

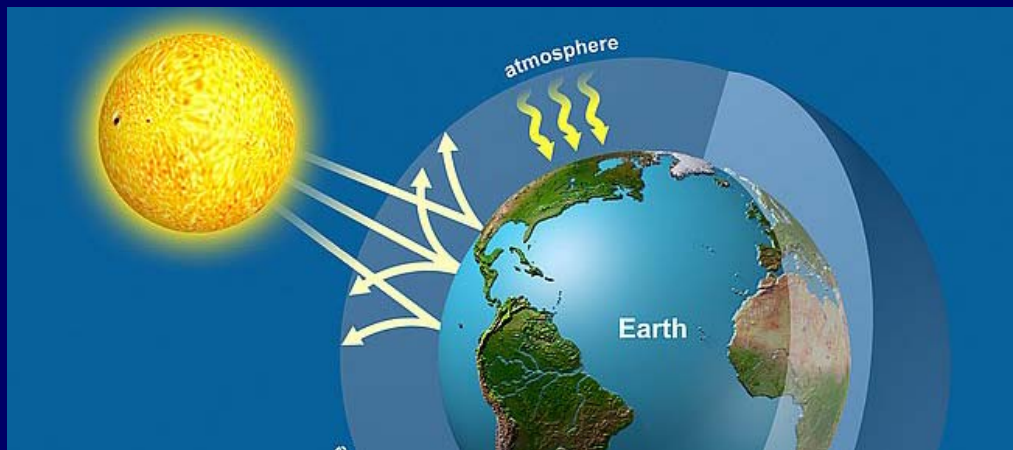
# Some notes as you study for exam 2...

- Practice exam 2 – Fall '12
  - Key is incorrect! #24 answer should be c NOT d
  - I will review #3-6, 8, 10-14, 19-27 (& perhaps Spring '12)
- Lecture 12 – slide 9 (ACT on AC power diss.)
  - Printout slide is different than lecture slide!
  - Printout states “rms”, lecture states “max”
- This weeks' HW – Circuit #4 (NOT on exam)
  - Answer is CORRECT
  - Many are doing this problem wrong (even if you are getting the correct answer!)

# Physics 102: Lecture 15

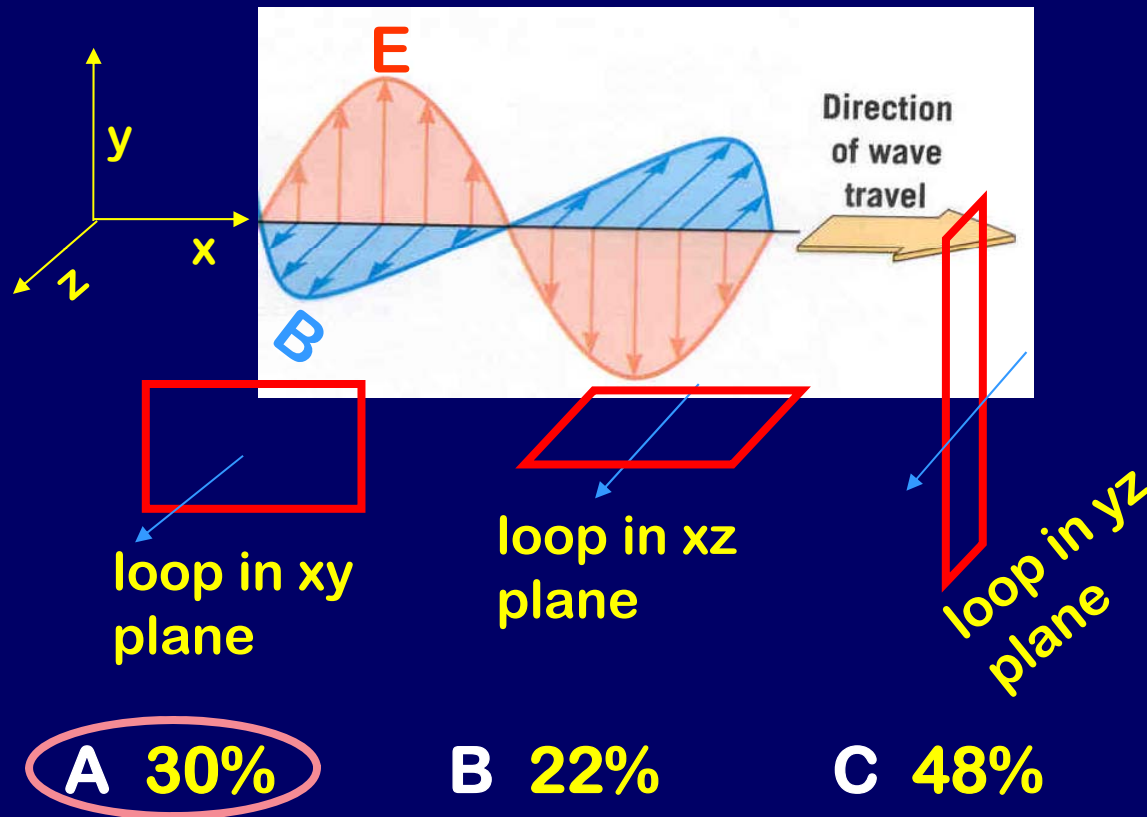
## Electromagnetic Waves

### Energy & Polarization



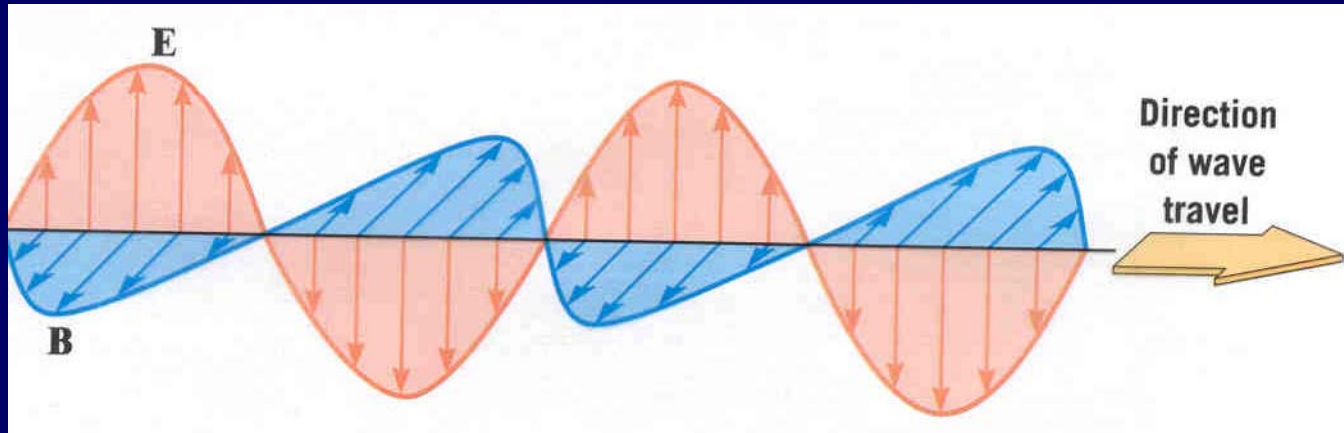
# Checkpoint 1.1, 1.2

"In order to find the loop that detects the electromagnetic wave, we should find the loop that has the greatest flux through the loop."



Only the loop in the xy plane will have a magnetic flux through it as the wave passes. The flux will oscillate with time and induce an emf. (Faraday's Law!!!)

# Propagation of EM Waves



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

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

← This is TRUE  
ONLY for EM waves

**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:

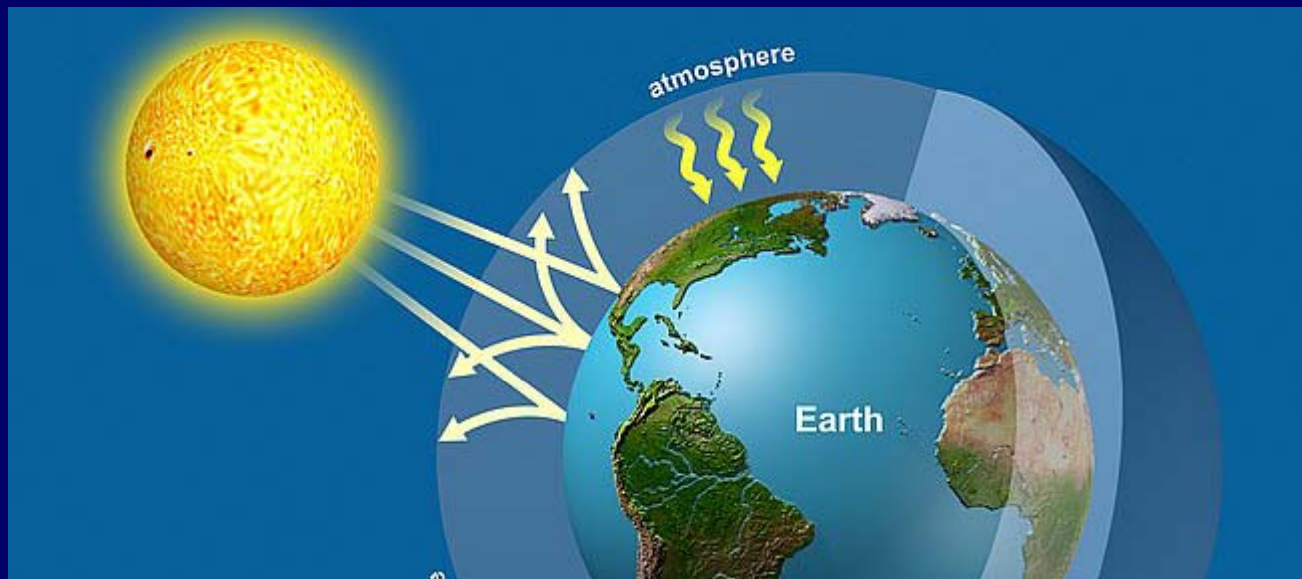
13% 1 increases

80% 2 decreases

7% 3 remains the same

$$E = cB$$

**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

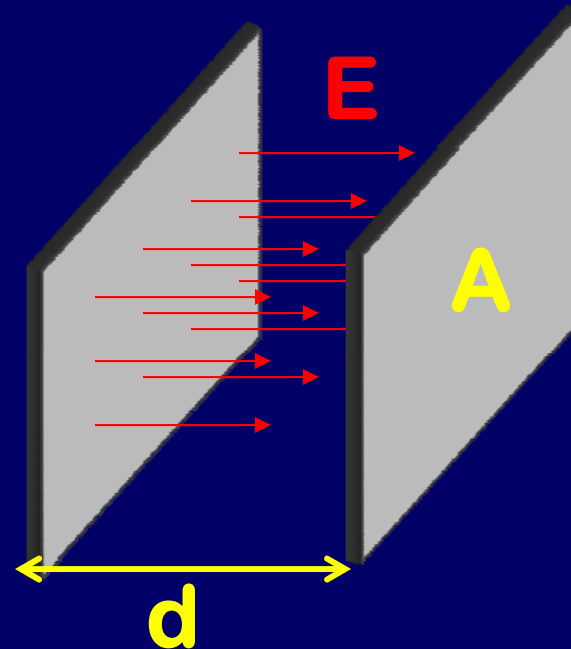
## Electric Fields

- Recall Capacitor Energy:

$$U = \frac{1}{2} C V^2$$

$$C = \frac{\epsilon_0 A}{d}$$

$$V = Ed$$



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

volume

# Energy in B field

## Magnetic Fields

- Recall Inductor Energy:

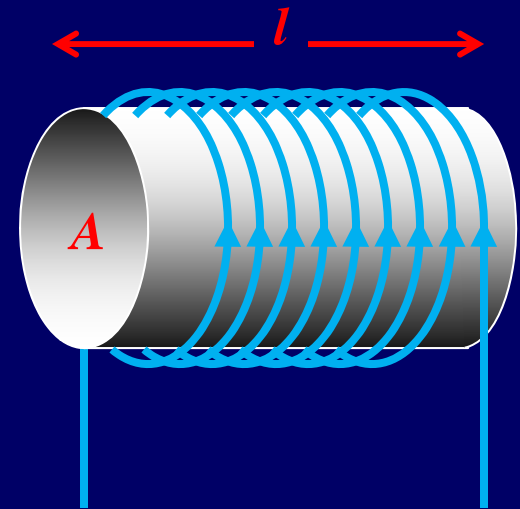
$$U = \frac{1}{2} L I^2$$

$$L = \mu_0 n^2 l A$$

$$B = \mu_0 n I$$

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

volume



# Intensity (I or S) = Power/Area



- **Energy ( $\bar{U}$ ) hitting flat surface in time t**

= Energy  $\bar{U}$  in laser beam (red cylinder):

$$\bar{U} = \left( \frac{1}{2} \epsilon_0 E_{rms}^2 + \frac{1}{2} \frac{B_{rms}^2}{\mu_0} \right) V = \left( \frac{1}{2} \epsilon_0 E_{rms}^2 + \frac{1}{2} \frac{E_{rms}^2}{c^2 \mu_0} \right) V$$
$$= \epsilon_0 E_{rms}^2 A c t$$

- **Power ( $\bar{P}$ ):**

$$\bar{P} = \bar{U}/t = \epsilon_0 E_{rms}^2 A c$$

- **Intensity (I or S):**

$$\bar{S} = \bar{P}/A \quad [\text{W/m}^2]$$

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

= "brightness"

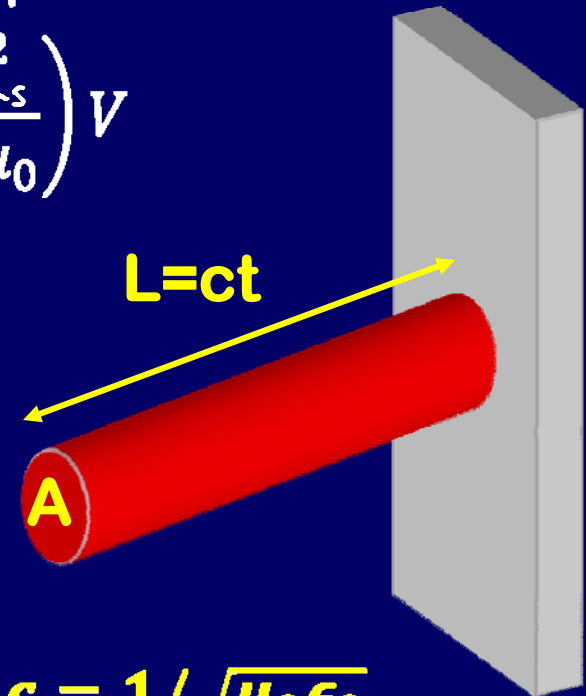
$$B = E/c$$

$$c = 1/\sqrt{\mu_0 \epsilon_0}$$

**U = Energy**

**A = Cross sectional area of laser beam**

**L = Length of laser beam**



## Example

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



$$S = P/A \quad P = S A = 1000 \times 1 = 1000\text{W}$$

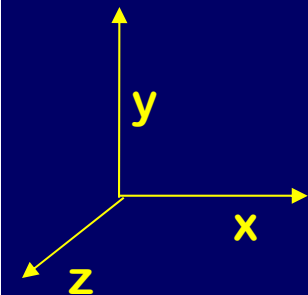
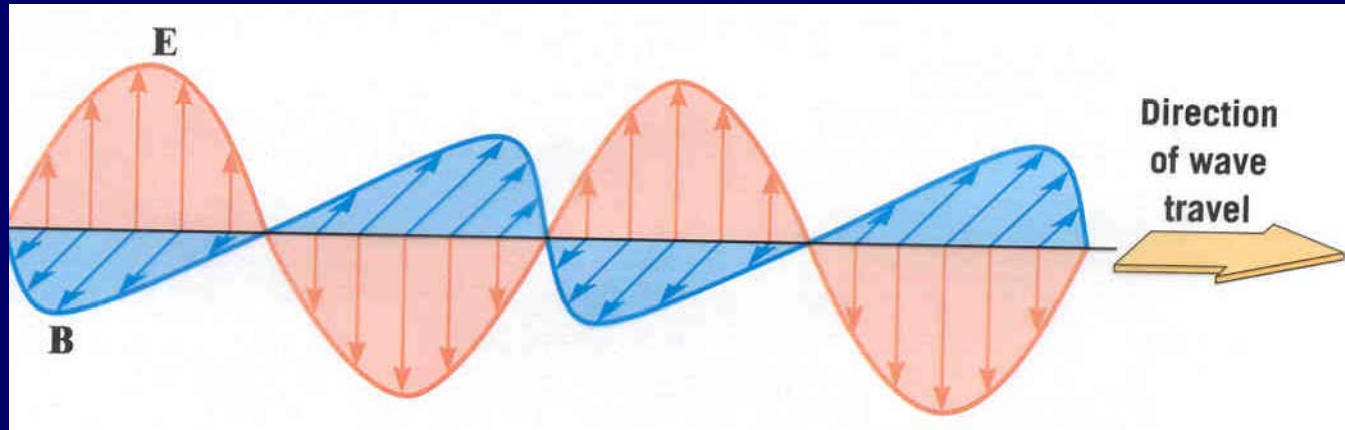
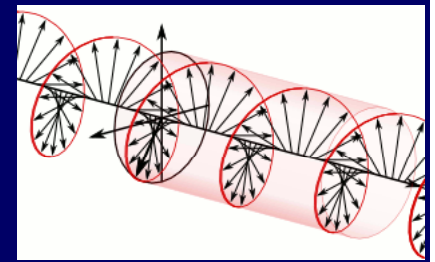
What is the rms magnitude of the electric field of the light when it hits the solar cooker?

$$\begin{aligned} S &= c\epsilon_0 E_{rms}^2 & E_{rms} &= \sqrt{S/c\epsilon_0} \\ & & &= \sqrt{1000/(3 \times 10^8 \times 8.85 \times 10^{-12})} \\ & & &= 614\text{V}/\text{m} \end{aligned}$$

# Polarization

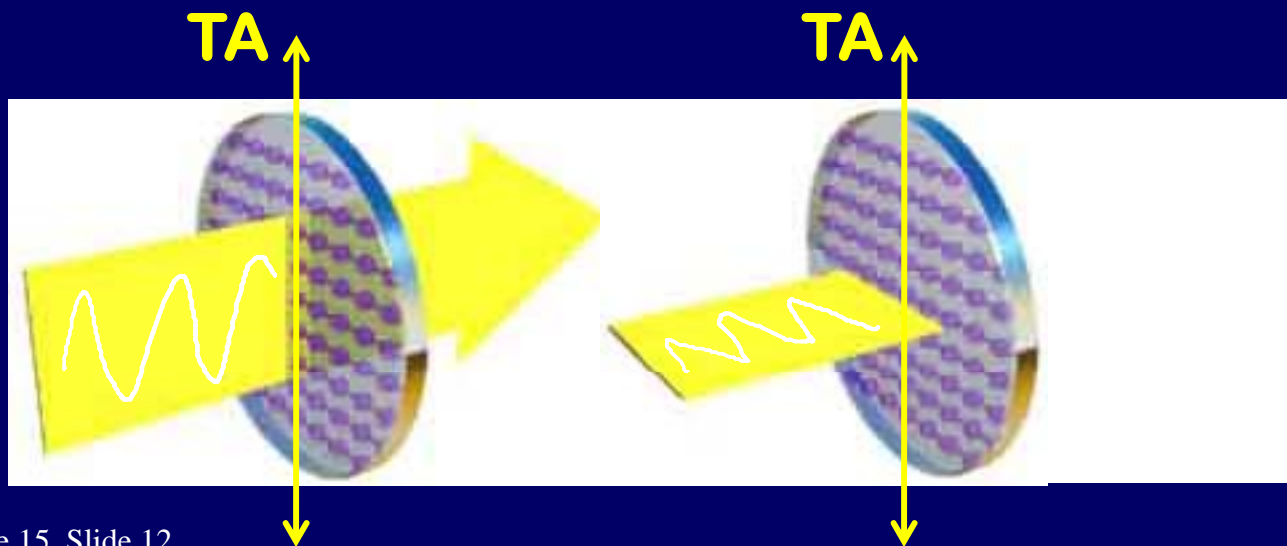
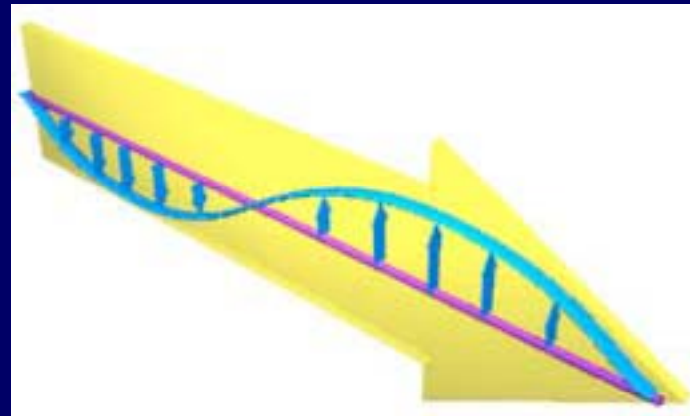
- **Transverse waves have a polarization**
  - (Direction of oscillation of E field for light)
- **Types of Polarization**
  - Linear (Direction of E is constant)
  - Circular (Direction of E rotates with time)
  - Unpolarized (Direction of E changes randomly)

$E \perp B$   
Always



# Linear Polarizers

- Linear Polarizers absorb all electric fields perpendicular to their transmission axis (TA)



# Linearly Polarized Light on Linear Polarizer (Law of Malus)

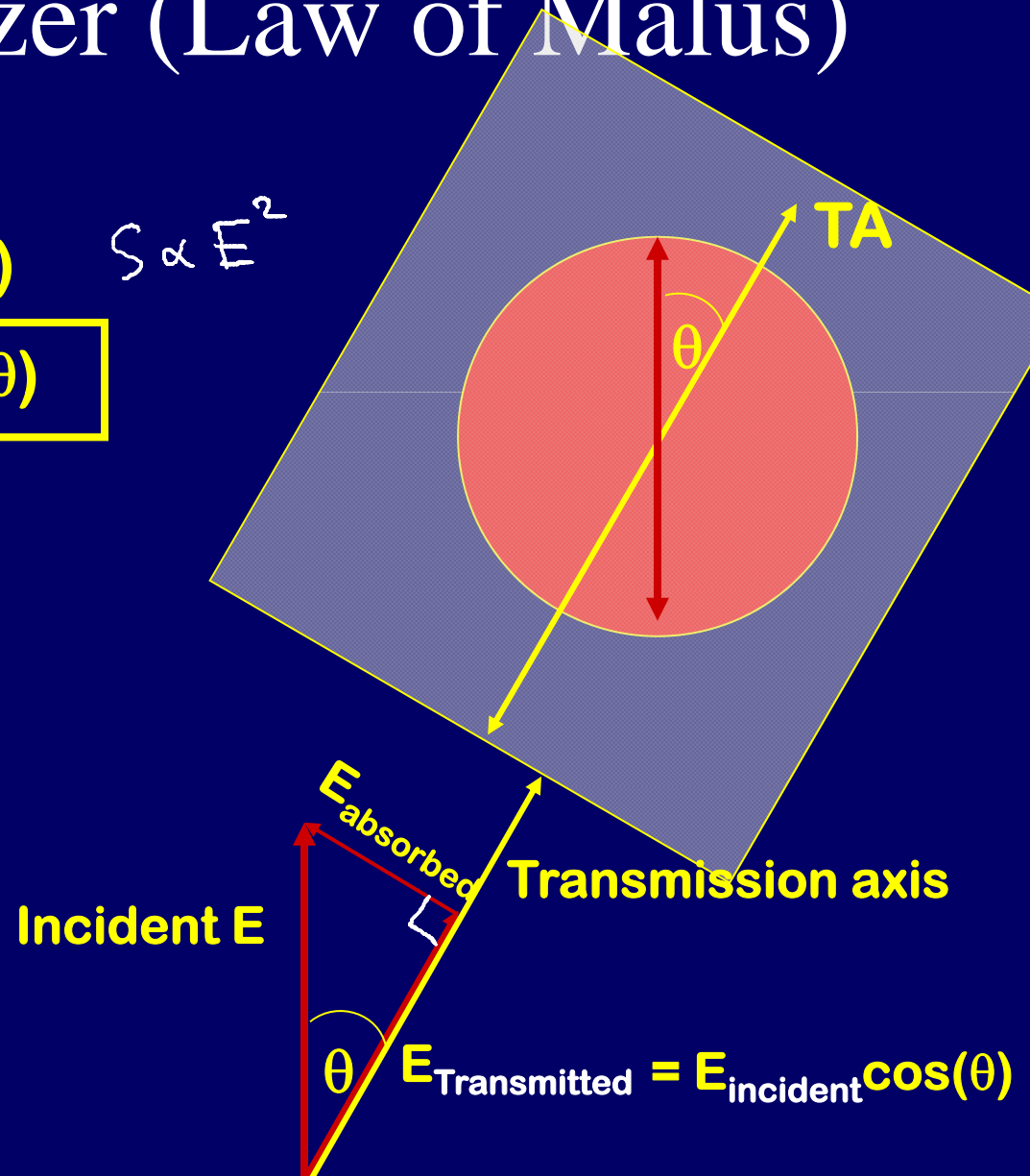


$$E_{\text{transmitted}} = E_{\text{incident}} \cos(\theta)$$

$$S \propto E^2$$

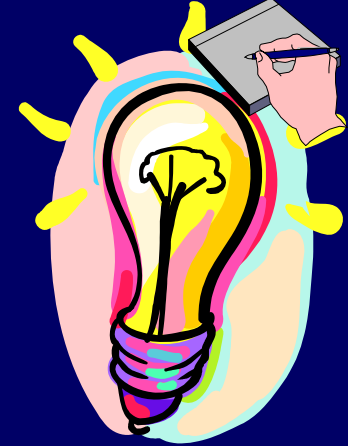
$$S_{\text{transmitted}} = S_{\text{incident}} \cos^2(\theta)$$

$\theta$  is the angle between the incoming polarization and the transmission axis

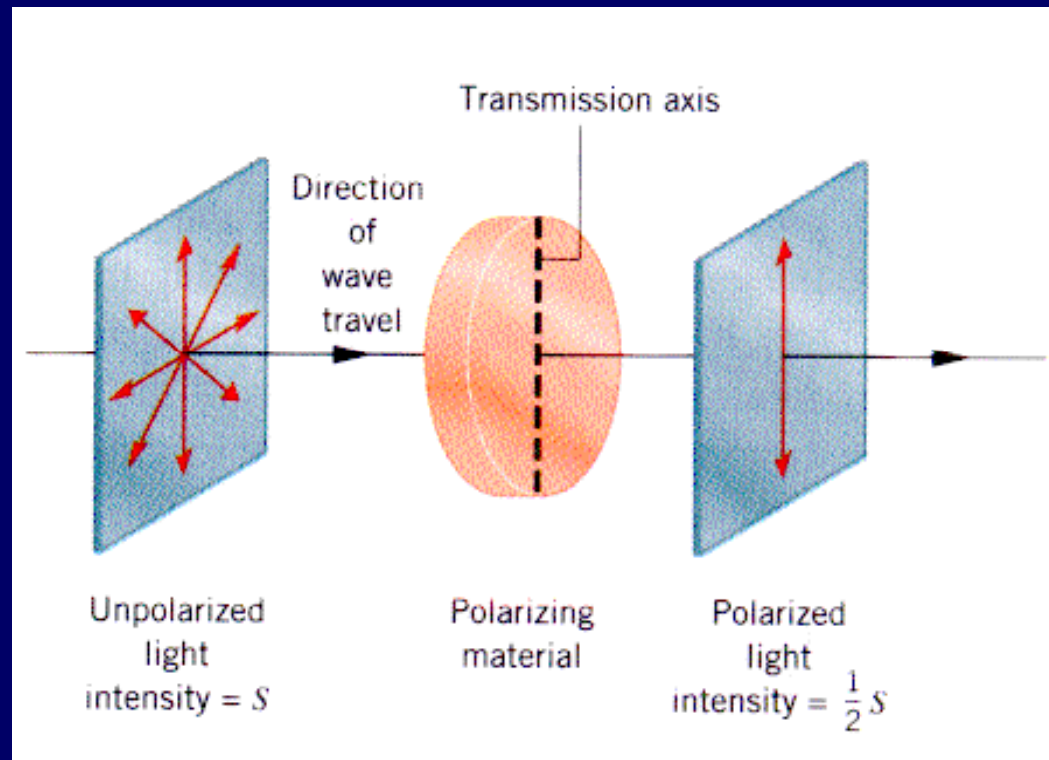
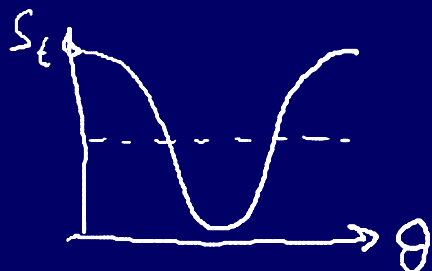




# Unpolarized Light on Linear Polarizer



$$S_t = S_i \cos^2 \theta$$



- Most light comes from electrons accelerating in random directions and is unpolarized.
- Averaging over all directions:

$$S_{\text{transmitted}} = \frac{1}{2} S_{\text{incident}}$$

Always true for unpolarized 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

$$S_{\text{transmitted}} = \frac{1}{2} S_{\text{incident}} \quad \text{for unpolarized light}$$



# ACT/CheckPoint 15.7

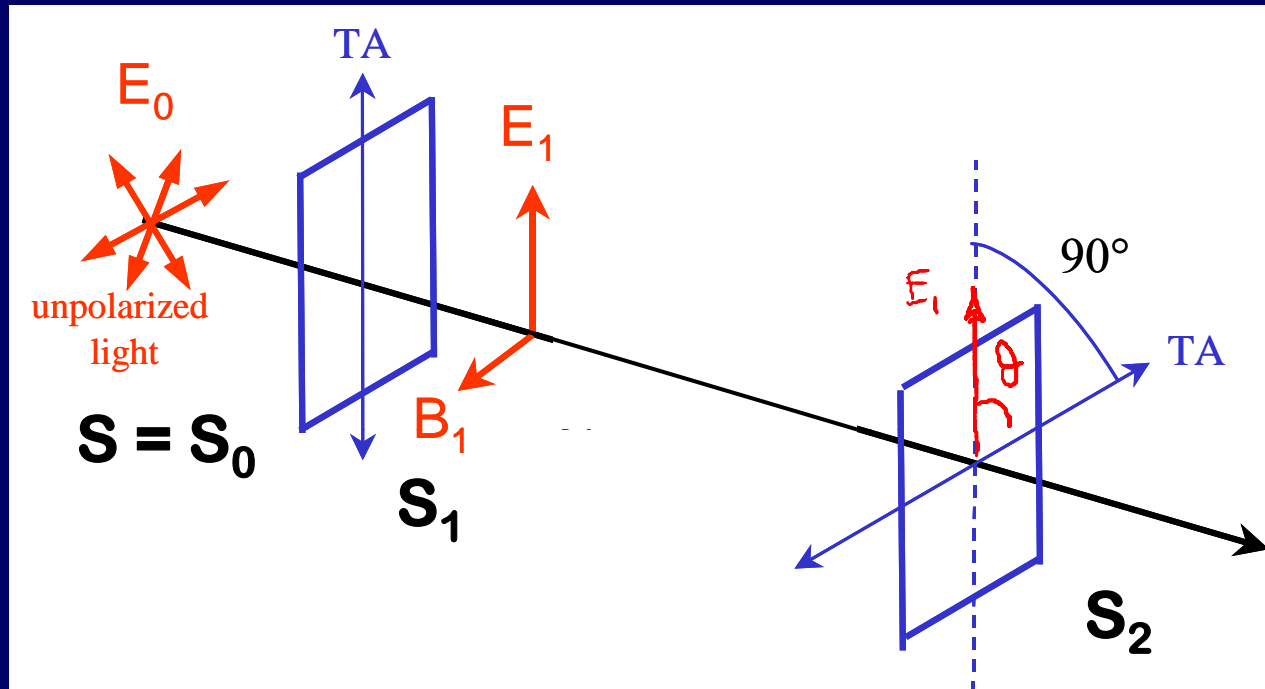
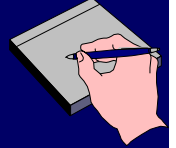
Now, horizontally polarized light passes through the same glasses (which are vertically polarized). The intensity of the light when it emerges is *TA is vertical*

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

$$S_{\text{transmitted}} = S_{\text{incident}} \cos^2(\theta) \quad \theta = 90^\circ$$

# Example

## Law of Malus – 2 Polarizers

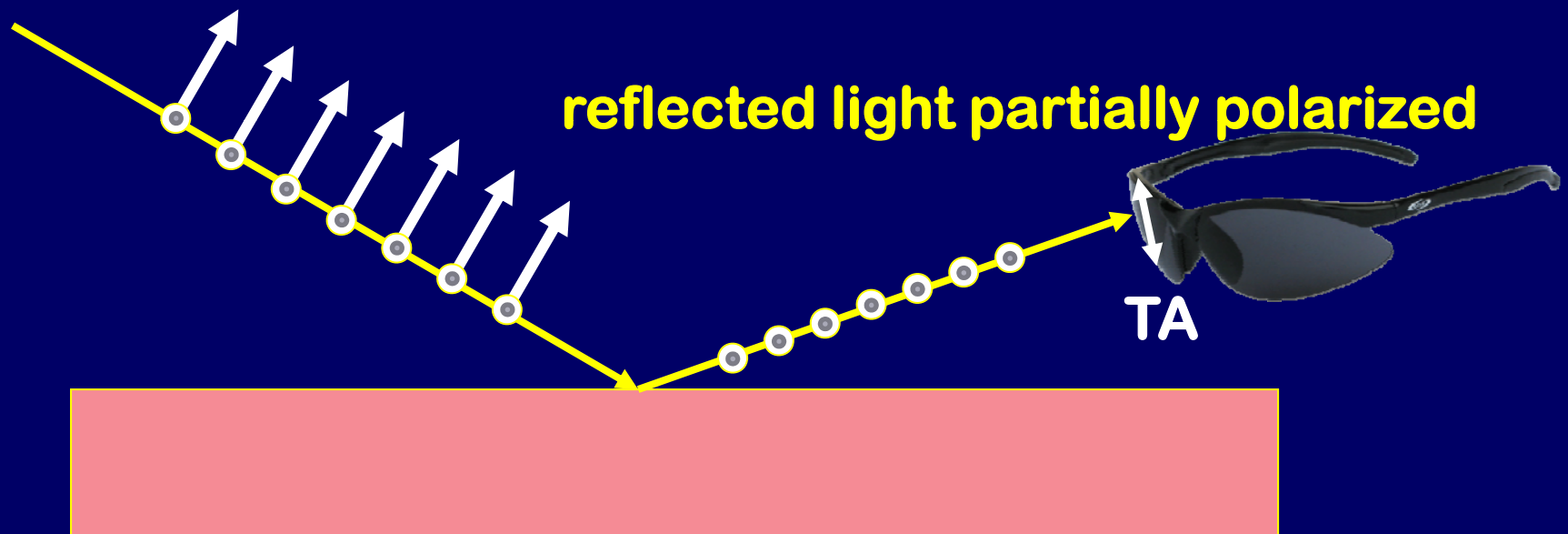


1) Intensity of unpolarized light incident on linear polarizer is reduced by  $\frac{1}{2}$ .  $S_1 = \frac{1}{2} S_0$

2) Light transmitted through first polarizer is vertically polarized. Angle between it and second polarizer is  $\theta = 90^\circ$ .  $S_2 = S_1 \cos^2(90^\circ) = 0$

# How do polarized sunglasses work?

**incident light unpolarized**

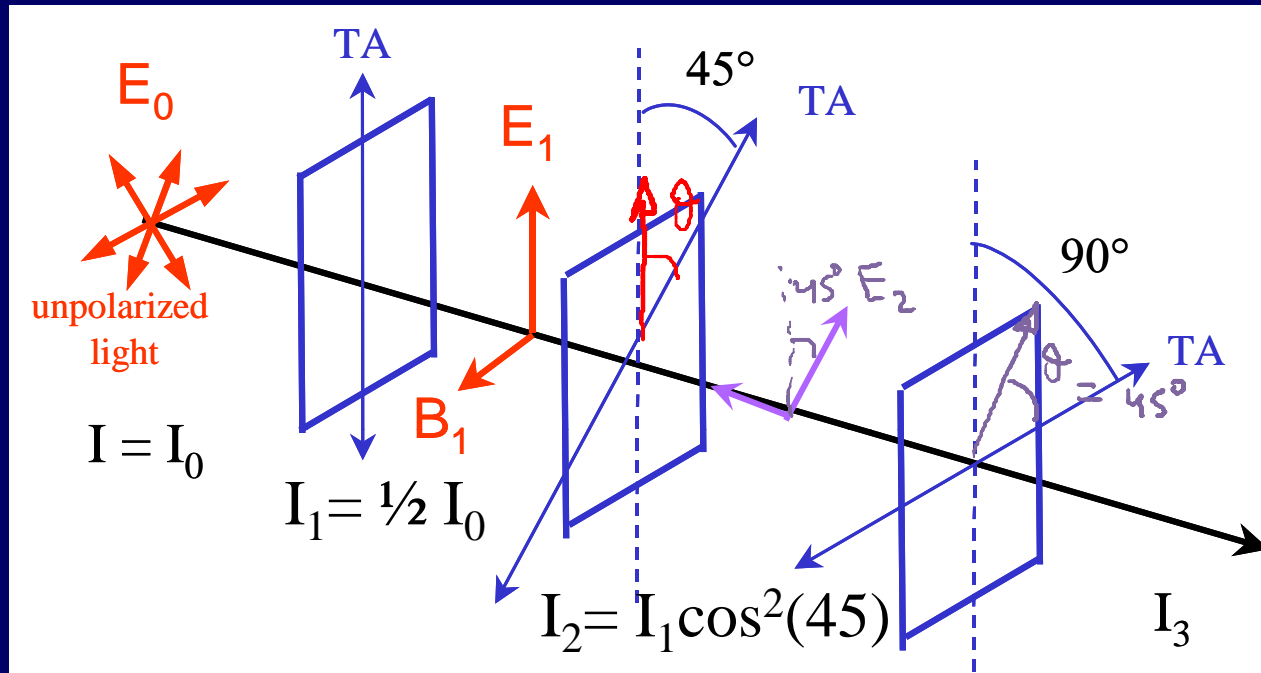


**reflected light partially polarized**

**the sunglasses reduce the glare from reflected light**

# Example

## Law of Malus – 3 Polarizers



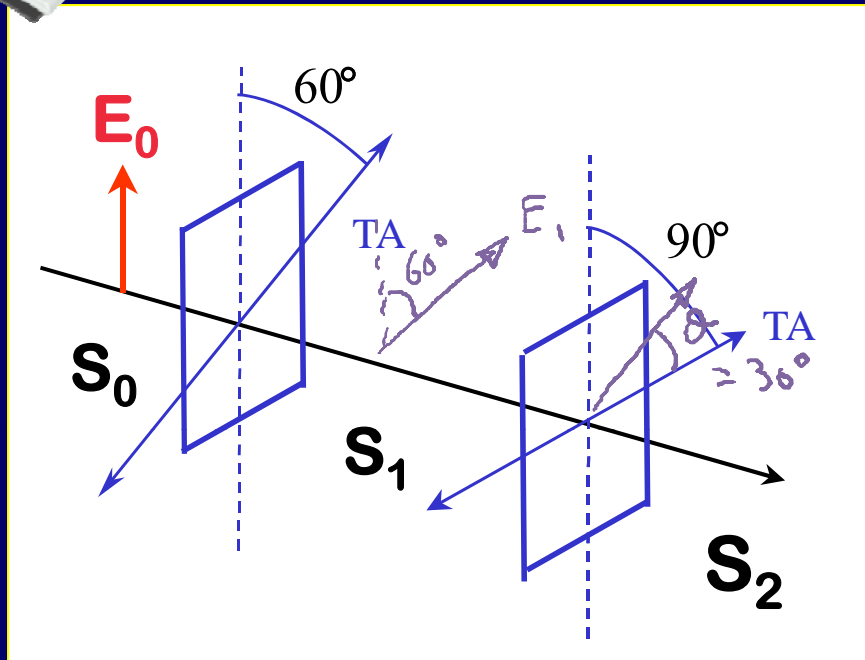
2) Light transmitted through first polarizer is vertically polarized. Angle between it and second polarizer is  $\theta=45^\circ$ .

$$I_2 = I_1 \cos^2(45^\circ) = \frac{1}{2} I_0 \cos^2(45^\circ)$$

3) Light transmitted through second polarizer is polarized  $45^\circ$  from vertical. Angle between it and third polarizer is  $\theta=45^\circ$ .

$$I_3 = I_2 \cos^2(45^\circ) = \frac{1}{2} I_0 \cos^4(45^\circ) = I_0/8$$

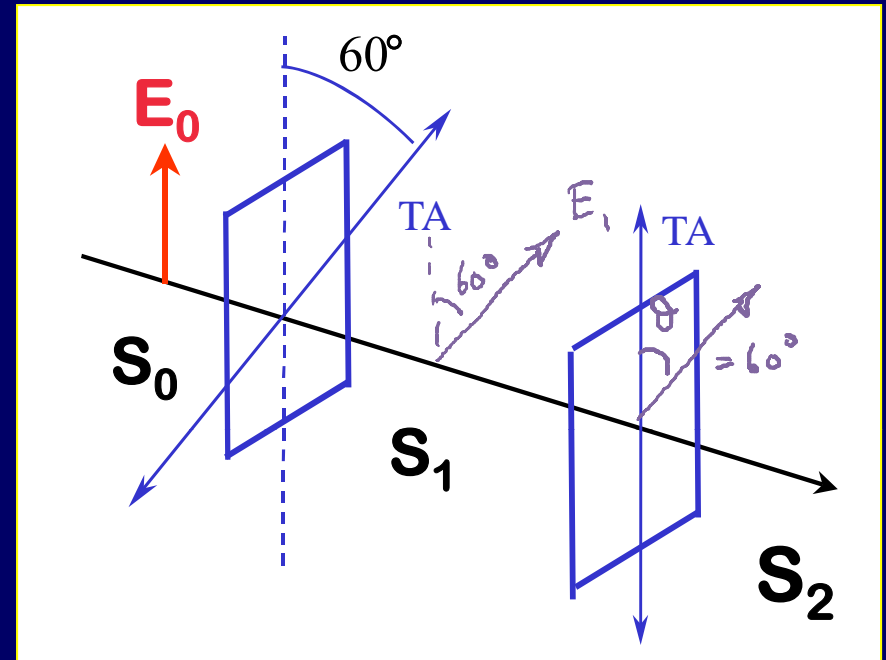
# ACT: Law of Malus



**A**

$$S_1 = S_0 \cos^2(60)$$

$$S_2 = S_1 \cos^2(30) = S_0 \cos^2(60) \cos^2(30)$$



**B**

$$S_1 = S_0 \cos^2(60)$$

$$S_2 = S_1 \cos^2(60) = S_0 \cos^4(60)$$

1)  $S_2^A > S_2^B$

2)  $S_2^A = S_2^B$

3)  $S_2^A < S_2^B$

See You Monday!