Lecture # 30

E&M waves & Polarization

SPEED OF ELECTROMAGNETIC WAVE

$\mathcal{E} \equiv \oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \oint \vec{B} \cdot d\vec{A} \equiv \dot{\Phi}_B$; $\oint \vec{B} \cdot d\vec{l} = \mu_0 \epsilon_0 \frac{d}{dt} \int \vec{E} \cdot d\vec{A} \equiv \mu_0 \epsilon_0 \dot{\Phi}_E$

imply E & M wave propagate

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \text{ m/s}$$

$B = \frac{E}{c}$, $\vec{E} \perp \vec{B} \perp$ direction of propagate of wave

Equation 33-8 Physics for Engineers and Scientists 3/e

ENERGY DENSITY IN ELECTROMAGNETIC WAVE

$u_E = \frac{\epsilon E^2}{2}$, $u_B = \frac{B^2}{2\mu_0}$

$$u = \frac{\epsilon_0}{2}E^2 + \frac{1}{2\mu_0}B^2 = \epsilon_0 E^2 \equiv u_{EM}$$

joules/m^3

because $u_B = \frac{B^2}{2\mu_0} = \frac{E^2}{2c^2\mu_0} = \frac{\epsilon E^2}{2} = u_E$

$(B = E/c)$ $\frac{1}{c^2} = \epsilon_0\mu_0$

Equation 33-17 Physics for Engineers and Scientists 3/e

POYNTING VECTOR S

$$\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}} \times \vec{\mathbf{B}} = \text{joules}/m^2 s$$

$$c^2 = \frac{1}{\epsilon_0 \mu_0}$$

$$|\vec{S}| = \frac{EB}{\mu_0} = \frac{EE}{c\mu_0} = c\frac{EE}{\mu_0 c^2} = c\,\epsilon_0\mu_0\frac{E^2}{\mu_0} = c\left(\epsilon E^2\right)$$

↑ energy density

$$|\vec{S}| = c\,u_{EM}$$

Equation 33-23 Physics for Engineers and Scientists 3/e

TIME-AVERAGE ENERGY FLUX (INTENSITY) IN PLANE WAVE

$$I_0 \equiv \bar{S} = \frac{1}{2\mu_0 c} E_0^2 = \frac{\bar{E}_{rms}^2}{\mu_0}$$

Daylight has an energy flux of about 1 kW/m².
How much energy would a 5 × 5 m solar panel produce in one hour?

$E = 1 \times (5 \times 5) = 25$ kW hr

Equation 33-24 Physics for Engineers and Scientists 3/e

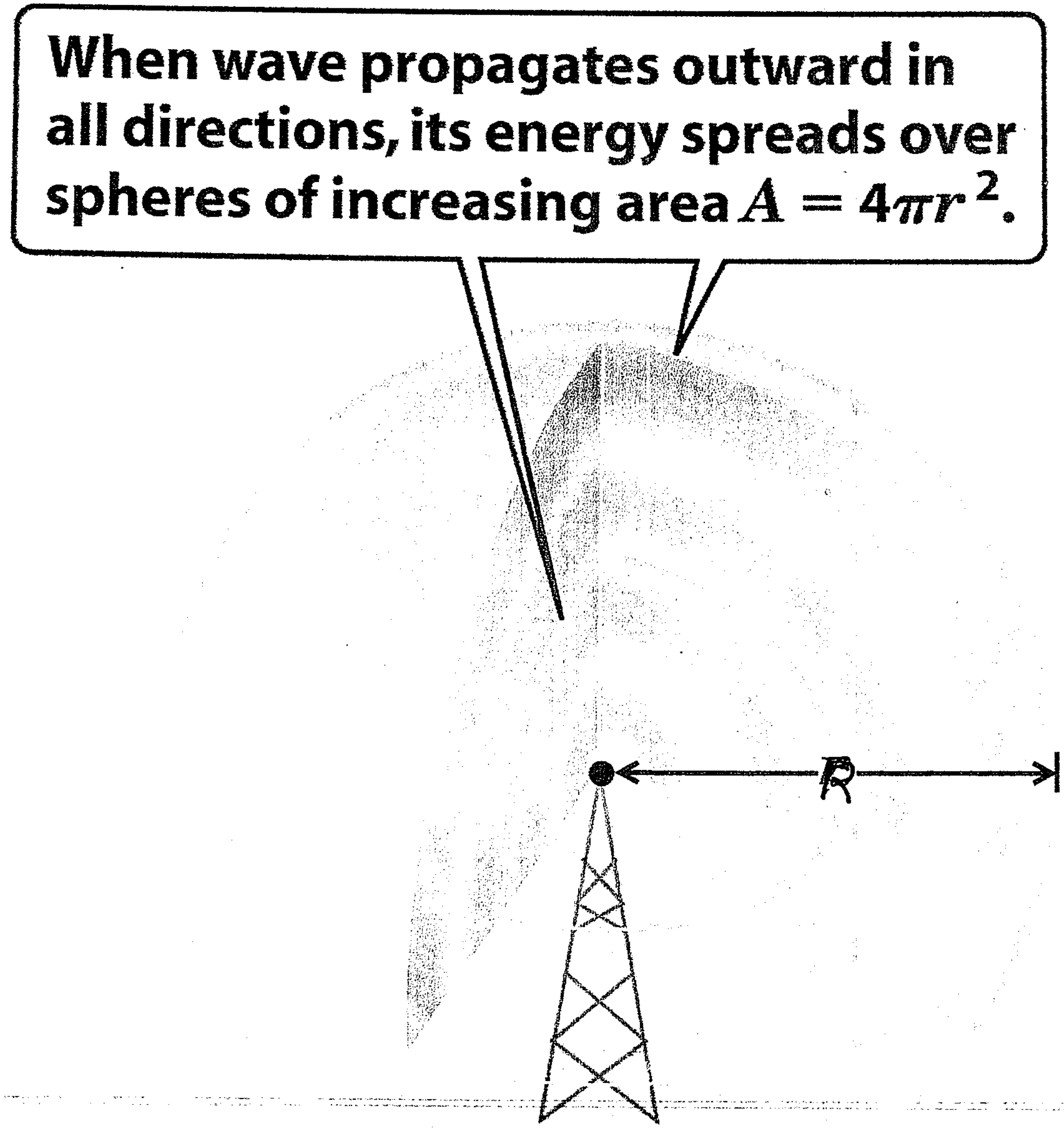


Figure 33-26 Physics for Engineers and Scientists 3/e

Emerging Energy ~~Flux~~ independent of radius

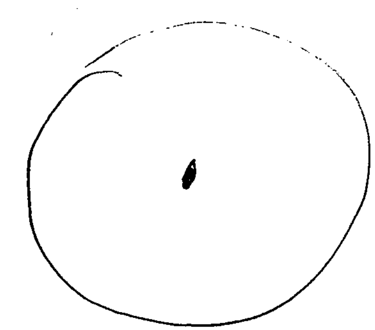
$Power\,G = \bar{S}\,(4\pi R^2)$

$$\bar{S} = \frac{Power\,G}{4\pi R^2}$$

ENERGY FLUX *S* IN TERMS OF POWER *P* FOR SPHERICAL WAVE

Intensity

$$I_0 \equiv \bar{S} = \frac{\bar{P}}{4\pi r^2}$$



Equation 33-26 Physics for Engineers and Scientists 3/e

In which direction does this E&M wave propagrate?

a. To the right

b. To the left

This wave is polarized

a. Vertically

b. Horizontally

Propagating E&M waves must be polarized.

a. True

b. false

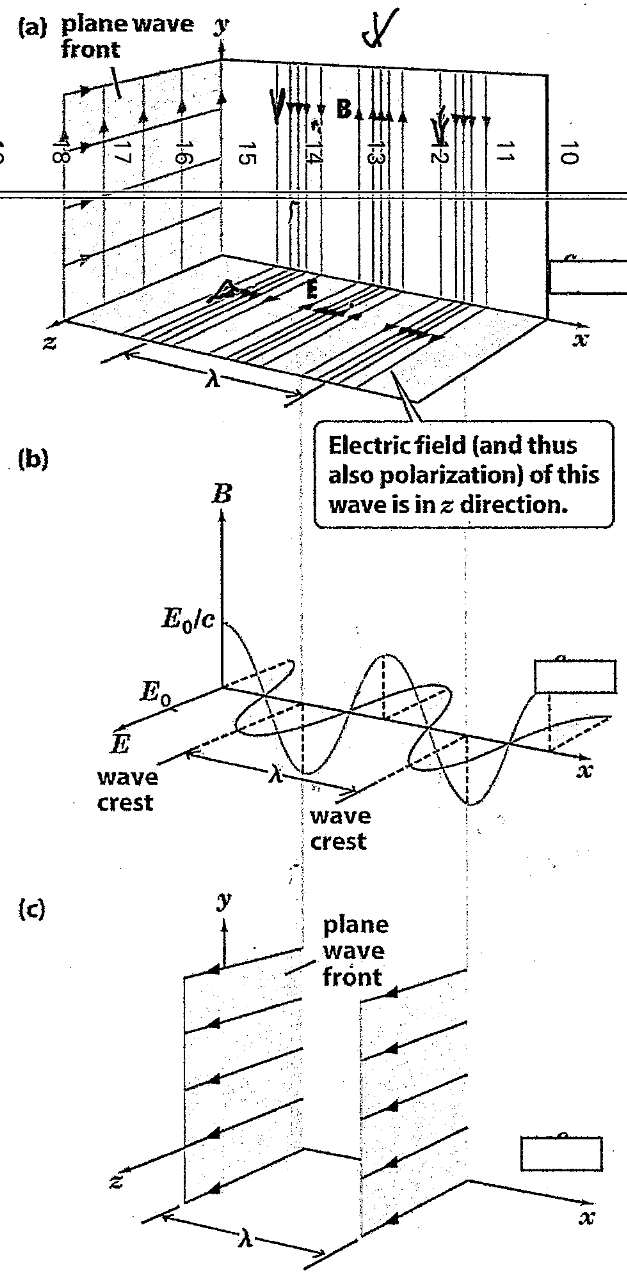


Figure 33-12 Physics for Engineers and Scientists 3/e

$B = -\hat{y} B_0, \quad B = E_0 \hat{z}$

$E \times B = E_0 B_0 \quad \hat{z} \times (-\hat{y})$

$\hat{z} \times \hat{y} = -\hat{x}$

$= E_0 B_0 \hat{x}$

$B = \hat{y} B_0 \times (-E_0 \hat{z})$

$= E_0 B_0 \; -\hat{z} \times \hat{y}$

$E B_0 \hat{z}$

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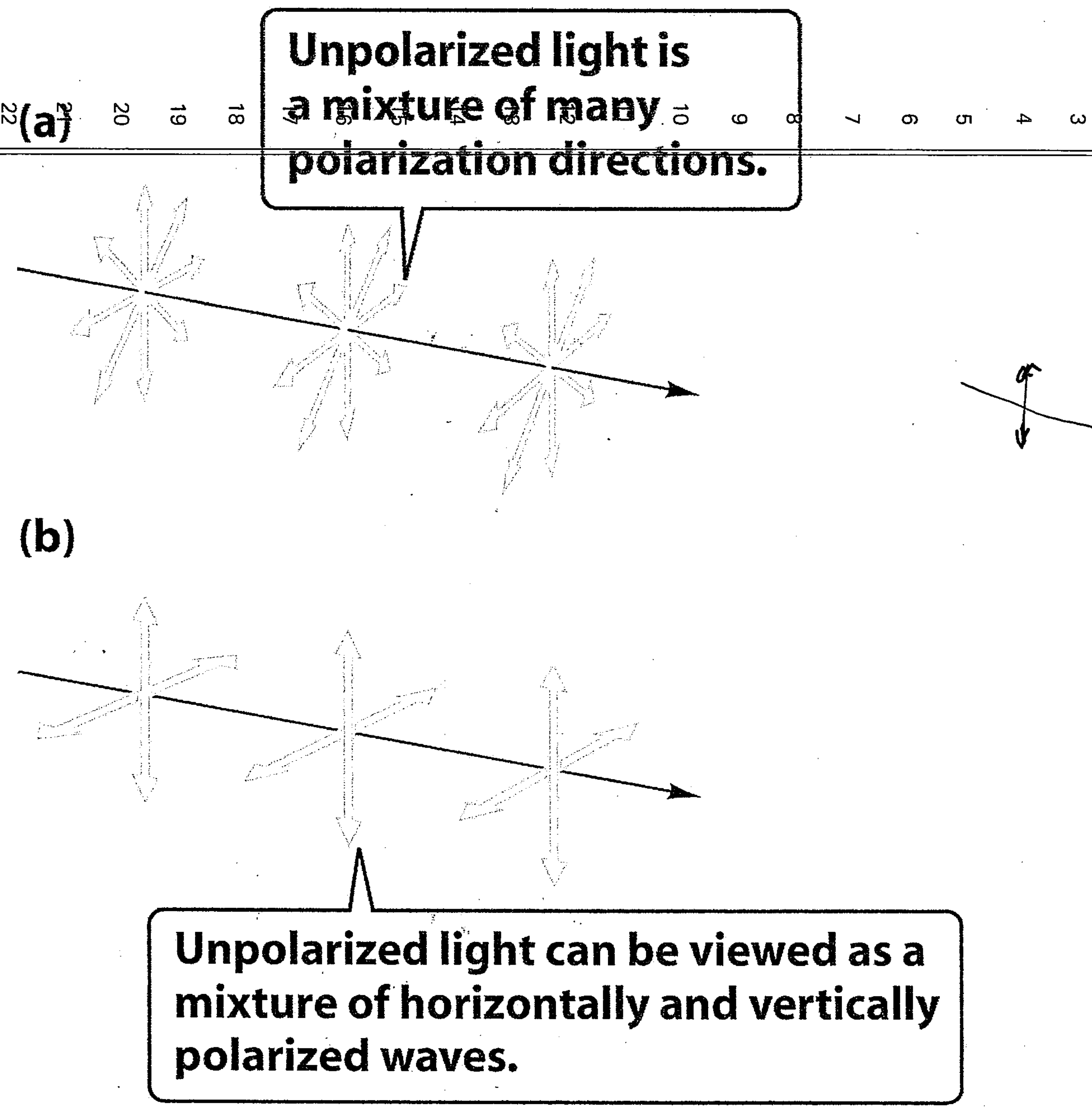


Figure 33-14 Physics for Engineers and Scientists 3/e

Polarized EoM waves

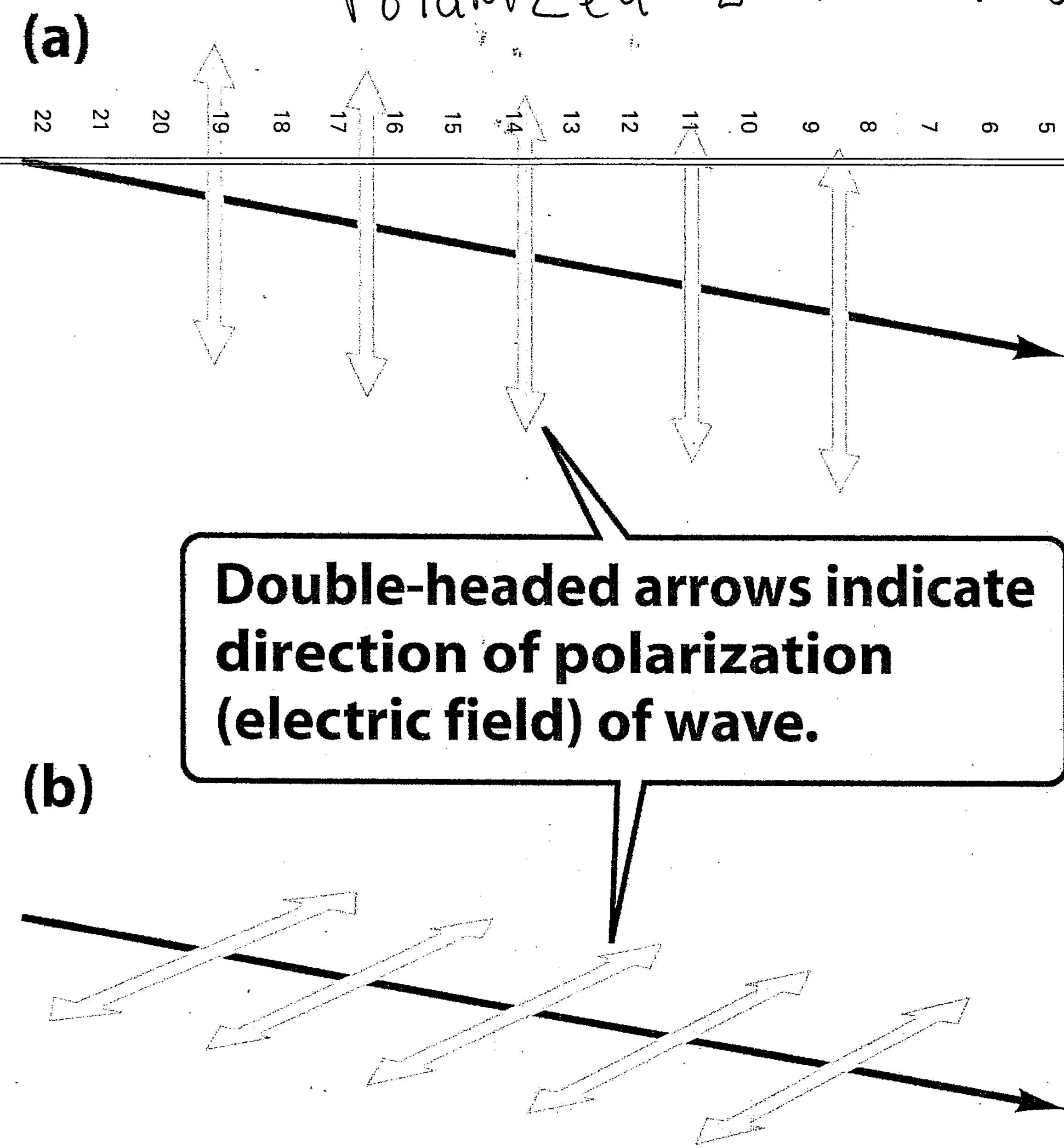


Figure 33-13 Physics for Engineers and Scientists 3/e

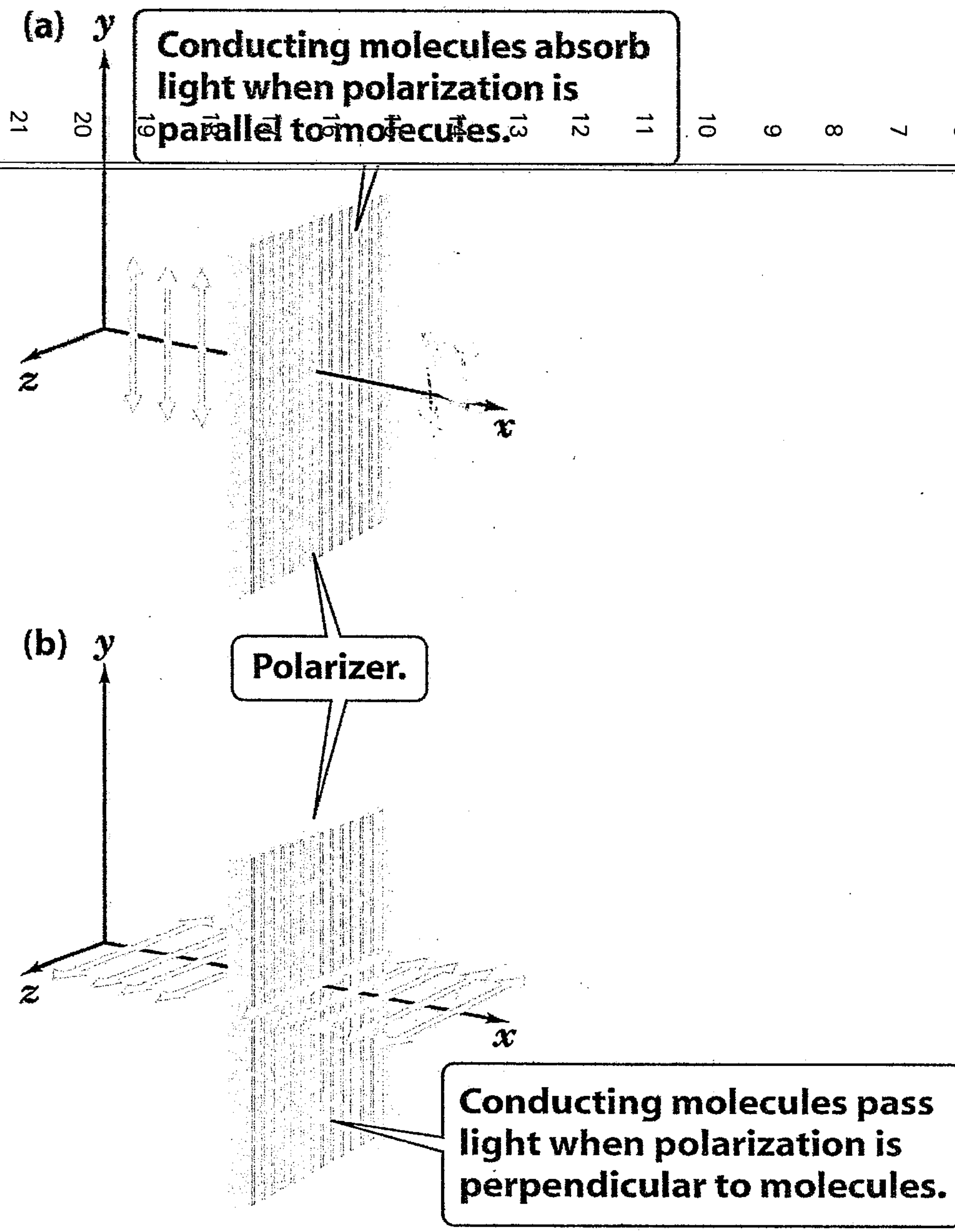


Figure 33-16 Physics for Engineers and Scientists 3/e

Fabricating polarized waves

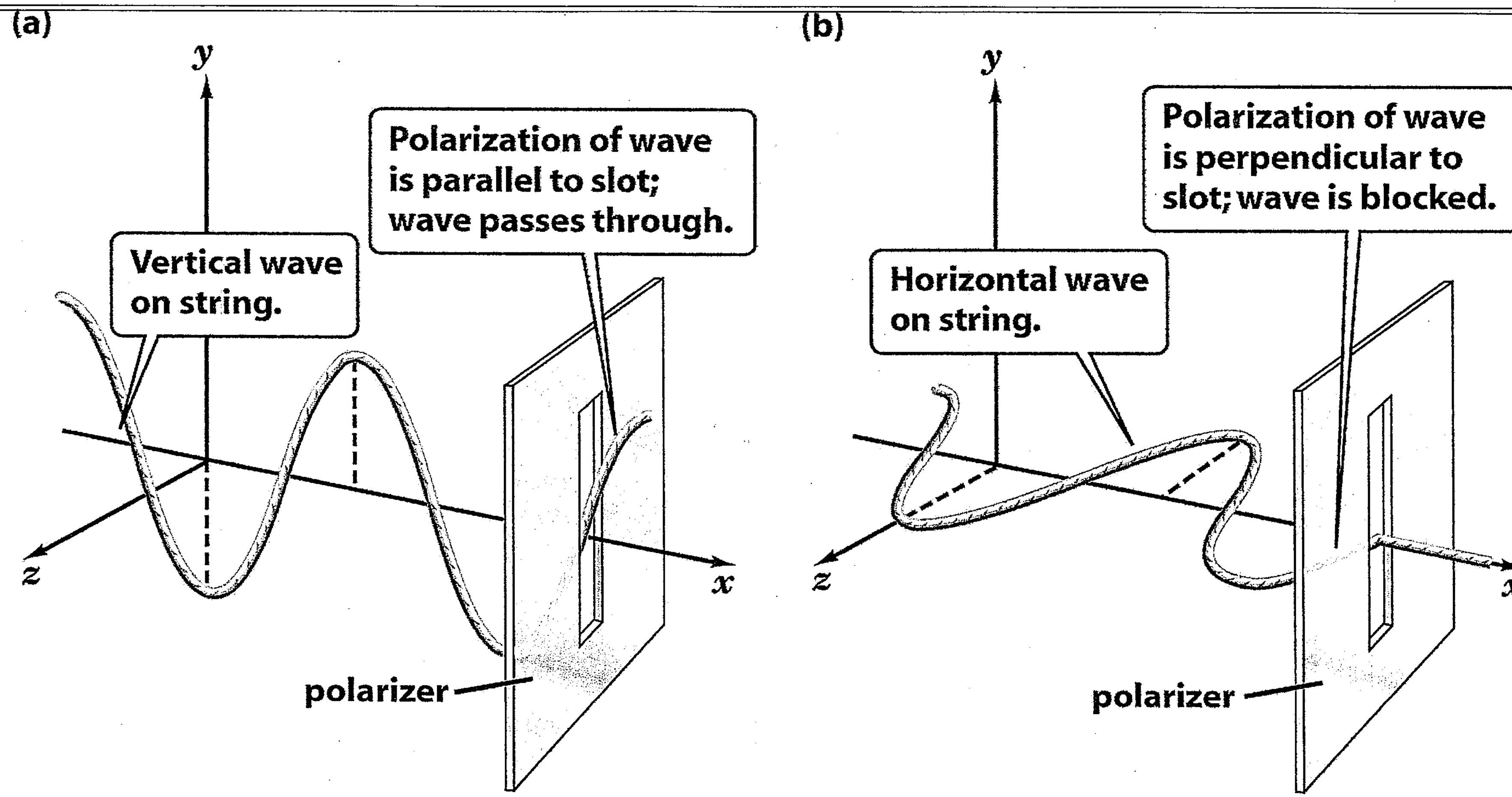


Figure 33-15 Physics for Engineers and Scientists 3/e

Figure 33-18 Physics for Engineers and Scientists 3/e

$E_0'' = E_0' \sin\phi$ $I_0 \sin^2\phi$

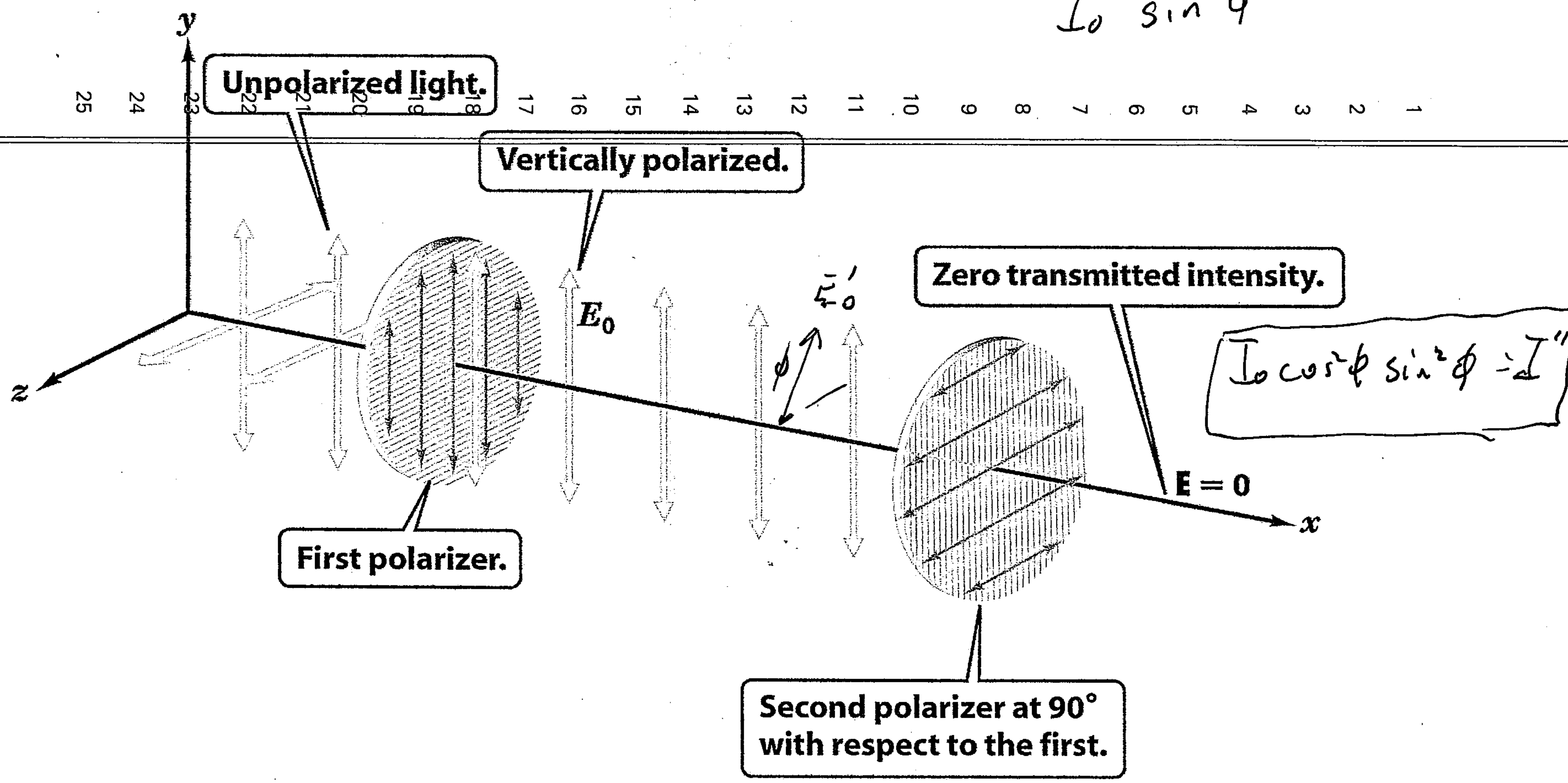


Figure 33-19a Physics for Engineers and Scientists 3/e

If we insert a polarizer between first and second polarizer at an intermediate polarization angle, will any wave energy propagate through the second polarizer?

a. Yes b. no

$|\vec{E}_{01}| = |\vec{E}_{02}| \equiv E_0$

Initially $|\vec{E}| = \sqrt{2} E_0$

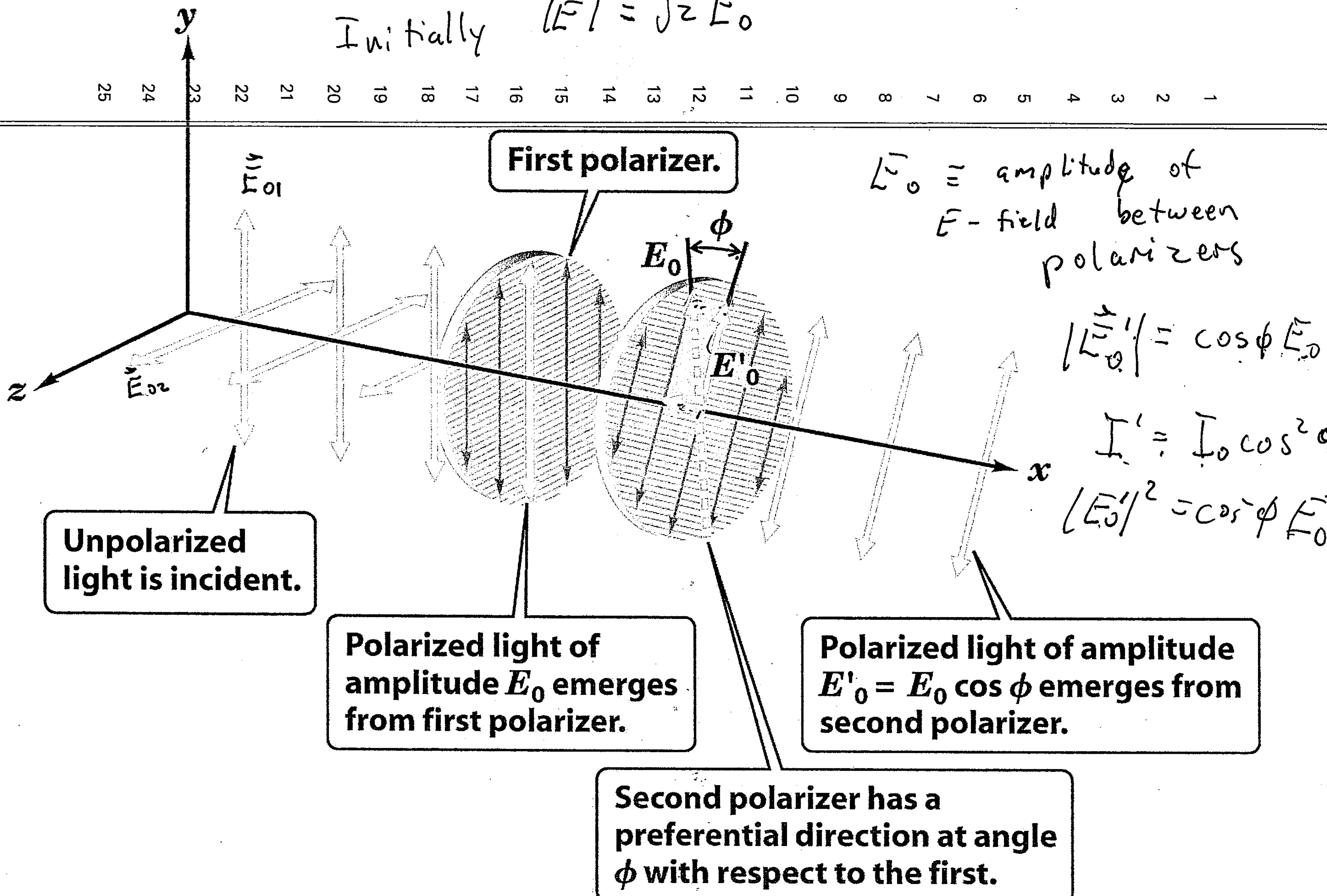


Figure 33-17 Physics for Engineers and Scientists 3/e

PRESSURE OF ELECTROMAGNETIC WAVE

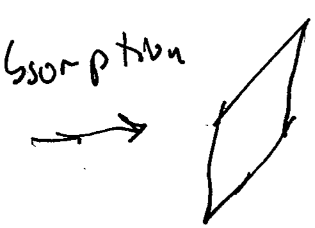
Momentum Flux $\equiv (\epsilon_0/\mu_0)^{1/2}\,\vec{E}\times\vec{B} = \vec{S}/c$

$$[\text{pressure}] = \begin{cases} \dfrac{S}{c} & \text{(absorption)} \\[2ex] \dfrac{2S}{c} & \text{(reflection)} \end{cases}$$

$S_i - S_t$ = Pressure

total reflection

absorption



Twice as much pressure is generated from reflecting light compared to absorbing light