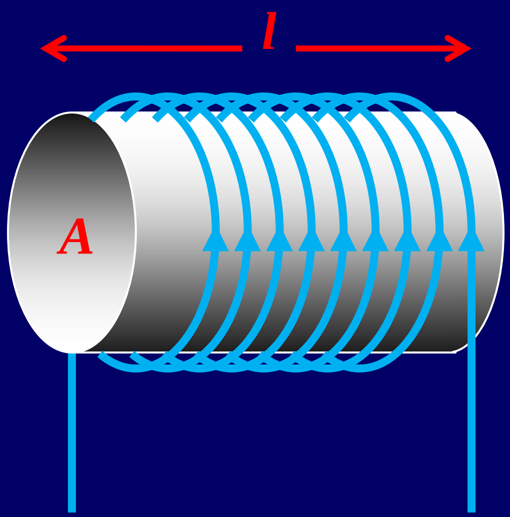
- Recall Capacitor Energy:

  $U = ½ \, C \, V^2$

$$C = \frac{\varepsilon_o A}{d} \qquad V = Ed$$

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\frac{\varepsilon_0 A}{d}E^2 d^2 = \frac{1}{2}\varepsilon_0 E^2 \underbrace{Ad}_{\text{volume}} = \frac{1}{2}\epsilon_0 E^2 V$$

Energy in B field



Magnetic Fields

- Recall Inductor Energy:

  $U = \frac{1}{2} L I^2$

$$L = \mu_o n^2 l A \qquad B = \mu_o n I$$

$$U = \frac{1}{2} L I^2 = \frac{1}{2}(\mu_0 n^2 l A)\frac{B^2}{\mu_0^2 n^2} = \frac{1}{2}\frac{B^2}{\mu_0}\underbrace{Al}_{\text{volume}} = \frac{1}{2}\frac{B^2}{\mu_0}V$$

Intensity (I or S) = Power/Area

- Energy (U) hitting flat surface in time t

= Energy U in laser beam (red cylinder):

$$U = \left(\frac{1}{2}\epsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}\right)V = \left(\frac{1}{2}\epsilon_0 E^2 + \frac{1}{2}\frac{E^2}{c^2\mu_0}\right)V$$

$$= \epsilon_0 E^2 Act$$

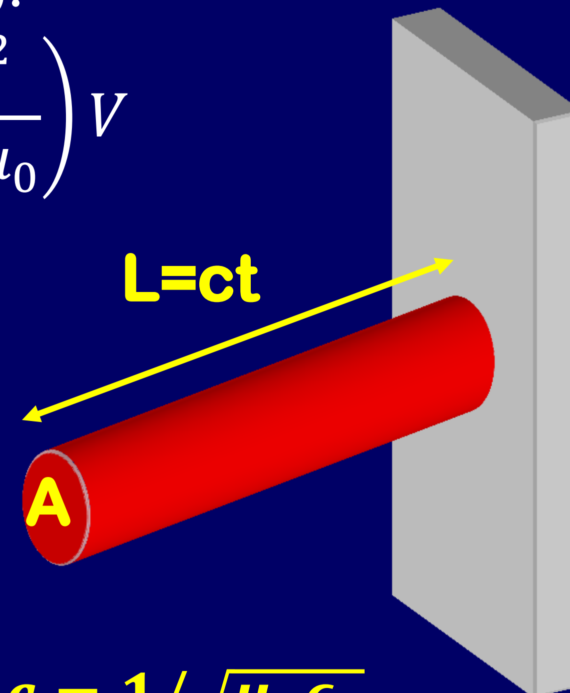
- Power (P):

P = U/t

- Intensity (I or S):

S = P/A [W/m^2]

$= c\varepsilon_0 E^2_{rms}$



$B = E/c \qquad c = 1/\sqrt{\mu_0\epsilon_0}$

U = Energy
A = Cross sectional area of laser beam
L = Length of laser beam

Example

The intensity of sunlight at the earth is approximately $1000 W/m^2$. A solar cooker collects light using a $1\ m^2$ area and focuses that light onto a pot of food. How much power is delivered to the food?

$$S = P/A \qquad P = \qquad\qquad = \qquad\qquad = \qquad\qquad W$$

What is the rms magnitude of the electric field of the light when it hits the solar cooker?

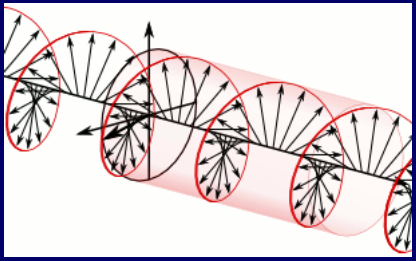
$$S = c\epsilon_0 E_{rms}^2 \qquad E_{rms} =$$

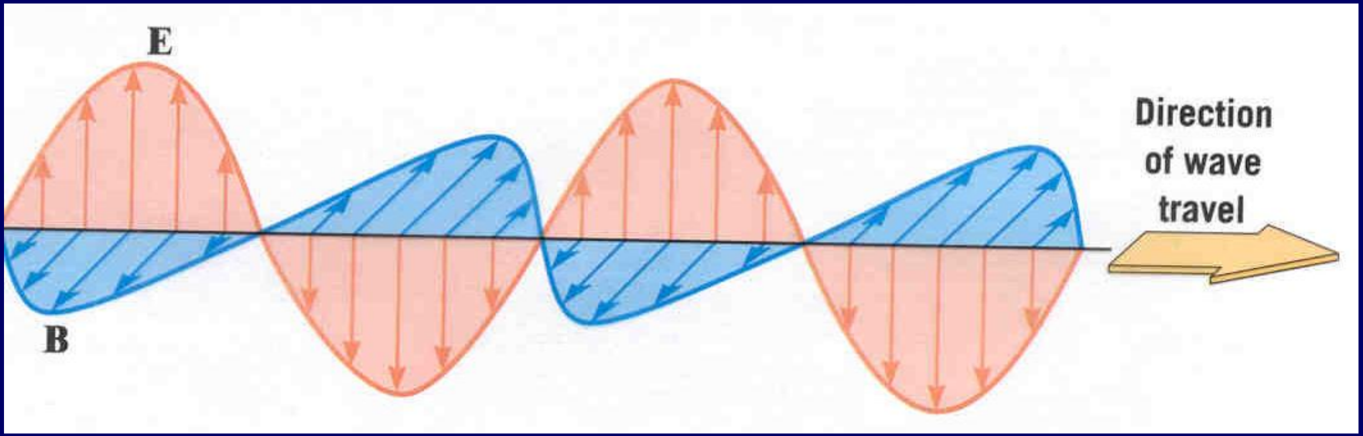
$$=$$

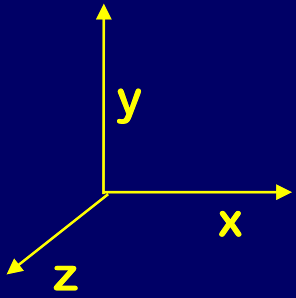
$$=$$

Polarization

- Transverse waves have a polarization
  - (Direction of oscillation of E field for light)
- Types of Polarization
  - Linear (Direction of E is constant)
  - Circular (Direction of E rotates with time)
  - Unpolarized (Direction of E changes randomly)

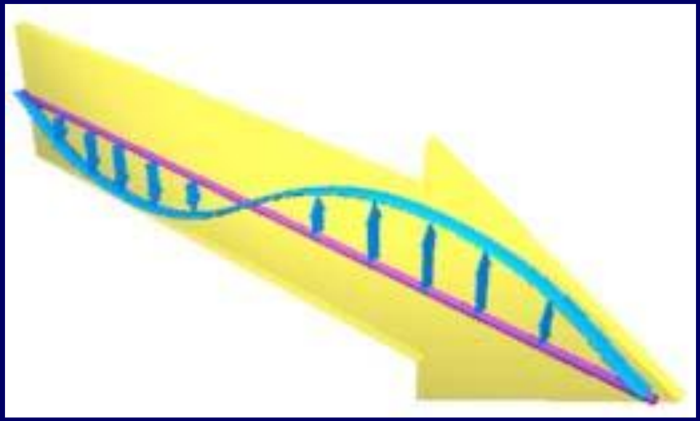


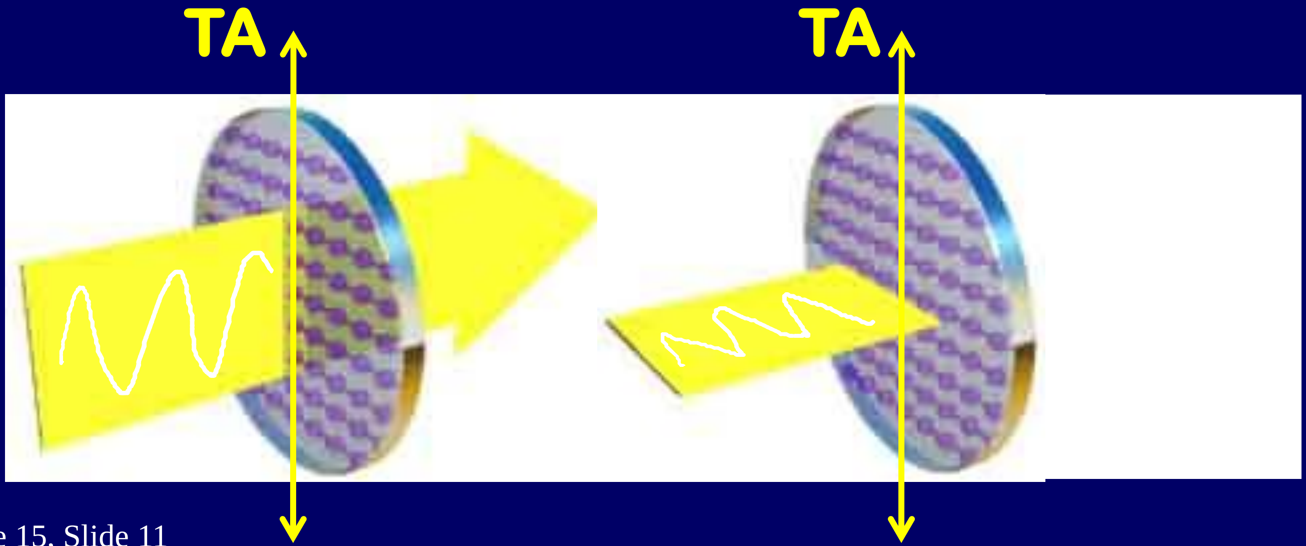




Linear Polarizers

- Linear Polarizers absorb all <u>electric fields</u> perpendicular to their transmission axis (TA)



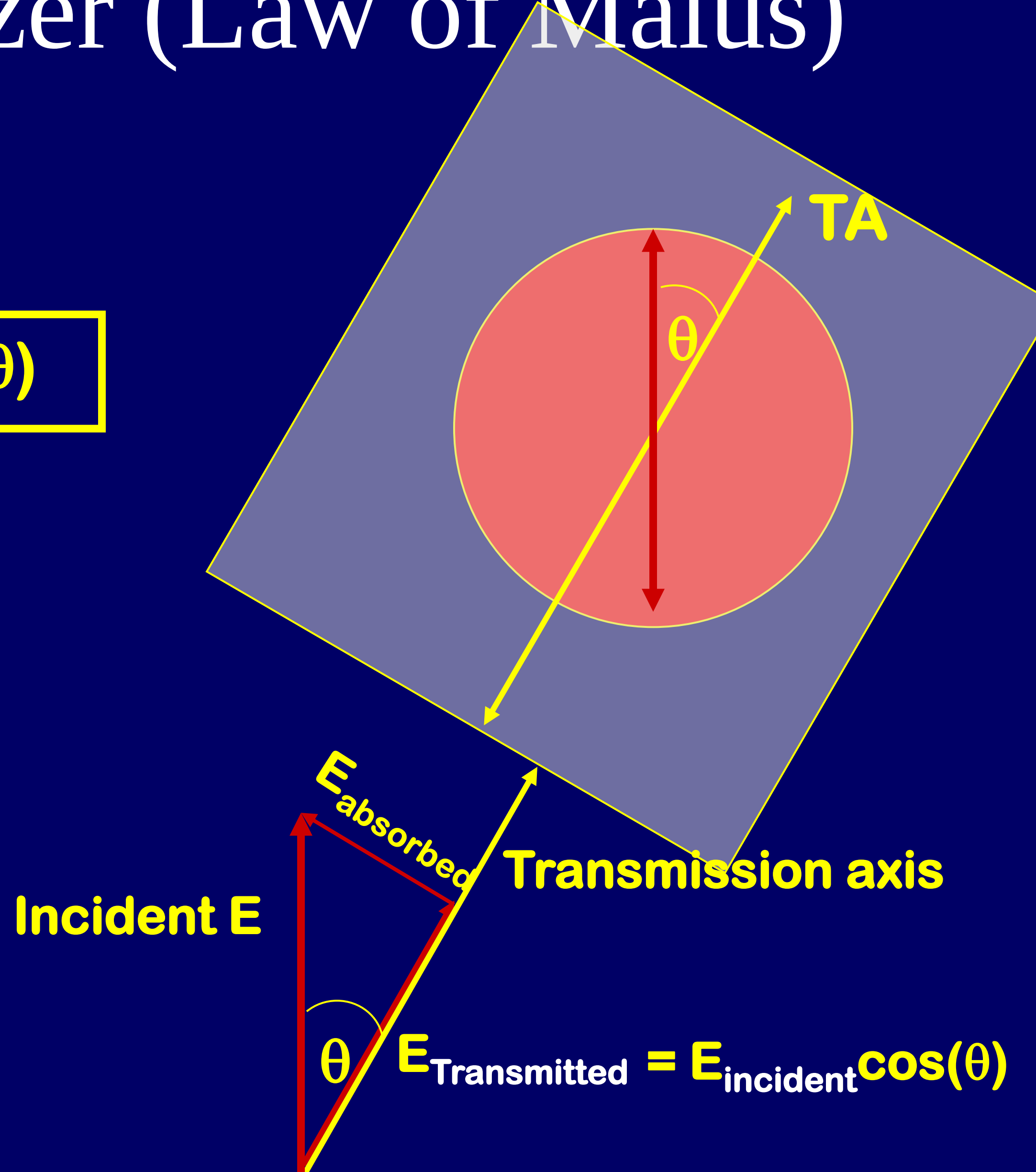


Linearly Polarized Light on Linear Polarizer (Law of Malus)

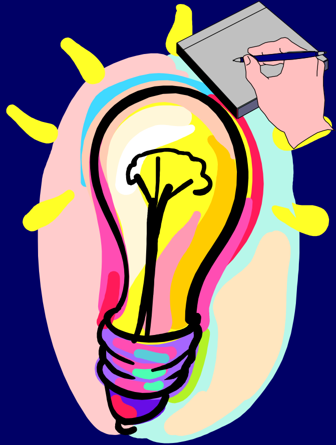
$E_{tranmitted} = E_{incident} \cos(\theta)$

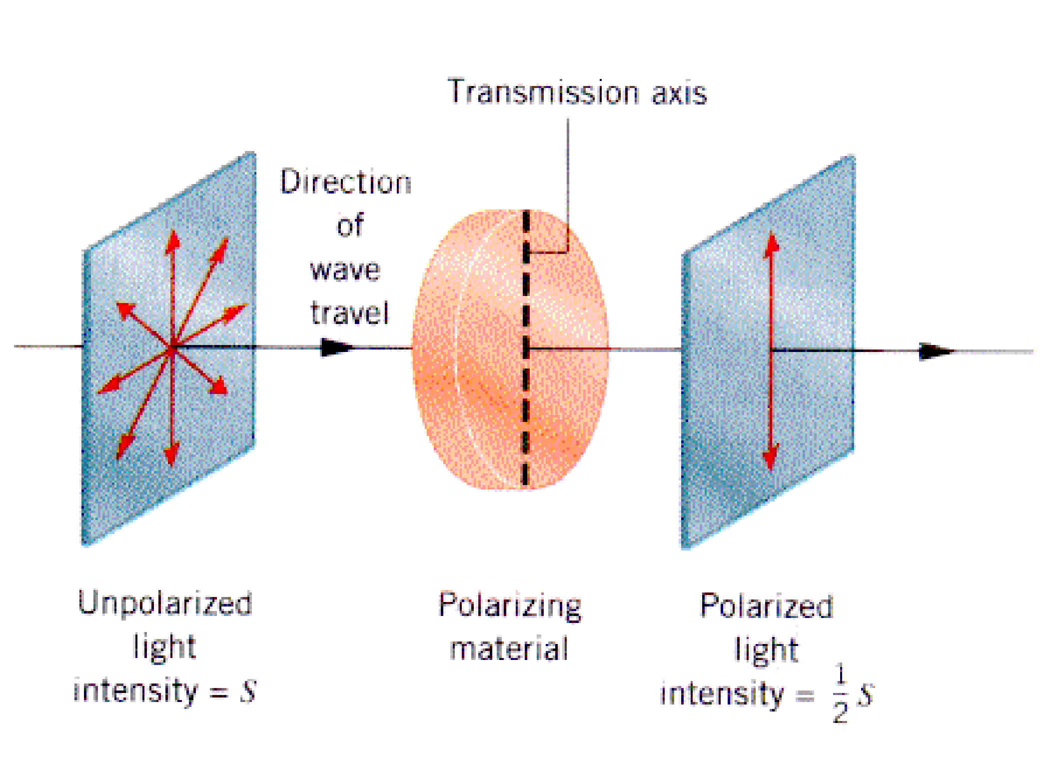
$$\boxed{S_{transmitted} = S_{incident} \cos^2(\theta)}$$

θ is the angle between the incoming polarization and the transmission axis



Unpolarized Light on Linear Polarizer





- Most light comes from electrons accelerating in random directions and is unpolarized.
- Averaging over all directions: $\boxed{S_{transmitted} = \frac{1}{2} S_{incident}}$

Always true for <u>unpolarized</u> light!

CheckPoint 15.6

Unpolarized light (like the light from the sun) passes through a polarizing sunglass (a linear polarizer). The intensity of the light when it emerges is

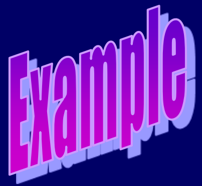
1. zero
2. 1/2 what it was before
3. 1/4 what it was before
4. 1/3 what it was before
5. need more information

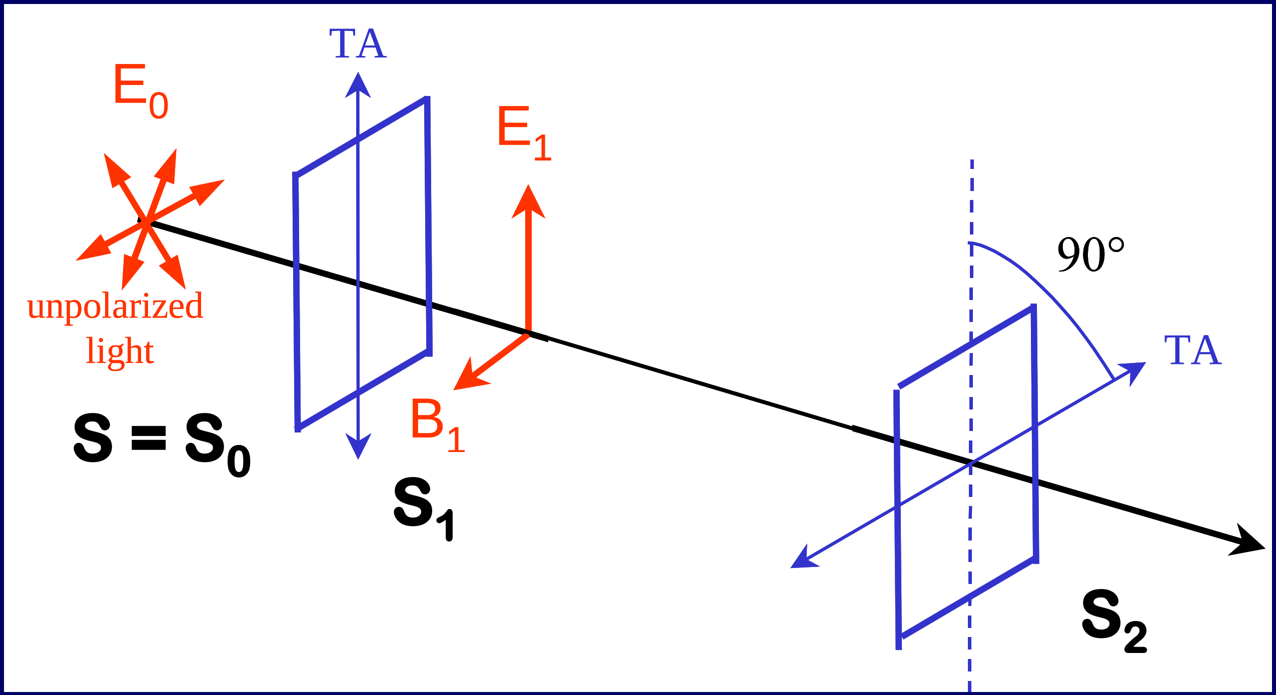
ACT/CheckPoint 15.7

Now, horizontally polarized light passes through the same glasses (which are vertically polarized). The intensity of the light when it emerges is

1. zero
2. 1/2 what it was before
3. 1/4 what it was before
4. 1/3 what it was before
5. need more information

Law of Malus – 2 Polarizers

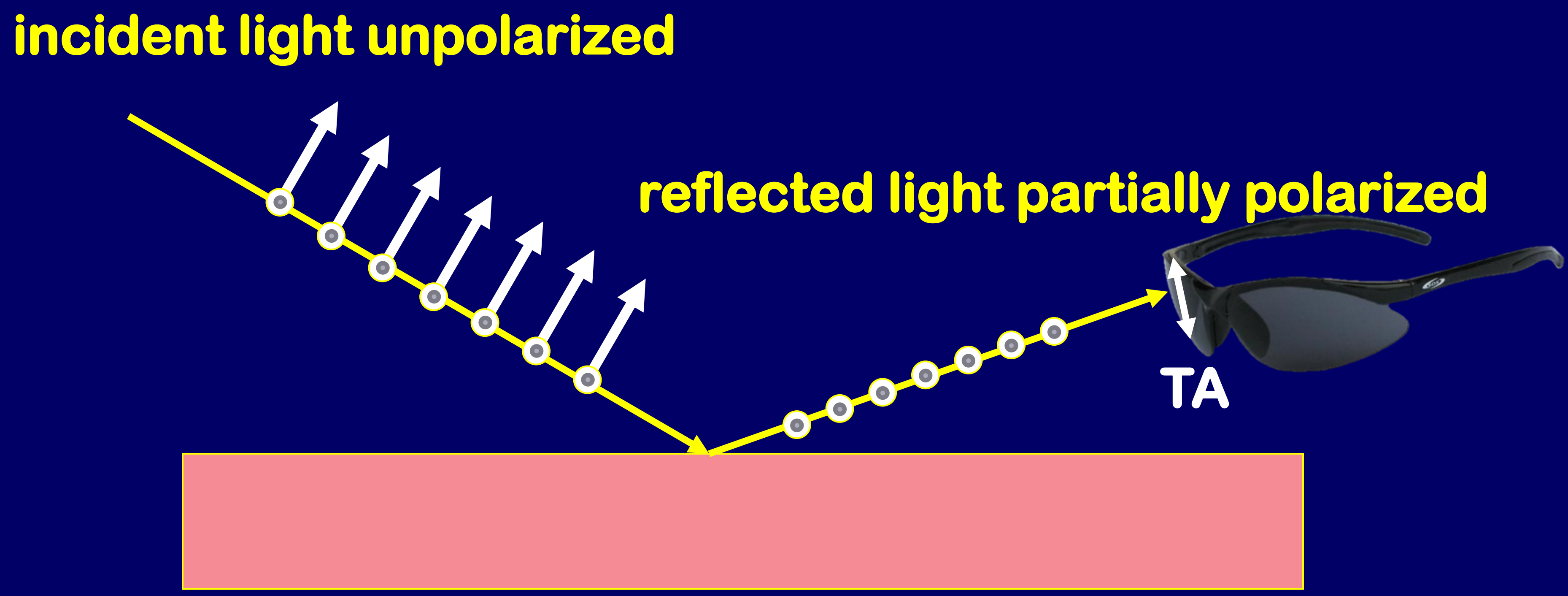




1) Intensity of unpolarized light incident on linear polarizer is reduced by ½ . S_1 =

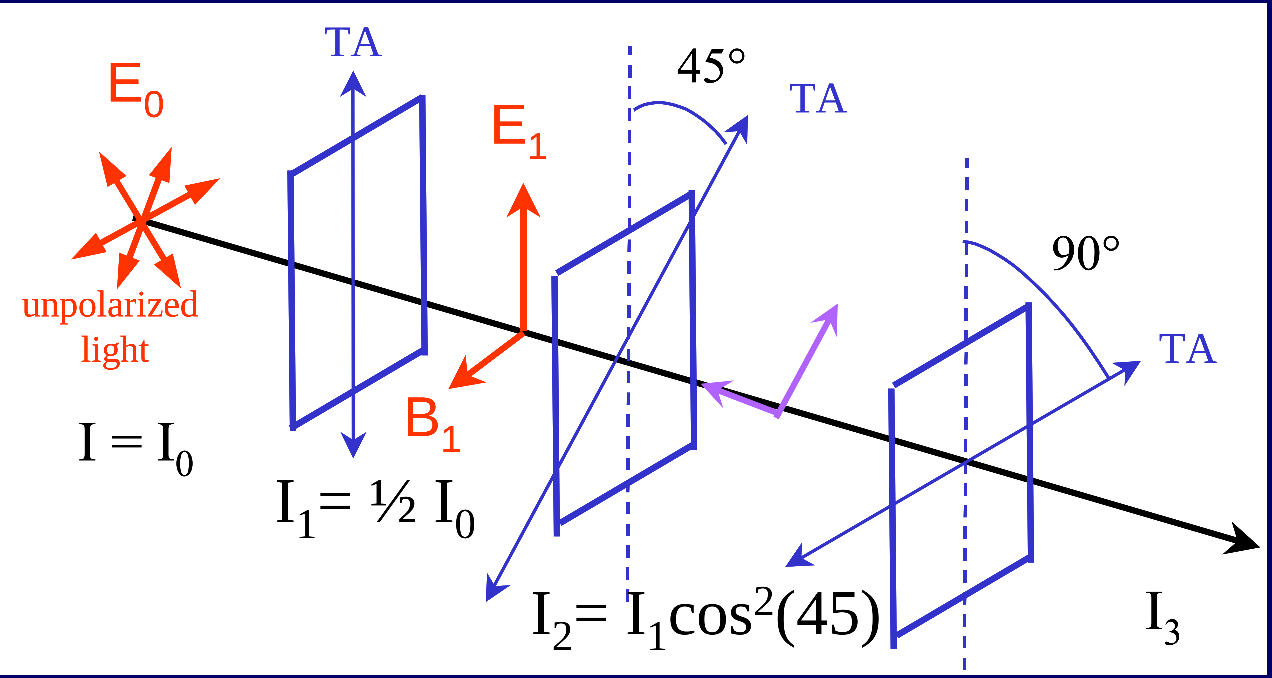
2) Light transmitted through first polarizer is vertically polarized. Angle between it and second polarizer is θ=90°. S_2 =

How do polarized sunglasses work?



the sunglasses reduce the glare from reflected light

Law of Malus – 3 Polarizers



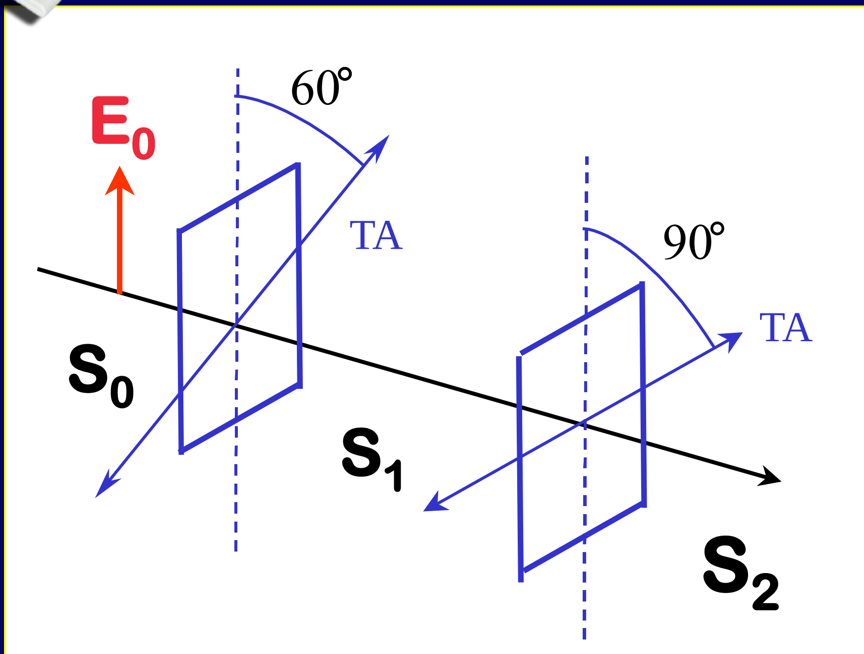
2) Light transmitted through first polarizer is vertically polarized. Angle between it and second polarizer is θ=45º.

$I_2 =$

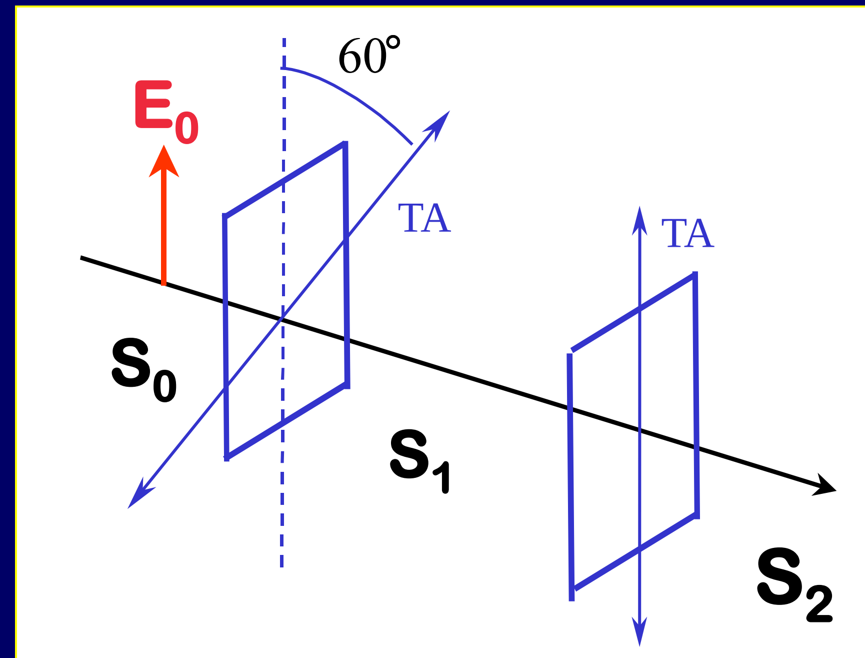
3) Light transmitted through second polarizer is polarized 45º from vertical. Angle between it and third polarizer is θ=45º.

$I_3 =$

ACT: Law of Malus



A



B

1) $S_2^A > S_2^B$ 2) $S_2^A = S_2^B$ 3) $S_2^A < S_2^B$